Education for Sustainability

Winnie Wing Mui So
Cheuk Fai Chow
John Chi Kin Lee *Editors*

Environmental Sustainability and Education for Waste Management

Implications for Policy and Practice

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With this background, and in light of UNESCO's Education 2030 Agenda (2017), this *Education for Sustainability* Book Series has been launched. Its purpose is to echo and enhance the global importance of education for a sustainable future as an educational vision. The Series provides insights on a broad range of issues related to the intersection of, and interaction between, sustainability and education. The Series showcases updated and innovative practice, discusses salient theoretical topics, and uses cases as examples.

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Supported by the expertise of a distinguished and diverse International Advisory Board, this Series features authoritative and comprehensive global coverage, as well as diversified local, regional, national, and transnational perspectives. As a complement to the Schooling for Sustainable Development Book Series, it explores issues that go beyond primary and secondary schooling into university, vocational, and community education settings. These educational issues involve multiple stakeholders ranging from international agencies, governmental and non-governmental organizations, educational and business leaders to teachers, students, and parents. The research topics covered include global themes related to environment such as climate change education, disaster prevention and risk reduction, biodiversity education, and ecological education. They also include human ecological issues such as global citizenship, peace education, childhood development, intergenerational equity, gender studies, and human rights education. Further, they include society-oriented issues such as governance, green skills for sustainable development, sustainability leadership, and applied learning.

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John Chi Kin Lee
Editors

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Editors
Winnie Wing Mui So
The Education University of Hong Kong
Hong Kong, New Territories, Hong Kong

John Chi Kin Lee
Centre for Education in Environmental Sustainability
The Education University of Hong Kong
Hong Kong, New Territories, Hong Kong

Cheuk Fai Chow
Centre for Education in Environmental Sustainability
The Education University of Hong Kong
Hong Kong, New Territories, Hong Kong

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Series Editors' Introduction

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The authors and co-editors are responsible for the choice and presentation of information and views contained in this book series and for opinions expressed therein, which are not necessarily those of UNESCO and The Education University of Hong Kong, and do not commit the respective Organizations.

May 2019

John Chi-Kin Lee
The Education University of Hong Kong
Hong Kong SAR, China

Rupert Maclean
RMIT University
Melbourne, Australia

Peter Blaze Corcoran
Florida Gulf Coast University
Fort Myers, FL, USA

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Editors and Contributors

About the Editors

Winnie Wing Mui So is a Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong, the Director of the Centre for Education in Environmental Sustainability and the Associate Dean of the Graduate School. Her main research areas are STEM education, science and environmental education. She has been active with professional contribution, being the past President of the Asia-Pacific Education Research Association and Executive Member of the World Education Research Association, Hong Kong Educational Research Association and East Asian Association for Science Education.

Cheuk Fai Chow is an Associate Professor of the Department of Science and Environmental Studies and the Director of Knowledge Transfer at the Education University of Hong Kong. He received his B.Sc. (Applied Chemistry) and Ph.D. from the City University of Hong Kong. He obtained a Croucher fellowship and did his postdoctoral training with Nobel laureate Jean Marie Lehn (The University of Strasbourg, France). His research interest lies in applying his environmental studies for energy, water resource and plastic waste studies. e-mail: cfchow@eduhk.hk

John Chi Kin Lee JP, Vice President (Academic) and Chair Professor of Curriculum and Instruction, joined The Education University of Hong Kong (EdUHK) [formerly known as The Hong Kong Institute of Education (HKIEd)] since 2010. He is also the Director of the Centre for Religious and Spirituality Education (CRSE), Co-Director (Research) of the Centre for Excellence in Learning and Teaching (CELT) and Co-Director of the Centre for Education in Environmental Sustainability (CEES). He was Dean of Education and Professor of the Department of Curriculum and Instruction at The Chinese University of Hong Kong (CUHK).

Professor Lee has served as the Regional Editor (Asia-Pacific) of *Educational Research and Evaluation* and Executive Editor of *Teachers and Teaching* as well as editorial board members or advisory editors of many local, regional and international journals. He is also a prolific writer who has edited and written more than 25 books, and published over 100 journal articles and book chapters.

Professor Lee served as the Team Leader of a World Bank consultancy project on teacher education and has also held many visiting/guest/adjunct professorships at universities overseas and in Mainland China. He is the Changjiang Chair Professor conferred by the Ministry of Education, the People's Republic of China.

Contributors

Chung Sum Chan Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Tzu-Chau Chang National Taiwan Normal University, Taipei, Taiwan

Chi Chiu Cheang Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Irene Nga Yee Cheng Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Hong Chua Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Tsing Yi Island, Hong Kong

Tsz Yan Cheung Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Cheuk Fai Chow Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Simona Francesca Consoletti Department of Agriculture, Food and Environmental Science, University of Foggia, Foggia, Italy

Amy Cutter-Mackenzie-Knowles Sustainability, Environment & Education (SEE) Research Cluster, School of Education, Southern Cross University, Lismore, Australia

Wen-Jing Deng Department of Science and Environmental Studies and Centre of Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Lincoln Fok Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Sander Hoogendoorn CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands

Yu Huang Beijing Normal University, Beijing, The People's Republic of China

Maznah Hj Ibrahim Universiti Kebangsaan, Bangi, Malaysia

Krista Jansema-Hoekstra CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands

Y. T. Jin Centre for Environmental Education and Communications, Ministry of Environmental Protection, Beijing, The People's Republic of China

Kinh Thi Kieu The University of Danang, University of Education, Da Nang, Vietnam

Karin Kolbe Faculty of Mathematics and Sciences, University of Koblenz-Landau, Koblenz, Germany

Edwin Che Feng Lau The Green Earth, Hong Kong SAR, China

John Chi Kin Lee The Education University of Hong Kong, Hong Kong SAR, China

Yu Bon Man Consortium on Health, Environment, Education and Research (CHEER), and Department of Science and Environmental Studies, The Education University of Hong Kong, Hong Kong SAR, China

Wing Yin Mo Consortium on Health, Environment, Education and Research (CHEER), and Department of Science and Environmental Studies, The Education University of Hong Kong, Hong Kong SAR, China

Zubaidah Mohd Nasir Universiti Kebangsaan, Bangi, Malaysia

Andrea Emma Pravitasari Bogor Agricultural University, Bogor, Indonesia

Pepijn Prinsen Department of Organic Chemistry, University of Cordoba (UCO), Cordoba, Spain

Gerbert Romijn CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands

Lisa Siegel Sustainability, Environment & Education (SEE) Research Cluster, School of Education, Southern Cross University, Lismore, Australia

Jane Singer Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan

Winnie Wing Mui So Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Yiu Fai Tsang Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong;
School of Environment, Nanjing Normal University, Nanjing, Jiangsu Province, People's Republic of China

Annemiek Verrips CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands

Nengxiong Wang Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong;
Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Tsing Yi Island, Hong Kong

Ming Hung Wong Consortium on Health, Environment, Education and Research (CHEER), and Department of Science and Environmental Studies, The Education University of Hong Kong, Hong Kong SAR, China

Mashitoh Yaacob Universiti Kebangsaan, Bangi, Malaysia

Yi Yang Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, Hong Kong

Chi Ho Yeung Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, Hong Kong SAR, China

Yau Yuen Yeung Department of Science and Environmental Studies, The Education University of Hong Kong, Hong Kong SAR, China

Haakrho Yi Department of Gwangyang Research Group, RIST, Gwangyang City, Republic of Korea

Chun-Fai Yu Environmental Science Program, Division of Science and Technology, BNU-HKBU United International College, Zhuhai, Guangdong Province, People's Republic of China

Peter Hoi Fu Yu Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Tsing Yi Island, Hong Kong;
Department of Gwangyang Research Group, RIST, Gwangyang City, Republic of Korea

Chapter 1
Environmental Sustainability and Education for Waste Management

Winnie Wing Mui So, John Chi Kin Lee and Cheuk Fai Chow

'Around the world, waste generation rates are rising. In 2012, the world's cities generated 1.3 billion tonnes of solid waste per year, amounting to a footprint of 1.2 kg per person per day. With rapid population growth and urbanization, municipal waste generation is expected to rise to 2.2 billion tonnes by 2025' (The World Bank, 2018). In Europe, 'in 2014, the total waste generated in the EU-28 by all economic activities and households amounted to 2503 million tonnes; this was the highest amount recorded for the EU-28 during the period 2004–2014 (a time series that only exists for even years)' (Eurostat Statistics Explained, 2017). In 2016, it was estimated that 1.6 billion tonnes of carbon dioxide was generated from waste management globally, an amount that is expected to rise to 2.6 billion tonnes by 2050 if the current technologies, attitudes and behaviours of waste treatment remain unchanged (Kaza, Yao, Bhada-Tata, & Woerden, 2018). The increasing volume of waste is a global problem. With the improvements in quality of life and rapid urban and industrial development, the different types of waste are also increasing, including organic, paper, plastic, glass and metal as the most common. Faced with these enormous amounts of waste, countries are inclined to dispose of it by landfilling (Central and Eastern Europe: 84%, North America: 65%, Australia: 54%, Western Europe: 39%) and open dumping (Asia: 54%, Africa: 72%, South America: 74%). In some regions, recycling, composting and incineration are adopted, but the rates are not high (The Statista Portal, 2018).

W. W. M. So (✉) · J. C. K. Lee · C. F. Chow
The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: wiso@eduhk.hk

J. C. K. Lee
e-mail: jcklee@eduhk.hk

C. F. Chow
e-mail: cfchow@eduhk.hk

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With the natural degradation of some waste taking up to a few 100 years, these immense amounts of waste and mismanaged waste practices have a significant impact on natural ecology and cause harm to public health. For example, waste that goes into landfills will produce leachate, a type of toxic liquid which can escape into the surrounding groundwater if the landfill site is not adequately sealed. Plants and animals living downstream will be affected (Cabonne Council, 2018). Further, high demand for new landfill sites can affect natural habitats, resulting in the extinction of many species and biodiversity breakdowns. Open dumping can pollute the groundwater, providing areas for viruses and germs to breed. In some circumstances, waste will even be open-burnt, which seriously damages both local and global weather and atmosphere by the emission of air pollutants and particulates (Wilson et al., 2015). Moreover, wastes such as plastics or e-waste disposed into the ocean endanger the animals if they accidentally mistake the litter for food.

With the increasing volumes of waste worldwide, waste management has undoubtedly become an urgent problem. Integrated Sustainable Waste Management (ISWM) has emerged as one of the resolutions of municipal waste management. ISWM recognizes three fundamental dimensions of waste management, namely stakeholders, waste system elements and sustainability aspects. ISWM seeks stakeholder participation and gets them to agree to cooperate for a common purpose. Waste system elements, including 'generation & separation', 'collection', 'transfer & transport' and 'treatment & disposal' are widely implemented in most of the world, but equal weight is given by ISWM to the less understood elements of 'reduction, 're-use', 'recycling' and 'recovery'. The ISWM concept also identifies six sustainability aspects that provide policymakers with a set of tools to plan a desirable waste management system; they include 'technical', 'environmental/health', 'financial/economic', 'socio-cultural', 'institutional' and 'policy/legal/political' aspects. (Anschütz, IJgosse, & Scheinberg, 2004)

Being part of the environment, educators, policymakers and scientists are essential to achieving environmentally sustainable development. Sustainable development means 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987, p. 43). It emphasizes the balance of economic, social, environmental and technological considerations, as well as the incorporation of a set of ethical values. The 1992 *Rio Declaration on Environment and Development* listed 27 principles of sustainability. Of these, Principles 9, 10 and 11 provide more concrete directions for environmentally sustainable development in the aspects of technology, public participation and legislation, respectively. Principle 9 suggested enhancing the development, adaptation, diffusion and transfer of new and innovative technologies; Principle 10 advised that environmental issues should be handled with the participation of all concerned citizens at different levels; while Principle 11 proposed the importance of effective environmental legislation, standards, management objectives and priorities.

The discussion of sustainable development has aroused the public's attention ever since 1992. A more recent commitment to achieve sustainable development is the 2030 Agenda for Sustainable Development, which set out 17 Sustainable

Development Goals (SDGs) and 169 targets that are anticipated to stimulate action in the next 15 years for people, planet and prosperity. Of the 17 SDGs, goals 6, 7 and 12–15 are to establish the need to protect the environment through combatting environmental devastation such as climate change, land degradation, desertification, as well as through conserving and sustainably using resources including oceans, forests and ecofriendly production methods (United Nations, 2015).

The Rio Declaration expressed the need for the efforts of all countries to increase the awareness and involvement of all stakeholders through education and innovative technologies, encompassing regulation to achieve sustainable goals (United Nations, 1992). It is believed that population, urban development and waste generation will direct from 'North' to 'South' by 2030 (Wilson et al., 2015), so this book, *Environmental Sustainability and Education for Waste Management,* discusses the status of waste management in the Asia-Pacific region and in European countries, and provides possible policies, education strategies and new technologies to address this challenging issue. The book consists of three parts.

The first part on policy and social responsibilities for waste management has contributions from Malaysia, the Netherlands and Hong Kong, which share details of the solid waste management in Malaysia, the circular economy of plastics and the major problems in relation to the use of plastic and to what extent the Netherland's government policy is necessary and effective, and the suggestion of a holistic approach to waste management, mismanaged plastic waste and e-waste management in Hong Kong.

The second part on education has contributions to community and school waste management education from Romania, Germany and the UK; waste management education from the Chinese perspective; pupils' pro-environmental knowledge, attitudes and behaviours of plastic recycling education in Hong Kong; solid waste management in the tourist destinations of Hoi An, Vietnam and Puncak, Indonesia; as well as waste management and recycling education in Taiwan and Australia.

The third part looks at technology, and includes articles on Fenton technology for polypropylene waste degradation and the recovery of high-value chemicals from Hong Kong; carbon dioxide biosequestration and wastewater treatment using microalgae in Spain; utilizing different forms of waste sludge in eco-construction material production in China and Hong Kong; and the evaluation of the nutritional value of food waste-based feed pellets and common feeding materials for culturing freshwater fish in Hong Kong.

1.1 Part One—Policy and Social Responsibility for Waste Management

Policy implementation and building social responsibility are key to effectively achieving environmental sustainability for waste management at all levels. Social responsibility is about voluntarily doing something good for the environment beyond the legal requirements. It relates to individuals' and organizations' commitment. Policy means legal regulation. It is not only a '*driving force for the development of new technologies with better environmental properties*' (Formas & VINNOVA, 2008), but also forces and educates producers and consumers to change their behaviours and follow the rules. By integrating social responsibility and policy throughout organizations and the whole of society, this part consists of five chapters on different waste management practices and solutions for reference.

The chapter by Wenjing Deng focuses on different e-waste management policies and legislation in developed and undeveloped countries, current challenges of e-waste management and some potential sustainable approaches. The chapter takes Switzerland, China and the Basel Convention as examples to illustrate the fact that even though these countries have tried to establish formal e-waste management systems and prevent the transportation of toxic waste between nations, there are still several factors which hinder and challenge the effectiveness of e-waste management. These include unofficial transportation of toxic waste from developed countries to less developed countries, the lack of technological advancement in the developing countries, a low level of public awareness concerning the safety and health as well as the hazardous nature of improper recycling and disposal of e-waste. Some potential sustainable ways are also raised that may provide opportunities for underdeveloped areas.

The chapter by Mashitoh Yaacob, Maznah Ibrahim and Zubaidah Mohd Nasir examines Malaysian consumers' commitment to social responsibility in solid waste management from the perspectives of NGOs and youth by reviewing the literature. Solid waste management in Malaysia is still in its infancy and needs much improvement and support. Even though the Malaysian government introduced environmental campaigns before, they failed. The authors argue that the commitment of the consumer sector is more sustainable and longstanding compared to top-down enforcement. Through the literature and report findings, it is indicated that Malaysian consumers are more committed to performing recycling and reusing activities as compared to reducing activities.

In the chapter by Annemiek Verrips, Sander Hoogendoorn, Krista Jansema-Hoekstra and Gerbert Romijn, the authors provide a welfare-economic overview of the circularity of plastics, including the recyclability of several plastics and different techniques of separating waste. The circularity of plastics is one of the priorities in the government-wide programme for a Circular Economy in the Netherlands. The authors discuss the status of the worldwide use of plastics and the fact that the possibility of using bioplastics and recycled plastics to solve the plastics problem is limited due to several reasons. For example, plastic waste from households after sorting still consists of mixed materials with low market price and high processing cost using the current techniques. The authors provide some perspectives for policy and policymakers and suggest some policy options in different aspects.

The chapter by Lincoln Fok, Irene Nga Yee Cheng and Yau Yuen Yeung opens by addressing the value and popularity of plastics to raise the issue of mismanaged plastic wastes and their impact on human health, the environment and on the biota in particular. The authors also cite some cases, for example, debris entering the Pacific

Ocean due to the 2011 Tohoku tsunami in Japan and the significant amount of plastic waste and marine litter found in the South China Sea, to illustrate the impacts of marine debris on marine organisms. The chapter is followed by suggesting two main classes of remedial action to be taken: end of pipe and preventive measures. The former, e.g. cleaning up solid waste and improving waste collection infrastructure, are easier to execute but are unable to deal with the root of the issue. The latter, e.g. statutory control, environmental education, etc., are difficult to accomplish but should be valued over the shorter term solutions, to achieve the ultimate goal of rejecting single-use plastic products.

The chapter by Edwin Che Feng Lau reviews waste management status, problems and practices in Hong Kong, highlighting the roles of government, the private sector, NGOs and individuals in waste management. This chapter reveals that recyclers in Hong Kong encounter the difficulties of running their businesses with low-value recyclables, lack of support from the HKSAR government and cross-departmental collaboration on environmental policies when facing the growing amounts of waste. Lau proposes a holistic approach to waste management. He suggests a Producer Responsibility scheme to legislate the private sector to manage waste, a Polluter Pays Principle to force consumers to pay for the cost of treating their waste, and of course, he discusses the need to educate and establish a waste-conscious mindset and culture in society to achieve and sustain effective holistic waste management.

1.2 Part Two—Environmental Programmes from Schools and Universities, as Well as Community Education for Waste Management

The success of waste management, reduction and recycling necessitates the support of education, which entails both school and community education. This part consists of six chapters with contributors from different parts of the world including Australia, China, HKSAR, Germany, Japan and Taiwan. It is notable that there are relatively few published examples of education for waste management from Latin America. In the United States, waste reduction and recycling activities in schools are sometimes linked with green school development or district-level efforts such as the Logan County Solid Waste Management District (Logan County Solid Waste Management District, 2019).

Against the backdrop of the European Union (EU) Waste Legislation framework (European Commission, 2016), the chapter by Karin Kolbe compares the community and school education for waste management in Romania, the United Kingdom and Germany. In Romania, while there is no system-wide implementation of education for waste management initiatives, some schools and communities have promoted programmes such as 'Every Can Counts' and 'Recycling Patrol' (Lopotaru, 2013). In the United Kingdom, there are individual and nationwide programmes such as the Waste and Resources Action Programme (WRAP) which encompasses 'Recycle

Now', 'Love Food, Hate Waste' and 'Love your Clothes', which intend to partner with individuals, local authorities, businesses and community groups for recycling, reusing and reducing waste and resources (Waste & Resources Action Programme, 2018). In Germany, where an advanced waste management system has been established, there are few or no specific nationwide or cross-curricular initiatives for waste management in education.

The chapter by Huang Yu, John Chi Kin Lee and Jin Yuting overviews the waste management education in China. The chapter first gives a brief outline of international waste management trends by referring to examples from the United Kingdom, Germany and Japan. All these countries have established either a legal system or policies to manage different kinds of waste. China, as one of the countries with a large population and high levels of waste and environmental pollution, is no exception and has made significant efforts to enact laws and regulations so as to build up a circular economy and promote education for waste management, partially through the Centre for Environmental Education and Communications of the Ministry of Environmental Protection. Some initiatives are linked with eco-schools under the auspices of international organizations such as the Foundation for Environmental Education. The chapter then provides three case studies of primary schools in the Chinese Mainland to illustrate the implementation of education for waste management.

The chapter by Tzuchau Chang and John Chi Kin Lee examines the status of waste management and recycling education in Taiwan, where there is an Environmental Education Law. The chapter first refers to the situation of waste management and recycling schools in Southeast Asia, the United Kingdom, and Australia. For example, Sustainability Victoria (2016) in Australia launched the Victoria Waste Education Strategy document in the state of Victoria, one of the strategic directions of which is 'Support waste and resource recovery education for schools'. Another example from Australia is the Sunshine Coast Council, which has initiated recycling programmes and activities for schools and nearby communities (Sunshine Coast Council, 2018). The chapter then discusses how the Environmental Protection Administration Taiwan (EPAT) has implemented different initiatives such as the 4-in-1 Recycling Programme, which has enhanced overall waste recycling performance. The chapter also provides examples from different schools in Taiwan and illustrates waste management and recycling education as part of the environmental education activities in Taiwan's curriculum framework, Taiwan Sustainable Campus Project and Green School Partnership Network.

The chapter by Chi Chiu Cheang, Tsz Yan Cheung, Winnie Wing Mui So, Irene Nga Yee Cheng, Lincoln Fok, Chi Ho Yeung and Cheuk Fai Chow discusses a quasi-experimental study in primary schools in the Hong Kong Special Administrative Region (SAR), China. The chapter first highlights the issue of plastic pollution in Hong Kong. To enhance plastic waste recycling practices, an innovative plastic recycling bin (PRB) and 'I Act, U Act! Plastic Recycling' (IAUA) programme under the Centre for Education in Environmental Sustainability (CEES), the Education University of Hong Kong were implemented. In this context, a quasi-experimental, intervention-based study based on the concept of action competence (Jensen, 2002) was conducted to assess the pupils' pro-environmental behaviours, attitudes and knowledge related to recycling plastic. The results were positive and encouraging as after a 3-week school-based intervention, pupils revealed improvements in their use of the PRB, sorting accuracy and knowledge of classification of plastic waste commonly used in their daily lives as well as perceived recycling behaviour. Nonetheless, more measures might need to be pursued to improve and sustain pupils' attitudes towards environmental conservation.

In Southeast Asia, solid waste management has been an issue of increasing attention. Hoang and Kato (2016) provided an overview of some initiatives related to solid waste management education projects. For example, there were pilot projects initiated by universities in Malaysia and the Philippines to enhance participants' awareness of waste reduction and recycling. In Hanoi, Vietnam, there was also a pilot project which aimed to turn organic waste into compost, and through the involvement of university and elementary students and residents, the community members are encouraged to engage in a source separation programme of usage of eco-bags and organic waste (Hoang & Kato, 2016). In Indonesia, which lacks a unified waste management system, the government has promoted a waste bank programme to handle waste disposal (Zakianis & Djaja, 2017). There are community-based waste management and education practices such as the development of the Miftahul Jannah solid waste bank at the Quran Park (Taman Pendidikan Al-Quran, TPA) in the Sonosari settlements, Yogyakarta Special Region, Indonesia (Indrianti, 2016).

In the chapter by Jane Singer, Kinh Thi Kieu and Andrea Emma Pravitasari, the education of solid waste management based on the community in Vietnam and Indonesia as developing countries are discussed. The two tourist destinations of Hoi An, Vietnam and Puncak, Indonesia were selected as case studies. There are a concerted effort and partnership among local university students from the University of Education—The University of Danang (DUEd), researchers, government and community groups from Hoi An and the Cham Islands to enhance community members' and students' awareness of and community capacity for waste management through innovative waste education projects. Students involved in the training courses shared that they acquired more practical knowledge which is relevant to authentic examples as well as developing their own personal and research skills. In the case of rural Puncak-Bogor, Indonesia, university students and other volunteers helped the local village with grassroots participatory environmental planning and rural appraisal, as well as launching a litter campaign in the local community and waste management education in primary schools with the support of the Save Puncak Consortium and Bogor Agricultural University. These two case studies highlight the pivotal role of partnership and local involvement in the success of waste management education.

The chapter in this part by Amy Cutter-Mackinzie-Knowles and Lisa Siegel offers critical cartography of waste education in Australia which depicts that on the one hand, there had been an increase in recycling activities in the community, but paradoxically there was an increase in waste per capita from 2006–2007 to 2014–2015 on the other hand. There are also commonalities and differences between the government's promotion of a waste reduction programme with a resource recovery orientation and the wide array of waste education programmes such as worm farming, rubbish-free lunchboxes, and education about waste/landfill services offered at the local level. They then advocate a 'zero-waste' waste pedagogy based on a post-humanist perspective, which emphasizes de-centering humans as part of nature, challenging governmentality and mal-consumption, understanding the concept of 'thingification' and a more diversified approach to waste education.

All of these national and regional examples show that as Karin Kolbe explains in her chapter, different countries' societies may be positioned on an axis. One coordinate axis is related to the waste management system and policies, with Germany and Japan showing a more advanced stage of development. Another coordinate axis pertains to the community and school education for waste management where China and Vietnam are still at the initial stage, and the United Kingdom, Australia and Taiwan are at a more mature stage of development.

1.3 Part Three—New Science and Technologies for Waste Treatment

Science and technologies provide us with solutions to tackle problems caused by waste generation. A review of using innovations for municipal solid waste management gives us insights into various aspects of recycling and reduction: (i) collection (e.g. waste bin monitoring technology), (ii) transport (e.g. compact garbage collection trucks), (iii) segregation (e.g. a multi-compartment waste bin), (iv) sorting (e.g. optical sorting with cameras, UV and infrared spectroscopy), (v) recycling (e.g. deinking technology for paper recycling), (vi) processing (e.g. autoclaving), (vii) energy recovery (e.g. thermal conversion) and (viii) disposal (e.g. bioreactor technology) (Saleem, Zulfiqar, Tahir, Asif, & Yaqub, 2016). In Part Three of this book, there are four chapters on new science and technologies focusing on the regeneration of resources (energies, novel materials, and nutrients) from the treatment of plastic, food waste, wastewater and waste sludge.

The chapter by Cheuk Fai Chow and Chung Sum Chan reveals the potential applications of plastic wastes as sources to generate fine chemicals and energy. Current plastic waste degradation treatments require demanding operating conditions or long timespans. Effective technology for treatment is limited. The author demonstrates the utilization of Fenton technology with and without photo assistance to achieve a rapid and effective conversion of polypropylene plastic waste into energy source or high-value chemicals, respectively, under mild conditions. The degradation is controlled by the simple adjustment of the reaction conditions to create different desired products. Under ultraviolet-visible illumination, the positive pressure of carbon dioxide generated from the degradation of plastic waste could potentially be the source of mechanical energy for power-driven applications.

The chapter by Simona Francesca Consoletti and Pepijn Prinsen provides insights into the applications of microalgae in biosequestration for carbon dioxide (CO_2) capture, and in wastewater treatment technologies for the sustainable production of biofuels. Anthropogenic CO_2 emissions and release of eutrophic wastewaters contribute to global warming and eutrophication of water bodies, respectively. The author proposes a model to demonstrate the CO_2 biosequestration, which converts CO_2 into biomass by microalgae. This process is an important approach to dealing with climate change. Microalgae are also investigated in remediation treatment of wastewaters to remove CO_2-, phosphorus- and nitrogen-containing compounds, while at the same time producing biomass for biofuel.

The chapter by Nengxiong Wang, Yiu Fai Tsang, Hong Chua, Haakrho Yi, Yi Yang, Chun Fai Yu and Peter Hoi Fu Yu illustrates the prospective application of waste sludge as eco-construction materials. Waste sludge produced during water and sewage treatment can cause serious environmental and human health consequences in cases without proper treatment and disposal. The authors designed a method to treat sludge as a safe raw material to produce eco-construction materials, including bricks, concrete blocks, lightweight aggregates, cement and glass-ceramics. According to the characteristics of the different products, their applications and feasibilities have been discussed and analysed. The application of waste sludge was demonstrated to achieve waste stabilization and harmlessness, altering direct landfill disposal for a win-win strategy.

In the chapter by Wing Yin Mo, Yu Bon Man and Ming Hung Wong, the feasibility of using food waste-based feed pellets for culturing freshwater fish is demonstrated. Food wastes, including fruit peel and vegetables, meat, bone meal and cereal, were used to manufacture the feed pellets based on two formulations. With the analysis of the composition of the feed, essential amino acid profile, it was found that the two formulations of food waste-based feed pellets could provide sufficient amounts of nutrients (essential amino acid, crude protein, crude lipid, crude carbohydrate and total phosphorous), which are normally insufficient in common commercial fish feed. The growth performance in the fish feeding trials also indicated the suitability of the food waste-based feed pellets as feed for culturing freshwater fish.

1.4 Conclusion

This book provides discussions of the waste management practices of different countries and regions, which focuses on the policy and social responsibility, education and technology aspects. It is hoped that the concerted effort of different stakeholders can generate encouraging ways to manage the waste problem. Moreover, the detailed analysis of the situation in different parts of the world can be a useful reference for stakeholders in finding appropriate solutions in waste management.

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Winnie Wing Mui So is a Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong, and the Director of the Centre for Education in Environmental Sustainability. Her main research areas are STEM education, science and environmental education. She has been active with professional contribution, being the past President of the Asia-Pacific Education Research Association and Executive Member of the World Education Research Association, Hong Kong Educational Research Association and East Asian Association for Science Education.

John Chi Kin Lee JP, Vice President (Academic) and Chair Professor of Curriculum and Instruction, joined The Education University of Hong Kong (EdUHK) [formerly known as The Hong Kong Institute of Education (HKIEd)] since 2010. He is also the Director of the Centre for Religious and Spirituality Education (CRSE), Co-Director (Research) of the Centre for Excellence in Learning and Teaching (CELT) and Co-Director of the Centre for Education in Environmental Sustainability (CEES). He was Dean of Education and Professor of the Department of Curriculum and Instruction at The Chinese University of Hong Kong (CUHK).

Professor Lee has served as the Regional Editor (Asia-Pacific) of *Educational Research and Evaluation* and Executive Editor of *Teachers and Teaching* as well as editorial board members or advisory editors of many local, regional and international journals. He is also a prolific writer who has edited and written more than 25 books, and published over 100 journal articles and book chapters.

Professor Lee served as the Team Leader of a World Bank consultancy project on teacher education and has also held many visiting/guest/adjunct professorships at universities overseas and in Mainland China. He is the Changjiang Chair Professor conferred by the Ministry of Education, the People's Republic of China.

Cheuk Fai Chow is an Associate Professor of the Department of Science and Environmental Studies and the Director of Knowledge Transfer at the Education University of Hong Kong. He received his B.Sc. (Applied Chemistry) and Ph.D. from the City University of Hong Kong. He obtained a Croucher fellowship and did his postdoctoral training with Nobel laureate Jean Marie Lehn (The University of Strasbourg, France). His research interest lies in applying his environmental studies for energy, water resource and plastic waste studies.

Part I
Policy and Social Responsibility for Waste Management

Chapter 2
E-Waste Management: Challenges and Opportunities

Wen-Jing Deng

Abstract With the high speed of development in technology, electrical, and electronic waste (e-waste) had a rapid growth, which has been a heavy burden to ecological environment and human health over the last few decades. E-waste management has been an urgency puzzle to many countries since they are composed of a variety of organic substances like plastic and heavy metals like cadmium, chromium, mercury, and lead, which can accumulate in the food chain and the eco-environment due to the nonbiodegradable nature. Plastics as an important composition of e-products gathered in the landfills after their end of life, which contaminated the soil and groundwater. Recycling and disposing these materials in a safe and economical way will need huge investigation in technology and education by governments and industry. The electronic product updated fast due to the rapid growth of technology. There is a huge gap between the production and management properly. Large quantities of obsolete electronic products have been exported to the developing countries due to high cost and lacking labor, where, however, inappropriate and unsafe methods are used to manage this e-waste. In this review, the adverse effect the global management about e-waste is presented based on recent researches and surveys. The review also summarized some sustainable ways that would provide an opportunity for the underdeveloped areas. The developing technologies and improving policies of e-waste management are summarized. As an important part of e-waste recycling and management, legislative rules played a vital role in a certain region. In this review, the different policies and legislations would be compared between developed countries and developing countries. To solve the problem of e-waste fundamentally, the role of the individuals also would not be ignored. E-waste education would be an important part to help the individuals to change the lifestyles and strengthen their awareness about the positive effect of e-waste.

W.-J. Deng (✉)
Department of Science and Environmental Studies and Centre of Education in Environmental Sustainability, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: wdeng@eduhk.hk

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2.1 What Is E-Waste?

Electronic waste (e-waste) means various end-of-life forms of Waste Electric and Electronic Equipment (WEEE) end of life. There are various definitions of e-waste. The OECD (2001) indicated that e-waste means any appliance using an electric power supply that has reached its end of life. The EU WEEE Directive (EU, 2002) defined e-waste as all electronic substances or objects, which the owner disposes of or needs to dispose of according to the government legislation in force. The Basel Action Network (Puckett & Smith, 2002) indicated that "e-waste includes various and growing range of electronic equipment ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users."

According to the EU directive on WEEE, this may include items such as IT and Telecom equipment like computers, servers, mainframes, and monitors; office supplies like CDs, printers, scanners, copiers, calculators, fax machines; large household appliances like washing machines, microwave ovens, refrigerators, television, and air conditioners; small household appliances like battery cells, cellular phones, and transceivers; medical apparatus like CT scan machines, MRI, etc. consumer and lighting equipment like bulbs, CFL, and fluorescent tube lights; toys, leisure and sports machines; automatic dispensers, and so on.

2.2 The Quantity of E-Waste

It is very difficult to quantify the volume of e-waste generated globally. Balde, Wang, Kuehr, and Huisman (2015) estimated that the total e-waste produced all over the world was 41.8 million tonnes in 2014, and it was expected to rise to approximately 50 million tonnes by 2018. It was estimated that the e-waste annual growth rate is about 3–5% (Menikpura, Santo, and Hotta, 2014). This growth rate is about three times faster than that of other waste streams (Shamim, Mursheda, & Rafiq, 2015).

The amount of e-waste that is being generated in the world including China has increased significantly over the last 10 years. Specifically, the data estimate that over 130 million PCs, monitors, and TVs are eliminated annually, and this annual number is growing significantly in the United States (Bushehri, 2010). Bushehri (2010) estimated that over 315 million PCs would become obsolete between 1997 and 2004 and then between 2004 and 2007, an additional 185 million PCs would become e-waste in the United States. Totally, around 500 million PCs became obsolete by 2007 in the United States alone. Besides that, 130 million cell phones could also be discarded in 2005 alone in the United States (Realff, Raymond, & Ammons, 2004).

In Europe, it was estimated that 6 million metric tons of e-waste were discarded in 1998, and this was estimated to have doubled by 2010.

In Asian countries, about 610 million computers were obsolete in Japan by the end of December 2010, creating a big burden for this country with a small land area. In China, from 2003, there have been 5 million new PCs purchased each year and almost 10 million new TVs replaced every year (Hicks, Dietmar, & Eugster, 2005), which would result in generating about 1.11 million tons of e-waste every year. The main sources are the electrical and electronic industry and all electrical production processes, household appliance replacement, and all kinds of IT products, even including imports from other countries. India generates approximately 2.7 million tons of e-waste annually.

In terms of e-waste production per capita, the developed countries create much more than the developing countries. According to the US Environmental Protection Agency (Bastiaan, Zoetem, Krikke, & Venselaar, 2010), each household in the United States on average uses 34 electronic devices and electrical appliances, resulting in more than 5×10^6 tons of e-waste annually. For the EU, it was estimated that on average, each person contributes about 15 kg of e-waste annually, giving an estimated total of 7×10^6 tons (Bastiaan et al., 2010). Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, & Boni (2005) expressed that e-waste, as one of the fastest increasing forms of waste, constitutes about 8% of municipal waste. In developing countries, such as China and India, the mean production of e-waste per capita was only about 1 kg/year^{-1} (Widmer et al., 2005), but it is increasing rapidly. Because of the huge population, the total e-waste generated in these two countries will exceed that produced in the developed countries very soon. In addition, the amount of e-waste in the newly industrialized and developing countries is also growing because of the import of e-waste from developed countries. Some studies show that up to 50–80% of the e-waste that has been generated in developed markets is being shipped to developing countries for reuse and recycling (Widmer et al., 2005), often in violation of international laws. Approximately, 10.2 million units of computers were exported annually from the United States to developing countries, including China, India, and Pakistan (Wong, Wu, Duzgoren-Aydin, Aydin, & Wong, 2007).

With the high speed of development of technology and the growing competitiveness among various companies, the lifespan of many electronic devices has been gradually shortening. For example, in 1992, the average lifespan of a new computer was about 4.5 years, then after 20 years, it decreased to about 2 years or even less and is further decreasing (Widmer et al., 2005). That would cause much greater volumes of e-waste for disposal or exporting to developing countries. At the end of the twentieth century, the former 15 European member countries (EU15) estimated that the amount of WEEE generated varied between 3.3 and 3.6 kg per capita, then during the following 10 years, it rose to 3.9–4.3 kg per capita for the period 2000–2010 (EEA, 2003).

2.3 Effects on Environment and Human Health

Electronic devices themselves are not hazardous. When they are obsolete as e-waste, they are also harmless to the environment and human health. E-waste consists of valuable materials like gold, silver, copper, and other precious metals which could be used for recovery and reuse. However, due to the advanced technology and equipment and high consumption rates, the great part of e-waste recycling and disposal is not done in an environmentally friendly way. Other hazardous constituents present in the e-waste render it hazardous when it is dismantled and processed.

It is known that electronics and electrical equipment are efficient and environmentally friendly and bring convenience to humans, but when these devices become e-waste, they also become dangerous to the environment and to humans. First, such huge volumes of e-waste become a huge burden on governments when unprocessed e-waste is put directly into landfills coupled with the fast rate at which people replace their devices at present. If this e-waste is not properly disposed of, the harmful materials contained in it pose a real danger to human health and the local environment including water, soil, and air (Deng, Zheng, Bi, Fu, & Wong, 2007). Electronic devices such as PCs and mobile phones contain various toxic chemicals and plastics. For instance, cathode ray tubes (CRTs) in PC monitors contain various heavy metals such as lead, barium, and cadmium, which can be very harmful to human health, especially to children if they enter the ecosystem, for example, the water. These heavy metals can damage the human nervous system and respiratory system. The surface of plastics contains flame retardant materials, which can be released into the air and can damage human endocrine functions. If these materials are not handled properly, but are put directly into landfills, it would cause serious pollution to the surrounding environment.

There are many methods of e-waste disposal. Among them, landfill and incineration are widely used in both developed and developing countries, but both methods pose considerable contamination risks. Landfill produces leachates, which can potentially transfer toxic material into groundwater, while incineration by combusting the e-waste in an incinerator can emit toxic gases into the atmosphere. When these hazardous substances enter the environment, either through water or air, it would affect human health via the food chain or by breathing. Puckett and Smith (2002) reported that e-waste disposal may produce more than 1,000 toxic substances, the more commonly reported include persistent organic pollutants (POPs) such as dioxin, brominated flame retardants (BFRs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), and polyvinyl chloride (PVC), toxic metals such as barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), lithium (Li), lanthanum (La), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), silver (Ag), and hexavalent chromium (Cr(VI)). As mentioned above, 500 million PCs contain about 2,872,000 tons of plastics, 718,000 tons of lead, 1,363 tons of cadmium, and 287 tons of mercury (Puckett & Smith, 2002).

It has been reported that 50–80% of the e-waste collected for recycling in industrialized countries such as the United States ends up in recycling centers in Asia. However, the recycling industries in these countries, which include China, India, Pakistan, Vietnam, and the Philippines, are often crude and do not have the appropriate facilities to safeguard environmental and human health.

Guiyu, in Guangdong, China, for instance, was infamous for its involvement in primitive e-waste processing and recycling activities. It had become a major imported e-waste processing area by 1995, when it had about 5,500 shops employing some 1,50,000 people (Deng et al., 2006). The majority of the workers came from elsewhere in China. Typically, they labored without goggles, gloves, or proper ventilation, in fact without basic personal safeguards, and many were even minors. Common chores, such as grilling circuit boards over an open fire to melt the lead and plastic, exposed workers to PBDE and other toxic fumes, as well as high concentrations (43–389 times) of fine particulate lead (Li et al., 2008; Leung, Luksemburg, Wong, & Wong, 2007). As these processes often lacked pollution control measures, excessive releases of toxic pollutants into the environment, such as persistent organic and metal pollutants, resulted (Wang et al., 2005; Wong, Wu, Duzgonren-Aydin, Aydin, & Wong, (2007)). Wong et al. (2007) examined trace metal distributions in the sediments of the Lianjiang and Nanyang Rivers in Guiyu and found that the sediments of Lianjiang were seriously contaminated with Cd (4.09 ± 3.92 mg/kg), Cu (1070 ± 1210 mg/kg), Ni (181 ± 156 mg/kg), Pb (230 ± 169 mg/kg), and Zn (324 ± 143 mg/kg), whereas the sediments of the Nanyang River were slightly enriched with Cu (65.1 ± 101 mg/kg), Pb (47.3 ± 13.8 mg/kg), and Zn (107 ± 54.9 mg/kg) (Wong et al., 2007). Lead (Pb), as one of the conventional environmental chemicals, has been constantly discovered in the air, soil, water, sediment, and plants in Guiyu, and its level is usually much higher than in other reference areas (Huo et al., 2007). It was reported that the environment in Guiyu was seriously polluted and was no longer fit to live in, especially for children, who are more vulnerable to toxins than adults and are prone to long-term accumulation, resulting in many potential health risks (Li, Chen, Deng, Giesy, & Zheng, 2017).

Due to public pressure and frequent exposure in the international headlines, Guangdong's provincial government issued cleanup regulations and brought the pillar industry under a tight rein. After 10 years, the family-run recycling workshops were gone from Guiyu's streets. The government established all e-waste processing in an industrial park on the town's outskirts. The establishment of the industrial park made the environment cleaner, with the fumes and wastewater that are the by-products of the recycling process now treated before being discharged.

A study of 165 children aged 1–6 years old at a kindergarten in Guiyu revealed that 81.8% had blood Pb levels greater than 10 μg/dL (mean: 15.3 ± 5.79 μg/dL). It was concluded that those with the highest BLLs were children of parents who recycled circuit boards, whereas lower blood Pb levels were found in children whose parents recycled plastics (Huo et al., 2007). After 10 years, the environment in Guiyu had improved and developed; however, when Zhang, Schnoor, & Zeng (2012) evaluated the blood Pb levels of local children, the results showed that children in Guiyu, the exposed area, had higher blood Pb levels than children from the reference area (6.00 ± 2.75 mg/dL vs. 3.92 ± 1.96 mg/dL). Compared to 10 years earlier, the blood Pb levels had a significant decrease, but the mean concentration was still two times that of children from other areas. It is known that the residues of hazardous chemicals still poison the local people, especially the children.

2.4 E-Waste Legislation and Policy

Switzerland, as a developed country, is reported as a leading country in e-waste collection and disposal, and was the first country in the world to establish a formal management system for e-waste (Duygan & Meylan, 2015). Its e-waste management system is based on the principles of extended producer responsibility (EPR) (Sinha-Khetriwal, Kraeuchi, & Schwaninger, 2005), in an attempt to find the best way to balance the environment and the economy of e-waste treatment and disposal. To solve the problem of e-waste transportation from developed areas to developing countries, the Basel Convention was drawn up by global negotiation. The full name is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, and it is an international treaty which aims to reduce the transportation of toxic waste between nations, and specifically to prevent the transfer from developed to less developed countries. This Convention was ratified on March 22, 1989, and entered into force on May 5, 1992. As of November 2016, 184 states and the European Union had become parties to the Convention. China also ratified the Basel Convention in 1991, and has banned the import of e-waste since 2000, while also agreeing to the Ban Amendment in 2001.

However, unauthorized transportation of imported e-waste into China has never stopped, and it is also imported into other less developed areas. Developed countries such as Japan or Korea usually mix e-waste with other metal goods to transfer into China. On the other hand, other countries use Hong Kong as a transfer station to shift amounts of WEEE to the mainland of China because of the "One Country, Two Systems" policy (Kantarelis, Yang, Blasiak, Forsgren, & Zabaniotou, 2011; Quan, Li, & Gao, 2013). During the period 2001–2008, to improve the messy e-waste markets, the Chinese government imposed some more extensive regulations on e-waste disposal and management, including the prohibition of the importation of e-waste and some Administrative Measures on the Pollution of E-waste (Zhou & Xu, 2012). In addition, China implemented its Regulation on the Recycling of Waste Electrical and Electronic Products on January 1, 2011; this regulation incorporates a number of technical guidelines and policies (Wang, Kuehr, Ahlquist, & Li, 2013; Zhang et al., 2012). Subsequently, on January 1, 2015, the new Catalogue of WEEE Recycling (Batch 2) was issued, in which the number of WEEE types covered by the regulations was increased from five to fourteen. Seven national ministries, led by the Ministry of Finance, phased in the WEEE "old-for-new" (or trade-in) policy from 2009 to 2012 (Cao et al., 2016; Lu et al., 2015). As a temporary solution, this trade-in policy took an economic approach to enforcing the collection of WEEE for formal recycling. Later, more enforceable WEEE regulations were legislated, setting up an extensive formal recycling system funded by levies on EEE producers, with government subsidies for the recyclers (Salhofer, Steuer, Ramusch, & Beigl, 2016; Zeng, Li, Stevels, & Liu, 2013).

2.5 Challenges

In developing countries, due to the large population and lower salaries, the recycling of e-waste is very feasible. It was reported that before 2000, about 60% of obsolete electronic and electrical devices were handed over to individual collectors in the informal sector. These collectors then sold the products to informal plants for dismantling and mechanical treatment, after which the unusable materials were disposed of with no regard for environmental safety (Andrews, Raychaudhuri, & Frias, 2000). At present, there are massive numbers of family-run workshops for the informal recycling of e-waste all over the world. China's current RoHS regulations cover ten types of items (categories) and are more focused on minimizing the use of raw materials and recycling with environmentally friendly technology and supported by well-developed infrastructure. Despite this, some illegal enterprises still exist. In other developing countries, the recovery situation of e-waste is not optimistic. For example, in India, the policy focuses only on EPR, and there are limited recycling capacity and technology. Herat and Periathamby (2012) summarized the challenges in recycling e-waste in developing countries as follows.

The first major challenge is the unknown quantity of WEEE in some areas. As previously discussed, developed areas have established various regulations and guidelines to minimize the environmental impacts of e-waste disposal. However, most of the e-wastes is exported to the developing countries in semiofficial or unofficial ways, and there are no official statistical data of the actual quantity being exported. It can only be estimated by a preliminary model (Veenstra, Wang, Fan, & Ru, 2010). On the other hand, due to the rapid economic growth in many developing countries, the domestic generation of electronic waste in these countries is also expected to increase drastically, such as the situation in India (Dwivedy & Mittal, 2010), Nigeria (Osibanjo & Nnorom, 2008), and China (Liu, Tanaka, & Matsui, 2006). Since the WEEE contains various toxic chemicals in its matrix, the importation of e-waste by less affluent and developing countries is not very much different from the importation of toxic waste (Wong et al., 2007).

The next challenge is the lack of technological advancement. As the technological levels of these countries are generally low, the infrastructure and facilities for the proper treatment of WEEE are absent. Hence, huge quantities of toxic waste are mostly treated by primitive processes, namely manual dismantling, open burning, and acid leaching (Liu, Li, Zhao, Li, & Fan, 2009). Various toxic pollutants, both organic and inorganic, are released into the environment by these primitive technologies. Polycyclic aromatic hydrocarbons (Yu et al., 2006), halogenated compounds such as flame retardants (Qu et al., 2007; Xing, Chan, Leung, Wu, & Wong, 2009), polychlorinated biphenyls (PCBs) (Xing et al., 2009), and other combustible products during the thermal degradation of the nonmetal fraction of e-waste are also released into the environment (Brebu et al., 2004; Mitan et al., 2008). In addition, heavy metals such as lead, cadmium, mercury, copper, and chromium are leached into the environment (Duarte, Dessuy, Silva, Vale, & Welz, 2010; Leung et al., 2007), causing serious air (Deng et al., 2006), water (Li, Richardson, Walker, & Yuan, 2006), and land pollution (Cai & Jiang, 2006; Leung et al., 2007; Wang et al., 2005) simultaneously. Based on various studies, the pollutants are mainly generated and distributed widely by open site burning.

The last challenge is the need to improve safety and health awareness in the developing countries. These countries are facing several challenges related to enforcing and implementing regulations with their paucity of natural resources and the low level of public awareness concerning the hazardous nature of improper recycling and disposal of e-waste. Although the local citizens benefit from the precious metal recovery, the environment and health of their offspring most likely suffer from the substantial release of the toxic components formed in the recycling processes. Sepúlveda et al. (2010) and Leung et al. (2007) conducted reviews of the environmental fate and effects of hazardous substances released from electrical and electronic equipment during recycling in China and India. The concentration levels of various pollutants are found to be significantly higher than the reference values suggested by the World Health Organization (WHO). These contaminants enter the food chains in the affected areas and finally accumulate in human bodies by ingestion or inhalation routes (Zhao, Xu, Han, & Ling, 2006). Unfortunately, it has been documented that these pollutants have been found in the bodies of infants and children as well (Huo et al., 2007; Li et al., 2008; Guo et al., 2010). Damage to DNA and chromosomes (Liu et al., 2009) and the disturbance of hormone levels (Wang et al., 2010) are the identified adverse effects of these pollutants on human health. Despite the fact that the primitive treatments of the e-waste are creating pollution, the workers and residents may minimize the effects by implementing safety measures such as using personal protective equipment. However, since the citizens and workers are generally inadequately educated, they lack awareness of the serious risks concerning their safety and health.

2.6 Opportunities

It is known that e-waste does not only contain toxic chemicals, but also various valuable materials like metals. Some even contain precious metals such as gold and copper. Extracting these valuable metals from e-waste can generate huge profits. It is said that one ton of circuit boards can contain 80–1,500 g of gold and 160–210 kg of copper. The concentrations are 40–800 times the amount of gold from gold ore and 30–40 times the amount of copper from copper ore in the United States. It is reported that when 1 t of e-waste is recycled in the recycling process, there are many recycling substances which can bring environmental benefits. The first and most beneficial substances are metals which account for 52.42% of the total benefits; however, others can also bring environmental benefits such as recycling plastics and glass. The environmental benefits are good for human health, and for saving resources and ecosystem quality. E-waste recycling could avoid the exploitation of natural resources and can save energy and avoid polluting the environment during these processes. It has been reported that the greatest benefits are the avoidance of the emission of arsenic and cadmium (ion) into the water system (Deng et al., 2006; Wong et al., 2007). Due to the high-energy requirements of the extraction and processing of the materials, avoiding consumption of fossil resources appears to be more important than the other environmental impacts including metal resources, emissions into the air, and emissions into water.

Overall, proper e-waste recycling could reduce the potential impacts on the environment and human health, and even have various benefits for the ecosystem. With the development of technology and cost reduction, there have been many studies focused on particular aspects of this treatment and metal recovery. If the pollution can be controlled, the developing areas could utilize this opportunity to create high profits to improve their lifestyles and create job opportunities for the local people in the e-waste recycling industry.

2.7 Perspectives

The ideal method of e-waste management would be environmentally friendly principles which can avoid, or at least minimize, the release of hazardous substances into the natural environment, and at the same time reduce the human health risks. The future development direction has been improving the management approach and gradually improving the safety and health awareness of the people. The end-of-life management is a sustainable and environmentally friendly (Jimenez-Parra, Rubio-Lacoba, & Vicente-Molina, 2012; Zanghelini, Cherubini, & Soares, 2013). The developing countries should learn from other areas and develop proper methods and strategies fitting the development of their own countries.

Kumar, Holuszko, and Espinosa (2017) reviewed the global e-waste generation and collection, and also presented an overview of the legislation and practices, and made four suggestions about global e-waste management which mentioned the different responsibilities of various countries. The report indicated that the developed areas should focus on the development of technology and create new facilities for the e-waste management system. Then the developing countries should perfect the legislation and improve the people's awareness of e-waste management. The electronic producers should pay more attention to the recycling of e-waste which should bring huge profits for their own development and be of benefit to the nation. Finally, the review indicated that the regions should help each other with e-waste management.

As we have mentioned, if e-waste can be recycled properly, it could offer various opportunities for urban mining recovery and the urban economy. It can not only provide a large quantity of valuable metals by the disposal of huge volume waste, but can also decrease environmental and public health risks due to the management of harmful elements and chemicals in their composition.

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Wen-Jing Deng is currently an Assistant Professor in the Department of Science and Environmental Science at the Education University of Hong Kong. She has a solid experience in teaching, research and community service. Her research topics include waste management, indoor air quality, and environmental pollutants in the environment and health risk. Dr. Deng has published 39 peer-reviewed works published in high-ranked SCI journals. She presented over 30 lectures, worldwide. Dr. Deng is a highly cited author in the world in the field of Environmental Sciences with an Hirsch (H) index of 13 with over 1,800 citations. Her Research Gate (RG) Score is 28.50; >85.0%, with 1,616 citations.

Chapter 3
Solid Waste Management in Malaysia: The Perspectives of Non-governmental Organizations (NGOs) and Youths on Consumers' Commitment

Mashitoh Yaacob, Maznah Hj Ibrahim and Zubaidah Mohd Nasir

Abstract Solid waste management in Malaysia is under the responsibility of the Solid Waste and Public Cleansing Management Corporation or commonly known as SWCorp. It is licensed under the National Solid Waste Management Department, a department directed by the Ministry of Urban Well-being, Housing, and Local Government. SWCorp is responsible for setting up policies on solid waste management under the direct overview of the ministry. Solid waste management in Malaysia has undergone various levels of transformation from managing generated solid waste such as reusing and recycling before 2015 to reducing and segregating solid waste at source since 2015. The management of solid waste at source is emphasized by the enforcement of the 672 Act: Solid Waste and Public Cleansing Management Act 2007 in September 2015. Nevertheless, behavioral transformation requires a commitment to social responsibility, namely reducing, reusing, and recycling activities, in all sectors of the community. This chapter discusses and examines Malaysian consumers' commitment to social responsibility in solid waste management from the perspectives of NGOs and youth. The consumer sector is the most crucial group in the community as it represents the main grassroots. Furthermore, the commitment at grassroots is more sustainable and longstanding compared to top-down enforcement. Additionally, given that NGOs are more sensitive to the transformation of public behavior, and youth are our future decision makers on the fate of the environment, this chapter discusses consumers' commitment to social responsibility in waste management through the perspectives of NGOs and youth. The analysis regarding the commitment of Malaysian consumers through the perspectives of NGOs and youth indicates that Malaysian consumers are more committed to performing recycling and reusing

M. Yaacob (✉) · M. H. Ibrahim · Z. M. Nasir
Universiti Kebangsaan Malaysia, Bangi, Malaysia
e-mail: mash@ukm.edu.my

M. H. Ibrahim
e-mail: maznah@ukm.edu.my

Z. M. Nasir
e-mail: zuenasir@ukm.edu.my

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activities as compared to reducing activities. These findings illustrate Malaysian consumers' reluctance to embrace the philosophy behind behavioral transformation, that is prevention is better than cure. In this case, they are slow to adapt to the behavioral transformation activities related to reduce, segregate, and compost solid waste at the source.

Keywords Solid waste · Waste management · Malaysian consumer · Social responsibility · 3R

3.1 Introduction

Municipal solid waste (MSW) is highly related to the economic status of a country and the lifestyles of its population (Sreenivasan, Govindan, Chinnasami, & Kadiresu, 2012). Urbanization, rapid economic growth, and increasing urban populations have resulted in a marked escalation in the quantities of waste generated. Inadequate waste management will have a great impact on public health and may cause environmental degradation and resource depletion. Solid waste management is a study or discipline associated with the control of the generation, storage, collection, transfer and transport, processing, and disposal of solid waste. Wilson (2007) added that modern waste management has shifted to a more flexible waste hierarchy concept known as the 3Rs: reduce, reuse, and recycle. Some of Asia's developing countries are "the fastest and largest waste generators," and close inspection has revealed that a notable blend of general and specific elements of policy dynamics in the evolution and adoption of waste management policies need to be upgraded.

In the case of Malaysia, in spite of its aggressive economic development, solid waste management is still in its infancy and needs much improvement and support. In 2005, the waste generated in Malaysia amounted to 19,000 tons per day. With a projected population of over 31 million in 2016, Malaysia generates more than 25,000 metric tons of domestic waste per day. In 2015, the Solid Waste and Public Cleansing Management Corporation (SWCorp) produced the Mindset Transformation Plan toward a Clean, Beautiful and Prosperous Nation 2015–2020 (*Pelan Transformasi Minda ke Arah Negara Bersih, Indah dan Sejahtera 2015–2020*) in order to change the mindset of Malaysian consumers toward better waste management practices, which is, reducing, segregating, and composting waste (Kamarudin et al., 2015).

At present, the average per capita generation of municipal waste in Malaysia is about 0.85 kg/person/day depending on the economic and geographical status of an area (Zainu & Songip, 2017). In major cities such as Kuala Lumpur, it is estimated that the generation of waste is about 1.5 kg/person/day. Authorities in most major cities in Malaysia are seeking alternative waste management approaches as the landfill approach currently adopted is becoming unsustainable due to the rapid development and lack of new landfill spaces. In response to this situation, the Malaysian government, as part of the 10th Malaysia Plan (2011–2015), adopted waste recycling as a long-term strategy for municipal waste management.

The kind of waste generated the most is food waste, which is now about 45%, and which contains a high percentage of organic compounds. Thus, due to not being separated, more than 30% of potentially recyclable waste such as paper, plastic, aluminum, and glass are unfortunately directly disposed of in landfills. Consequently, by the year 2020, 16.76 million tons of waste is expected to be generated by nearly 30 million Malaysians. The steady increase in MSW generation over these years has resulted in government-funded public information campaigns to establish awareness and to create environmental consciousness among the general public. In 1988, the government introduced the Action Plan for a Beautiful and Clean (ABC) Malaysia, and recycling campaigns followed in consecutive years. However, due to minimal responses from the general public, the campaigns failed, although environmental awareness and knowledge of waste management among the public did increase slightly.

Thus, this chapter discusses and examines Malaysian consumers' commitment to social responsibility in solid waste management from the perspectives of NGOs and youth. NGOs and graduate students were chosen to compare their perspectives on issues of waste management practiced by consumers in Malaysia given that the consumer sector is the most crucial sector in the community as it represents the main grassroots of the population. Furthermore, the commitment at the grassroots level is more sustainable and longstanding compared to top-down enforcement. Additionally, NGOs are more sensitive to the transformation of public behavior, and youth are our future decision makers on the fate of the environment. Hence, this chapter discusses consumers' commitment to social responsibility in waste management through the perspectives of NGOs and youth.

3.2 Review of the Literature

Waste management and waste minimization should not always be the sole responsibility of local authorities. Other government agencies such as the Ministry of Housing and Local Government, Ministry of Environment, Ministry of Health, the various academic institutions, and non-governmental organizations (NGOs) need to work hand in hand to establish a more conducive environment for better waste management practices. By the year 2020, the Malaysian government plans to reduce the waste disposal at landfills, with a target of the reduction being at 40% through 22% recycling and 80% of intermediate treatment such as waste to energy, composting, and material recovery (Global Recycling, 2017).

Non-governmental organizations often act as agents of social change, although little is known about how they facilitate this change. NGOs create an impact by disseminating information, implementing public services, and advocating for environmental reforms which often involve collaborative processes with other stakeholders, although generally, empirical evidence of NGOs' involvement in sustainable waste management in the developing countries is sparse. On a separate note, a study by

Kamaruddin, Pawson, and Kingham (2013) found that gaining public participation or facilitating means for discussion is not easy as there are not many platforms available for discussion with the general public about sustainable waste management. The authors added that one of the barriers to advancing sustainable waste management activities is a lack of understanding among consumers as to why one should recycle when there is provision for recyclables collection. However, Kamaruddin et al. (2013) found that the evidence points to more successful efforts through participation and discussion among youths, in particular school students. Through the activities implemented in schools, the students took the opportunity to discuss their concerns and implement their aspirations. They also participated in current and creative ways to sustain the projects by extending recycling to water conservation projects, blogging, social networking, reporting and being consistently involved with monitoring the development of their activities. Hence, developing more creative and pertinent projects that encourage participation and build capacity such as knowledge, attitudes, and practice would be able to attract youth participation.

Meanwhile, the findings of Wahid, Rahbar, and Shyan (2011) indicate that the transformation of behavior among Malaysian consumers toward environmentally better waste management practices is more prone to be influenced by non-governmental organizations. However, studies by other Malaysian scholars (Rahbar & Wahid, 2010; Zulkifli, Harun, & Lim, 2014) have concluded that better waste management practices among Malaysian consumers occur through a process that is in accordance with the current development in the environment field, including the influence of domestic and foreign policy decision-making. Other studies, specifically those by Levine and Strube (2012), Baca-Motes, Brown, Gneezy, Keenan, and Nelson (2012), and Aytekin and Buyukahraz (2013), have measured the influences of social, demographic, knowledge, and individual factors on consumers' behavioral transformation toward better waste management practices. Levine and Strube (2012) found that knowledge among youth, that is, college students, is closely related to behavior in that those who are more knowledgeable behave in a more environmentally friendly way. The authors obtained similar findings regarding the role of age, as older students with more experience in universities showed more environmentally friendly attitudes.

The studies by Baca-Motes et al. (2012) and Aytekin and Buyukahraz (2013) focused on the knowledge and attitudes of consumers, which they found to have great effects on consumers' environmentally friendly behavior. Thus, the authors suggested that interventions using different mechanisms and targeting both knowledge and attitudes will clearly link to behavior change. Their findings illustrate that attitudes predict intentions, which consequently predict behavior and help to explain how attitudes change behavior.

Aytekin and Buyukahraz (2013), who studied green purchasing among consumers, found that consumers who have high knowledge, sensitivity, and awareness of the environment are likely to buy environmentally friendly products. The relationship between environmental interest and environmentally friendly behavior is also positive. In fact, environmental awareness affects the behavior of buying environmentally friendly products. The authors believed that to change the behavior of individuals toward better environmentally friendly practices such as waste management, they should be educated to have positive attitudes toward the environment. Only individuals who are concerned and sensitive about the environment, and who have an interest in resolving environmental issues can make changes in their behavior.

SWCorp was positive about consumers' support for waste segregation at source, and reported that there had been a noticeable increase in the number of households supporting the program. Following the enforcement of the 672 Act in the Malaysia Peninsular such as the states of Johor, Malacca, Negeri Sembilan, Kedah, Perlis, and Pahang on September 1, 2015, SWCorp claimed that the public are becoming more aware of the importance of segregating their household waste for environmental sustainability. SWCorp was of the opinion that segregating solid household waste is not at all a complicated task as only three categories of waste need to be separated, that is, paper, plastic, and other recyclables, whereas other countries where waste segregation is mandatory, have dozens of categories. Hence, over time, consumers will get used to it. However, SWCorp admitted that it is not easy to educate people to change their mindsets and practices (Bernama, 2016).

Nevertheless, through the literature review indicated that only a few studies have examined the types of waste management practiced by Malaysian consumers or the behavioral transformation of waste management practices from recycling and reusing to reducing and segregating solid waste at source as well as composting.

3.3 Methodology

Data and information on consumers' commitment to social responsibility in waste management discussed in this chapter were obtained through focus group discussion method of collecting data, which are, from two focus group discussions with the non-governmental organization group and the graduate student group. The profiles of the informants from the two groups are presented in Tables 3.1 and 3.2. The materials studied are relevant scientific literature and transcripts of the focus group discussions (FGDs). Verbatim and/or textual data (in the form of scientific literature and FGDs) were explored using the predetermined concept/thematic approach or the framework approach. Passages of text were identified, and labels of predetermined themes were applied to indicate the thematic ideas studied. Each theme was charted by completing a table where each case has its own row, and columns represent subtopics. Cells contain relevant summaries from the data set. All the texts associated with a thematic idea were examined together for patterns and connections, and different cases were compared.

Table 3.1 Profile of informants (NGOs)

Informant	Profession	Gender	Age	Education	Expertise	Malaysian NGO
Informant 1: Mrs. Z	Retiree	Female	55	[a]MCE	Environment	NGO 1 (WAS)
Informant 2: Mrs. N	Lecturer	Female	52	Master's	Law	
Informant 3: Miss N	Postgraduate Student	Female	26	Master's	Environment	NGO 2 (PEM)
Informant 4: Mr. N	Undergraduate Student	Male	21	[a]MCE	Zoology	
Informant 5: Mr. Y	Manager	Male	44	Diploma	Environmental education	NGO 3 (GRA)
Informant 6: Mr. M	Training executive	Male	29	Bachelor	Training and development	
Informant 7: Mr. H	Secretary	Male	60	Bachelor	Social welfare	NGO 4 (PER)
Informant 8: Mrs. M	Consultant	Female	41	Bachelor	Community development	NGO 5 (RCO)
Informant 9: Mrs. A	Vice President	Female	52	Master's	Environmental Management and waste disposal	NGO 6 (IKR)

[a]Malaysian Certificate of Education

Table 3.2 Profile of informants (students)

Informant	Currently studying Masters/Ph.D.	Gender	Age	Area of study	University
Informant 1: Shari	Ph.D.	Female	30s	Dengue prevention and control	Public K1
Informant 2: Ain	Ph.D.	Female	30s	Public service departments' mentoring program	Public K1
Informant 3: Ann	Master's	Female	20s	Bioremediation on shrimp farms	Public P2
Informant 4: Izu	Ph.D.	Male	30s	Renewable energy	Public N1
Informant 5: Tam	Ph.D.	Male	30s	Material science, i.e., stem cell	Public N1

3.4 Results and Discussion

The results illustrate the perspectives of NGOs and graduate students on consumers' commitment to social responsibility in waste management. The results also elaborate on the different types of waste management practiced by Malaysian consumers and the behavioral transformation of waste management practices adopted from recycling and reusing to reducing and segregating solid waste at source.

3.4.1 Types of Waste Management Practiced by Malaysian Consumers

According to Mrs. M from NGO 5 (RCO), recycling, which involves proper waste segregation, is one of the types of waste management practiced the most by consumers in Malaysia compared to other types of waste management such as composting, which is the least practiced by the Malaysian consumer. Hence, Mrs. M claimed that 51% of organic waste goes into the landfills. Her statement is supported by the findings of Ismail and Manaf (2013) who found that municipal waste in Malaysia contained around 48–68% organic waste. Contrary to Mrs. M from NGO 5 (RCO), Ann from the youth group, was of the opinion that recycling, which involves proper waste segregation, is not very popularly practiced by most consumers in Malaysia because a sense of personal responsibility and environmental benefits are yet to override incentives and personal gain. The generation gap between the two informants produced different takes on this issue. The informant from the youth group is more economically conscious compared to the informant from the NGO group. However, Tam from the youth group, decided that, compared to the economic aspect, household nurturing and education substantially affect consumers' waste management practices in terms of whether or not to reduce, reuse, recycle, segregate, or compost waste.

Tam, Ann, and Ain from the student group also thought that reusing is the most practiced method by Malaysian consumers compared to the other types of waste management activities, especially by consumers from middle-class families. In their opinions, pre-cycling or reducing waste, segregating waste, and composting are the waste management activities least often practiced by Malaysian consumers, particularly because these activities are perceived as time consuming, and all kinds of products come with too much packaging. Additionally, according to other informants, Shari and Izu from the student group, a few states in Malaysia do not subscribe to the 672 Act: Solid Waste and Public Cleansing Management Act 2007; hence, Malaysian consumers in these states are not sensitive to the various types of waste management activities.

According to Mrs. A from NGO 6 (IKR), the focus of campaigns is often on recycling, and overlooks the two steps before recycling, which is, pre-cycling or reducing and reusing. She added that recycling is at the lower level of waste management compared to pre-cycling or reducing and reusing. Mr. Y from NGO 3 (GRA) agreed with Mrs. A from NGO 6 (IKR) that efforts made are more focused on recycling, while there are almost none on pre-cycling or reducing and reusing. He added that consumers in Malaysia should emulate consumers in Indonesia in terms of transforming solid waste into crafts, and organic waste into compost. He added that Malaysian consumers should change their views on waste; "it is not waste but a new resource" he said. Hence, he added, the government approach to addressing the waste disposal issue should be changed accordingly, that is, not to focus only on recycling but also on pre-cycling or reusing. As an example, the division called Urban Farming in the Department of Agriculture Malaysia has been promoting the use of recyclables in urban farming. The informants from the student group did not comment on campaigns on waste management and/or urban farming. But they agreed with the informants from the NGO group that waste once generated should be seen as a commodity, not as waste, and should be utilized for other purposes via reusing as well as recycling activities.

Consequently, Mrs. M from NGO 5 (RCO) was of the opinion that prior to pre-cycling or reducing, reusing and recycling, one should perform the 5Ss, that is, sort, set in order, sweep, standardize, and sustain (Fig. 3.1). She believed that it is easier for people to do pre-cycling or reducing, reusing, and recycling activities once they are used to the 5S method. This opinion is supported by Mr. M from NGO 3 (GRA), who added that teachers in schools also have to be role models for their students. He added that teaching a module on environmental education must be established for schools and preschools. Tam, from the student group, agreed with Mr. M that education, formal or informal, is important and plays a big role in changing consumers' behavior toward environmentally friendly waste management practices. However, none of the students commented on the 5Ss and their relation to waste management practices.

The opinions of the informants from the NGO group, namely, Mr. M from NGO 3 (GRA) and Mrs. M from NGO 5 (RCO), indicate that the 5Ss should first become a part of the culture of Malaysian consumers, and only then will pre-cycling or reducing, recycling, and composting activities naturally follow (Fig. 3.2). However, Miss N from NGO 2 (PEM) was of the opinion that the type of waste management practiced by Malaysian consumers is seasonal and depends on whether or not there is a campaign, such as campaigns on recycling, green campuses, and the 3Rs. The waste management activities performed by the Malaysian consumers are not sustainable and only last for the duration of the campaigns. However, a number of institutions, both educational and commercial, have adopted the 5Ss in their workplaces under the institution's quality management system (QMS). But, the question raised is that how much this practice has continued into their homes and has affected the other types of waste management remains unanswered.

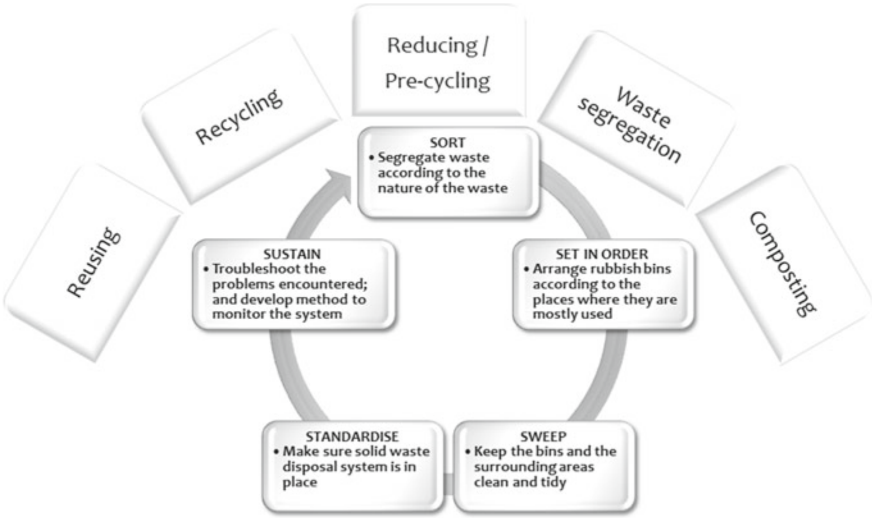


Fig. 3.1 Solid waste disposal and the 5Ss

Fig. 3.2 Levels of waste management according to the informants

3.4.2 Behavioral Transformation of Waste Management Practices from Recycling and Reusing to Reducing and Segregating Solid Waste at Source

According to Mrs. M from NGO 5 (RCO) and Miss N from NGO 2 (PEM), the rate of recycling activity performed by Malaysian consumers is still very low, although it is increasing depending on residential areas. Additionally, the composting rate is the lowest compared to the other waste management practices. Hence, one can only hope that Malaysian consumers' behavior may be transformed to reducing and segregating solid waste at source, meaning to say that reducing and segregating waste at source are yet to be performed diligently by Malaysian consumers. Ann, one of the informants from the student group, hold the opinion that reusing is the only waste management activity that is consistently performed by Malaysian consumers for generations, while the other waste management activities such as recycling, segregating waste, and composting are not consistently practiced by Malaysian consumers. Hence, the informants were of the opinion that the behavioral transformation of waste management practices from recycling and reusing to reducing and segregating waste at source including composting has yet to occur in a substantial manner.

Mr. H, from NGO 4 (PER), agreed with Mrs. M from NGO 5 (RCO) and Miss N from NGO 2 (PEM) advocated that reducing, segregating waste at source, and composting activities are not widespread and are still performed at a minimum rate by Malaysian consumers. He added that urban and suburban areas are different in terms of the type of neighborhood and the community leadership of the areas, specifically, community leaders who are active would mobilize the community to perform environmentally friendly waste management practices, but unfortunately, many are not. He believed that this is rooted in the lack of actions by those who have knowledge and awareness of the importance of protecting the environment. Thus, they cannot be a model for the community. Tam, from the student group, agreed with Mr. H that the social and physical environment one lives in, that is, village versus city residential areas, substantially affects one's commitment to waste management practices as these two areas are different in terms of social norms and the facilities provided. In the villages, with so much open space and lack of facilities, consumers are more prone to dump waste improperly compared to consumers living in the city. Their opinions are supported by Zulkifli et al. (2014) who found that "the level of knowledge on the environment" is not a strong determinant of behavior, meaning that those with a high level of knowledge of the environment may not necessarily translate their knowledge into behavior. The findings of Wahid et al. (2011) also support the views of Mr. H from NGO 4 (PER) in that "environmental knowledge related to waste" although related positively with "green purchasing behavior," did not show a significant relationship, noted as, $p > 0.05$ (Fig. 3.3).

Mr. H noted that the unfavorable rate of transformation process toward diligent reducing, segregating, and composting wastes amongst consumers in Malaysia is due to the community adopting a wasteful lifestyle (Fig. 3.3). For instance, open houses in festive seasons, and food prepared buffet style in households and hotels or restaurants often create food wastage. On the other hand, the findings of Levine and Strube (2012) and Aytekin and Buyukahraz (2013) contradict the NGOs' views and Malaysian scholars' findings, as they found that respondents who are more knowledgeable behave in a more environmentally friendly way. The opposite findings of the western scholars, that is, Levine and Strube (2012) and Aytekin and Buyukahraz (2013), compared to the findings of the current study, via FGD, and of Malaysian scholars illustrate that although both Malaysians and westerners are knowledgeable of the importance of protecting the environment, Malaysians however, have a greater tendency not to act on their knowledge compared to westerners. Ann, from the student group, agreed with the NGOs' views and the findings of the Malaysian scholars that the tendency of Malaysian consumers to commit to environmentally friendly waste management practices is less in comparison with consumers in other countries, especially consumers in developed nations.

However, Ain, Izu, and Shari, from the youth groups, were more positive and thought that the change in behavior toward diligent reducing, segregation of waste, and composting activities are happening, although at a very slow rate, which is in their opinion consistent with the facilities provided. Additionally, Mr. N from NGO

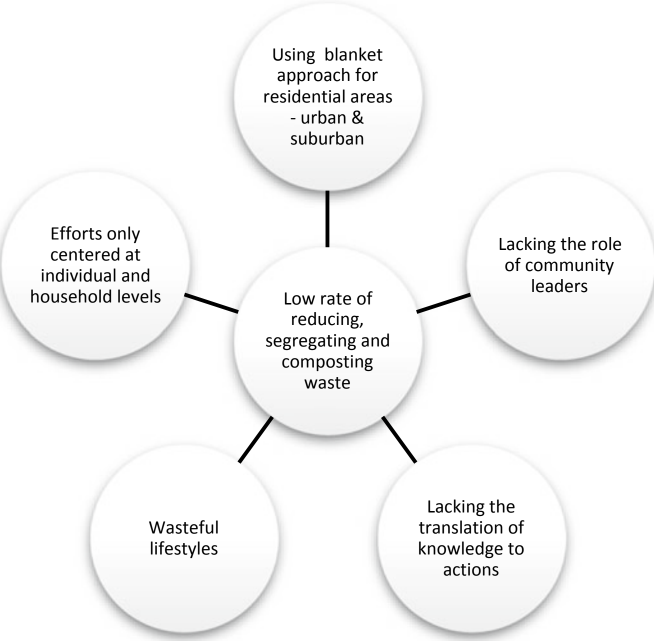
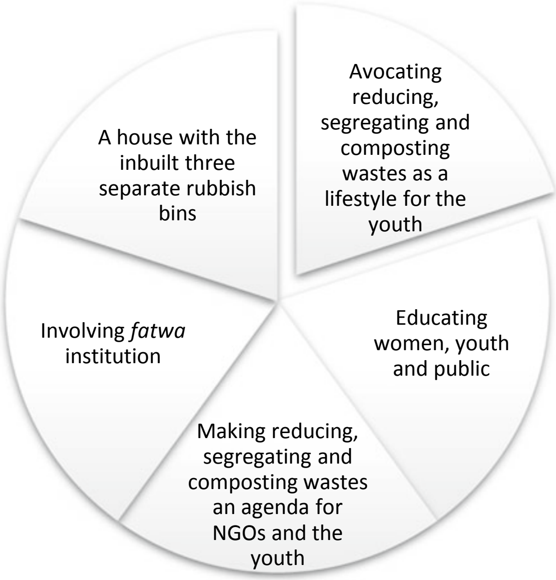


Fig. 3.3 Low rate of EEB performed and its factors according to the informants

2 (PEM) agreed with the views of the students as he believed that the behavioral transformation of consumers toward reducing and segregation of waste as well as composting among the youths in Malaysia is visible, although it is not widespread and is occurring at a slow rate. He pointed out an example of a student, Mr. Izham (a Horticulture Graduate from a local university), who initiated www.kebunbandar.com—an agriculture consultancy firm specializing in urban gardening. Mr. Izham has assisted an orphanage to gain income from growing chilies and supplying 20–30 kg of them to supermarkets every 2 days. Mr. N from NGO 2 (PEM) added that although at the moment efforts like this are concentrated at the individual and household levels (Fig. 3.3), the trend of using recyclables (such as wooden pallets, drum barrels, and glass bottles) amongst the youth of Malaysia is becoming more popular as vintage style has a comeback into the green practice. These recyclables are considered trendy by young people for flooring, interior décor, furniture, and many more functions, and they are gaining many followers. Mr. N admitted that he is a product of campaigns on reducing, recycling, and reusing during his school days, and in his case reducing, reusing, and recycling behavior have lasted until today; he cannot bring himself to throw rubbish anywhere but in a rubbish bin, and he would feel very guilty should he do otherwise. He emphasized that reducing, reusing, and recycling activities need to be a lifestyle of the youth should we hope to have them embrace environmentally friendly waste management practices (Fig. 3.4).

Fig. 3.4 Different approaches to accelerate EEB according to the informants



According to Mrs. A from NGO 6 (IKR), since women hold a lot of purchasing power, especially in decision-making regarding the purchasing of household items, we should therefore focus on educating women to be smart buyers, to purchase based on needs and not desire, and hence to pre-cycle or reduce and reuse. She noted that admirable transformation process of waste management practices amongst Malaysian consumers should be publicized by Malaysian NGOs. For example, Malaysian Islamic Relief has been performing reusing activities for the past 2–3 years through opening charity shops selling old reusable clothes, books, and other articles donated by the surrounding community members. The money obtained is utilized to aid beneficiaries in need (Fig. 3.4).

Mr. Y from NGO 3 (GRA) and Mrs. N from NGO 1 (WAS) agreed that to transform consumers' behavior into environmentally friendlier waste management practices, legal authorities such as the sustainability *fatwa* (edict) institution need to be involved. He noted that, to date, there has been no single *fatwa* issued for environmental protection in Malaysia. Additionally, Ain, from the youth group, thinks that environmental law enforcement such as the 672 Act is an important catalyst for transforming consumers' commitment to better practices in waste management activities, that is, reducing, segregation of waste, and composting.

3.5 Conclusion

The informants from the NGO group agreed that recycling activities are performed the most by consumers in Malaysia compared to the other types of waste management activities, while composting activities are performed the least. However, informants from the youth group were of the opinion that consumers in Malaysia are most committed to performing reusing activities compared to other types of waste management activities. Hence, it can be concluded that the results from the FGDs illustrated that reusing and recycling are the common types of waste management practiced by consumers in Malaysia.

Unfortunately, however, pre-cycling or reducing and waste segregation as well as composting are rarely performed by consumers in Malaysia. On a separate note, the informants from both the NGO group and the youth group were unified in their views that the behavioral transformation of waste management practices toward diligent reducing, segregation of waste, and composting activities do exist, but at a very slow rate due to various factors. These factors are discussed and identified relate to the types of residential areas, such as urban versus suburban areas where suburban areas, for example, may not be affluent as they may lack community leaders, and lack the translation of environmental knowledge into action. The Malaysian suburbanites may still have the feature of wasteful lifestyles and the green practice efforts among them may only be centered on the individual and household levels.

Thus, in conclusion, the reducing, segregation of waste at source, and composting behaviors of Malaysian consumers are not accelerating at the speed that we hoped for; which in fact, some of the activities are decreasing in practice. However, on a positive note, there is a trendy transformation of behavior toward diligent reducing, segregation of waste at source, and composting already happening among Malaysian youths such as among university students.

The analysis regarding the commitment of Malaysian consumers through the perspectives of NGOs and students indicates that Malaysian consumers are more committed to performing recycling and reusing activities as compared to reducing, segregation of waste, and composting activities. These findings illustrate Malaysian consumers' reluctance to embrace the philosophy behind behavioral transformation which is: prevention is better than cure. In this case, they are slow to adapt to the behavioral transformation activities related to reduce, segregate, and compost solid waste at the source. Additionally, the emerging issues regarding the relationship between the 5S method and the management of solid waste disposal brought into the FGDs should be studied in future research.

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Mashitoh Yaacob is an Associate Professor at Pusat Citra Universiti; and Deputy Director and senior research fellow at Institute of Islam Hadhari, Universiti Kebangsaan Malaysia. Dr. Mashitoh Yaacob obtained B.A. (Hons) in Social Sciences and Humanities (1995) and M.Env.Mngt. in Environmental Management (1996) from Universiti Kebangsaan Malaysia and Ph.D. in Environmental Philosophy from The University of Waikato, New Zealand (2009). Her main contributions are in Islamic environmental ethics; environmentally ethical behavior; ethics of consumption; and education for sustainable development. She currently teaches and supervises students on and related to the areas of Environmental Philosophy, Islamic Civilization, and Environmental Ethics. She has produced policy papers, and authored and co-authored more than 100 articles in journals, books, proceedings, and seminars in the field of environmental philosophy.

Maznah Hj Ibrahim obtained Bachelor of Arts majoring in Psychology and English from Wilmington College, Ohio, USA. She graduated with a master's degree from the University of Wales, United Kingdom in M.Ed. TEFL and Educational Technology. Maznah is a senior lecturer at Pusat Citra, Universiti Kebangsaan Malaysia. She has been teaching liberal arts courses for 18 years. Her research interests relate to women and development and teaching and learning issues. Her other teaching passionate includes integrating environmental awareness in her service-learning projects. She won several teaching awards, which features environmental awareness and inculcating upcycling interest among local Malaysian students.

Zubaidah Mohd Nasir obtained B.Sc. (Hons) in Parks and Amenity Management from Universiti Teknologi Mara (2008) and M.Sc. in Environment and Development from Universiti Kebangsaan Malaysia (2015). She is a research fellow at Institute of Islam Hadhari, Universiti Kebangsaan Malaysia and currently, she continues her studies in Ph.D. level in food waste recycling in Islamic context. She was the graduate research assistant at Institute of Environment and Development, Universiti Kebangsaan Malaysia in 2009–2016. Ms. Zubaidah has been involved in various research projects such as The Formation of Sustainable Development Campus through Curriculum Development, Informal Recycling Activities, Ethical Business Practices, and Environmental Fiqh and Islamic Environmental Ethics.

Chapter 4
The Circular Economy of Plastics in the Netherlands

Annemiek Verrips, Sander Hoogendoorn, Krista Jansema-Hoekstra and Gerbert Romijn

Abstract Production of plastic has grown enormously to over 320 megatons in 2016 and will continue to increase in the future. Most important environmental damage caused by plastic is pollution, especially the plastic soup, and the emission of CO_2, which causes climate change. The depletion of natural resources, oil and gas, is not considered to be an important issue in relation to plastic. Because in the long run, less oil and gas will be used worldwide due to the upcoming of sustainable energy, oil and gas supplies will be sufficient for the production of plastic for several 100 years. At the moment, the environmental benefits of recycling household plastic are limited. It provides no solution to reduce plastic soup or littering. CO_2 reduction is limited to about 0.15% of total CO_2 emission in the Netherlands. Increasing recycling of household plastic will not automatically increase environmental benefits. In this stage, augmenting quality of recycled plastic is to be preferred over increasing the amount. The government could subsidise innovation in this matter and stimulate the quality of recycled plastic in a financial way. Enterprises could alter their strategy by using plastics that cause less problems in recycling. The use of biobased plastic, which refers to plastic made of biomass, is no solution in the field of plastic soup. About three-quarter of all bio-based plastic used worldwide is not biodegradable. Above this, for bioplastic to be biodegradable you generally need an industrial environment. Biobased plastic can reduce CO_2 but net results vary widely due to side effects on the environment. Possible measures to reduce littering and plastic soup would be extending the packaging deposit-refund system, regulation with respect to plastic in cosmetics, innovation in removing plastics from wastewater and measures to reduce plastic in organic waste which is turned to compost.

Keywords Plastic recycling · Biobased plastic · Plastic soup · Packaging deposit-refund system · Environmental benefits

A. Verrips (✉) · S. Hoogendoorn · K. Jansema-Hoekstra (Deceased) · G. Romijn
CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands
e-mail: A.S.Verrips@cpb.nl

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4.1 Introduction

The circular economy and the policies on the circular economy aim to reduce the use of natural resources, promote reuse and recycling and reduce waste production, in order to reduce the ecological footprint of human activity. The underlying reasoning is that human activity is depleting the planet, both with respect to natural resources and the habitability of the physical environment.

CPB Netherlands Bureau for Economic Policy Analysis studies the economic aspects of a circular economy and related policies. In doing so, it looked at the impact of the circular economy on social welfare. This concept principally includes all matters important to human beings, and also those for which there is no market or market price (e.g. nature, safety, landscape environment).

This publication provides a welfare-economic overview of the circularity of plastics, from raw materials to waste. Plastics are used a lot, worldwide, and their use is still increasing. In addition, the use of plastics comes with substantial environmental problems. Plastics, therefore, are also one of the priorities in the Government-wide programme for a Circular Economy, by the Dutch Ministries of Infrastructure and Water Management, and Economic Affairs and Climate (Ministries of Infrastructure and Water Management, and Economic Affairs and Climate, 2016). In relation to this analysis, all authors visited two organisations: AVR (a waste-processing plant) and SUEZ (a company that collects, separates and recycles waste). The aim of these working visits was to obtain information from people working in the field and to experience the process of burning and recycling of waste ourselves. Useful information received on the recycle-ability of several plastics, on nonusable waste and on different techniques of separating waste.

The purpose of this analysis is to outline the main aspects of the circular economy of plastics, in order to provide a number of perspectives for policy and policymakers. Section 4.2 describes the main findings from the analysis.[1] Section 4.3 contains the policy implications that follow from the analysis. The closing section provides the conclusions (Sect. 4.4).

4.2 Findings

4.2.1 Worldwide Use of Plastics is Greatly Increasing

Since the 1960s, the global use of fossil fuel-based plastics has increased 20-fold (Ellen MacArthur Foundation, 2016). The use of plastics has thus increased much more rapidly than the global GDP. Oil and natural gas provide the resources for the production of fossil fuel-based plastics (so-called *virgin plastics*). The use of such

[1]This paper is published in Dutch (Verrips et al., 2017a). An in-depth analysis is provided in Verrips et al., (2017b).

'virgin plastics' is projected to increase from 320 Mt today, to around 1.1 Gt by 2050. The largest share of plastics used in the Netherlands is for packaging (around 40%). In addition, large amounts are also used in construction (around 20%, mainly in the form of PVC), consumer goods and passenger vehicles.

Alternative ways of producing plastics concern the use of biomass (bioplastics) and recycled plastics (recyclate). The global share of bioplastics is currently around 1%. In the Netherlands, around 10% of plastics are produced from recyclate.

4.2.2 Depletion of Resources for the Production of Fossil Fuel-Based Plastics Will Play a Minor Role in the Coming Decades

Between 4 and 8% of the total demand for oil and natural gas is for the production of plastics (as resource and as fuel). Increasing the sustainability of the transport and industrial sectors is likely to lower the general demand for oil and natural gas. In such a case, there would be plenty of oil and natural gas available for the production of plastics for hundreds of years to come. There are also technical possibilities for using a larger share of the oil and natural gas stocks in the production of plastics. However, production costs would increase, as hydraulic fracturing (or fracking) becomes more expensive as larger shares of oil and natural gas are used in plastics production.

Questions about the security of supply concern two main points of consideration. The first is whether sufficient resources would be available and to what extent we are dependent on countries on whom we would perhaps rather not depend. The other point concerns the prevention of large price shocks that would have a backlash on the real economy. These points are related. A well-developed world market for a certain resource means that there are many competing suppliers and customers who are able to secure their mutual current and future trade positions via liquid financial markets. This does not completely rule out price shocks, but will make them less likely. However, if market access for suppliers is restricted, markets are small (few transactions), or supply is non-contestable in other ways, the slightest rumour may lead to price peaks and market panic whereby countries will close their markets or use their market power.

Oil and natural gas production are spread all over the world. A decline in the demand for oil as a result of CO_2 taxation, together with the emergence of alternatives, would decrease the global market for oil-producing countries. In such a case, oil would increasingly become more of a resource instead of a fuel.

The price of plastics is far less volatile than that of oil. This, first and foremost, suggests that there are more factors determining the costs of plastics production, in addition to the price of the primary resource. Moreover, the production of plastics is spread all around the world. In that sense, there seems to be a well-developed market for plastics sourcing. Guaranteeing supply thus appears less of a strong argument for reducing the use of oil and natural gas in the production of plastics.

4.2.3 Damage to the Physical Environment is the Most Important External Effect

An important external effect relates to litter, which has a negative impact on the landscape, nature and the environment. A fair amount of this litter, consisting largely of packaging, will end up in the oceans. Plastics disintegrate into so-called microplastics, which can damage human and animal health. The so-called *plastic soup* is a major environmental problem that is still increasing.

Another source of microplastics in Dutch waters, besides litter, is wastewater. These microplastics, for example, are released when clothing is washed, or they originate from plastics in cosmetics. Furthermore, rainwater contains wear particles from tyres, microplastics from the wear and tear of paint, rubber granules from artificial grass on soccer fields and plastics from compost that is based on biodegradable waste.

A recent study by the WUR (Speksnijder, 2017) shows that the Arctic Ocean also contains large amounts of microplastics. These microplastics could accelerate the melting of the ice caps and thus speed up the impact of climate change. Moreover, they are located in an area of relatively large biodiversity. An analysis of ocean currents reveals that these microplastics originate particularly from north-western Europe. The external effects of the plastic soup, therefore, have a large international component. For that reason, the solution to this problem requires collaboration between countries.

4.2.4 CO_2 Emissions of Producing, Recycling and Burning of Plastics

Another large external effect is the emission of CO_2. Of all the emissions related to the production of plastics, CO_2 is by far the most important component in the Netherlands. Plastics-related emissions of nitrogen oxide (NO_x), sulphur dioxide (SO_2) and particulate matter (PM_{10}) in Europe are relatively limited because of the implemented emission standards. The most important emission is CO_2, followed by particulate matter (mainly from production processes in certain countries outside western Europe). CO_2 is emitted not only during extraction and production processes, but also during incineration and recycling.

Some of the CO_2 emissions are included under the Emissions Trading System (ETS). However, not all countries are involved: the production of plastics in, for example, China and the United States is not part of the ETS. Nor does the ETS include CO_2 emissions from the incineration of plastics in waste-incineration plants. In the Netherlands, 14% of residual waste consists of plastics. Waste incineration in such plants is also used for generating heat and electricity. If this heat and electricity had been generated in another way, this would have involved the emission of CO_2.

In the current energy mix, these so-called avoided emissions form around one-third of the CO_2 that is emitted during the incineration of plastic waste.

4.2.5 Possibilities of Bioplastics Solving the Plastics Problem are Only Limited

Bioplastics do not seem to be a viable solution to the problems of litter and plastic soup, because they are only biodegradable to a limited degree. Currently, only a quarter of these plastics are biodegradable. Those that are, mostly require an industrial environment of heating in order to biodegrade. This, therefore, will not happen to bioplastics that end up as litter.

Is there anything to gain, in terms of lower CO_2 emissions from the production of bioplastics? The answer strongly depends on the type of biomass used and the location in which it is grown. Production is less efficient than that of using fossil resources. Oil palms are the most efficient crop species, in terms of land use and CO_2 reduction, but this type of cultivation involves deforestation. An alternative would be the use of sugars as the resource for bioplastics; this reduces CO_2 emissions as well as the risk of negative impacts on nature, compared to using vegetable oils. In addition, the negative effects on the environment of the amount of water that is needed in the cultivation of biomass must also be taken into account, as well as the emission of acidifying compounds and nitrous oxide, a very strong greenhouse gas related to the use of artificial fertiliser.

The external effects of biomass production are potentially large. The amount of land required to produce bioplastics from biomass is relatively large. And because land is scarce, there is also competition with food on the basis of price ratios, with nature (landscape and biodiversity) and with the demand for energy. It is uncertain whether the increasing demand for biomass can be fully met by technological development increasing the production per hectare and by second- and third-generation biomass—which involves the use of more waste flows.

4.2.6 Limited Options for the Application of Recycled Plastics, Given Current Technology

Current techniques cannot fully separate plastic waste into homogenous flows of individual types of plastic. For this reason, the largest part of the plastic waste from households after sorting currently consists of mixed materials with a low and sometimes negative market price (called 'mix'), and for a small part of more homogenous flows of one type of plastic. Some of the 'mix' is being exported, but a limited part is stored or ultimately incinerated. The situation for regranulate, originating from homogenous flows, is more positive. There are more applications for this material and it has a higher market value. Yet, price levels are still below those of virgin plastics. This is partly caused by the lower quality that results from imperfect separation methods. Regranulate from homogenous flows also has its limitations with respect to application possibilities. These limitations refer to regulation around additives and food safety and include the fact that certain plastics retain the odour of the original product.

Recyclate will be more competitive under higher oil and natural gas prices and higher CO_2 prices. Nevertheless, the limitations of the application possibilities for recycled plastics, under the current state of technology, still determine their low market price.

4.2.7 Technological Development is Crucial

Technological developments may, for instance, improve the quality of regranulate, and reduce the cost of recycling. It is debatable at which pace developments will take place and to what degree certain barriers, in practice, could also be overcome with new techniques. An example of a new technique is chemical recycling, during which the original resource material is re-extracted. This could potentially remove important limitations in applications, but currently still involves high costs and a high use of energy. It is as yet unclear whether this process will ultimately result in environmental gains.

Technological development is also very important for other forms of circularity. One example is ecodesign, through which it is easier to recycle products or to extend the lifetime of products and concepts. Earlier CPB research (Noailly & Shestalova, 2013) shows that from the viewpoint of social welfare, the market is not investing sufficiently in innovation in sustainable technologies, compared to the innovation investments in existing techniques.

4.3 Policy Implications

This CPB analysis concerns an inventory of the circular economy of the plastics value chain, from the perspective of welfare across the board. The analysis does not include possible comprehensive policy options in this area, the advantages and disadvantages of those options and the related societal costs and benefits. There is already a large number of policy measures in this field, on European, national and municipal levels. European policy, for example, sets targets for the amount of residual waste. National policy includes, for example, subsidies and regulations, and municipal policy is about the system of waste collection. Furthermore, certain policy involves an important role for industry, such as the covenants that are held by the Packaging Waste Fund. Nevertheless, the findings generally indicate what would be possible promising and less promising policy options for the Netherlands.

The analysis reveals that the most important external effects related to plastics are caused by litter and the ‘plastic soup’, as well as by CO_2 emissions. Below, a concise description is given of policies that would address these effects to lesser or greater degrees. The description is not exhaustive, an analysis of the costs and benefits of such policy requires additional research.

4.3.1 Reduced Use of Plastics: Lower CO_2 Emission Levels and Less Waste

Less use of plastics also means less litter, therefore less plastic material in the oceans and fewer CO_2 emissions. Ideally, the external effects caused by production, use and waste of a certain product should be incorporated into the price, for example, through taxation. The idea is that such taxation leads to fewer of these polluting products being bought, thus to lower consumption levels and, partly, to a shift towards alternative products and technologies.

Examples of such taxation are the waste collection and processing rates. The collection and recycling of plastic packaging in the Netherlands are funded from the Packaging Waste Fund. This fund is financed by packaging companies. In 2015, the fund incurred around 230 million euros in costs, of which around 200 million was for the collection, separation and recycling of waste. Around three-quarters of this relates to plastic packaging. This causes an increase in the costs for the producers of packaged goods, which in turn provides them with an incentive to reduce the amount of packaging they use or to switch to a substitute material. These costs are partly incorporated into product prices and, therefore, are ultimately paid by consumers. Higher prices lead to consumers buying fewer packaged goods. In this way, some of the external effects of the use of plastics may become internalised in the product price. This analysis has not looked at tax levels, costs, behavioural effects, or the impact of such taxation on the welfare of society.

The external effects that are related to plastic products vary according to the type of plastic and its application. In addition, it is very difficult to estimate what the consequences of the use of plastics will be for the plastic soup. Taxation may lead to the substitution of plastics with other materials, but those are likely to have their own impact on society and the environment. A shift from plastics to other materials will therefore not necessarily lead to environmental benefits.

Another way of reducing the amount of plastic used would be through regulation, which obviously includes a task for the government. The industry itself may also enter into covenants and agreements. Incentives for entrepreneurs to do so include regulations and cost saving (through taxation), but may also be driven by how they would like to be perceived by consumers (sustainable image and corporate social responsibility).

Furthermore, education and information provided to companies and consumers may increase awareness and reduce the negative effects related to the use of plastics.

4.3.2 Policy Related to Litter and Plastic Soup

Plastic soup is an international problem that, to a large extent, calls for internationally coordinated policy. At the same time, as the Netherlands also adds to the plastic soup, litter and plastics in the water are also a national problem.

Expanding the deposit-refund system is a type of policy that directly helps to prevent litter and thus also reduces the plastic soup. Over ninety per cent of plastic litter consists of packaging; expanding the deposit-refund system provides an incentive for users to collect litter instead of discarding it into the environment.[2] The ban on free plastic bags offered in shops is likely to be effective in reducing litter. There are also other types of policy aimed at litter prevention, such as expanding the cleaning capacity for public spaces and enforcing (and sanctioning) anti-litter regulation, as well as providing adequate waste containers in public areas (to prevent litter being blown about).

Litter is an important source of the plastic soup, but not the only source. Government policy could also contribute to combatting other sources. With respect to regulation, this would possibly mostly be in an international context (e.g. to counter the use of plastics in cosmetics). Artificial grass granules end up in the environment via rainwater runoff; regulation could be a viable policy option here. Another starting point is the stimulation of innovation in order to improve techniques for filtering plastics out of wastewater (e.g. caused by washing textiles). The pollution caused by plastics in biodegradable waste that ends up in the environment via compost is discussed later in this section.

The Netherlands could also contribute to reducing the amount of plastics in the oceans by stimulating innovation and, more directly, by helping with the cleanup. The Dutch initiative 'The Ocean Cleanup' of Boyan Slat may successfully contribute to solving this problem.

4.3.3 Question Marks Around Intensifying the Recycling of Separated and Sorted Plastic Waste

It has been found that, currently, most of the plastic waste that is being separated from household waste consists of a mix that has a low market value, due to substantial application limitations. A greater effort in relation to the recycling of plastics, for instance by stricter regulation about the maximum allowed amount of residual household waste, will lead to an even larger flow of product with such limited application possibilities. This may then lead to stock formation or to the already separated waste being incinerated after all. A share of the Dutch 'mix' finds its way to Germany, where it is used in the production of low-quality products, while Germany

[2] CE Delft has studied the costs and impact of a number of variants for expanding the deposit-refund system (CE Delft, 2017).

incinerates part of its own mix with energy recovery (Van der Heijden, 2017). This negatively affects the environmental benefits.

Recycled plastics from homogenous flows know a broader range of applications, but also have their limitations, for example, those related to odour and food safety. Such limitations are likely to be reduced through technological development in separation techniques, as well as by regulation or agreements within the industry about the use of certain types of plastics, additives and colouring agents. Nevertheless, this will be no easy feat because of the many different types of plastics and additives that are needed, due to product characteristics and preconditions around food safety.

4.3.4 More Focus on Quality Rather Than Quantity

According to the Netherlands Institute for Sustainable Packaging (KIDV) and the Packaging Waste Fund, the quality of the recycled plastics—and therefore also their application possibilities and the price could already be improved using currently available techniques. Slowing down the sorting process could improve separation and thus achieve a smaller share of low-quality 'mix' as well as yield a mix of higher quality. This would increase processing costs, though. Current financial incentives, however, are only aimed at the highest possible output, with the precondition of a maximum of 55% 'mix', instead of the highest possible market value. The Packaging Waste Fund pays a fixed tariff for waste collection and separation. Municipalities focus more on quantity because of their objectives to reduce the amount of waste per inhabitant. Organising the set of instruments with a greater focus on quality could improve the environmental benefits of recycling plastic waste. This could be included in this year's framework agreement on packaging (Raamovereenkomst Verpakkingen).

An alternative could be to impose a ban (for the Netherlands or the EU as a whole) on, for example, black plastic packaging and/or other types of packaging that cannot be recycled easily, or a covenant by which companies commit to increasing the recyclability of their packaging.

4.3.5 Reducing Residual Waste Leads to Greater Risk of Polluted Biodegradable Waste, a Source of the Plastic Soup

An additional effect of focusing on the amount of residual household waste is that it increases the chances of polluting the biodegradable waste. Although data are not available, the trend appears visible in everyday practice at waste-incineration plants. Biodegradable waste is turned into compost. Plastics in compost in the Netherlands is a source of the plastics that end up in surface waters.

4.3.6 Effect of Plastics Recycling on CO_2 Emissions Is Limited with Respect to the Effort Taken

There appears to be no direct relationship between the separation of plastic waste by households and a reduction in litter or plastic soup. Recycling of plastics is therefore not the solution to these problems. As stated above, the availability of resources for plastics offers a few starting points for government policy on this subject. Recycling of plastics does lead to a lower emission of CO_2. As an indication of the CO_2 reduction resulting from a specific policy to enhance consumer recycling of plastics, a rough calculation was carried out. In 2015 this reduction on an annual basis was between 1,75,000 and 2,50,000 tonnes of CO_2, which equals 0.1–0.15% of total CO_2 emissions in the Netherlands (around 165 megatonnes), or for example less than 1% of the CO_2 emitted by road traffic in the Netherlands. This seems like a modest result in comparison to the size of the measure.

4.3.7 Reuse, Repair, Extending Product Lifetime and Ecodesign

Reuse, repair, extending product lifetime and ecodesign (products that are designed in such a way that they can be reused or recycled more easily) are possible solutions to reduce the demand for plastics and, thereby, also reduce the amount of plastic waste. Furthermore, a shift from ownership towards utilisation by consumers (e.g. in the 'sharing economy') may also lead to a decline in the use of plastics. The policy aimed at solving the primary problems (resources or waste) could lead to an encouragement of these business models as a solution. However, this is beyond the scope of this study and requires further analysis.

4.3.8 Bioplastics: Quality Criteria for CO_2 Reduction and Side Effects

Bioplastics may contribute to a reduction in CO_2 emissions. The CO_2 benefits vary greatly, depending on crop type and location. The required biomass is in competition with food, energy and nature; the degree of land use is potentially large and there are certain side effects (e.g. nitrogen, phosphates and water). Research by CE Delft shows that quality criteria may be helpful in ensuring the environmental benefits from lower CO_2 emission levels and in preventing as many negative side effects as possible, such as those on nature. This would be a task for national or international governments.

4.3.9 *Stimulating the Technological Development of Sustainable Technologies is Very Important*

Finally, it is important to note that many of the limitations that are mentioned above are a snapshot in time, based on the current state of technology. The government is able to make a contribution towards reducing negative environmental effects involved in the use of plastics by stimulating innovation through subsidies, green deals and/or fiscal measures. This is necessary due to the suboptimal bias towards polluting technologies. Subsidies would accelerate the profitability of sustainable energy technologies, as well as removing the innovation bias (Acemoglu, Aghion, Bursztyn, & Hemous, 2012). This may provide innovative sustainable initiatives from within society with the financial scope they need in order to become established enterprises.

4.4 Conclusions

The reasons for making the plastics value chain more circular include their claim on scarce resources, environmental pollution during resource extraction and production of plastics, and the pollution caused by plastic waste (plastic soup, litter, waste disposal and incineration). The main impact is that of environmental pollution. This publication gives an overview of the plastics value chain, providing insight into the problems described and suggesting policy options. The main conclusions are:

1. Production volumes of plastics, over the past 50 years, have increased more strongly than global GDP. This trend is expected to continue over the coming decades.
2. The depletion of fossil resources for plastics production (oil and natural gas) will play only a modest role over the coming decades, as the global sustainability of the transport and energy sectors will leave sufficient oil stocks for the production of plastics, for a few hundred years to come. Moreover, also the security of supply of oil and natural gas is unlikely to play a major role in the debate around the production of plastics.
3. The use of plastics involves external damage, particularly as a result of environmental pollution: the plastic soup, littering and CO_2 emissions. Particulate matter emissions, NO_x and SO_x, have in western Europe been effectively curtailed through regulation.
4. Bioplastics and the recycling of plastics form only a limited alternative to the fossil fuel-based production of plastics.

    a. Bioplastics, made of biomass, are not expected to be the solution to the problems of litter and plastic soup.
    b. There is a certain benefit with respect to CO_2 emission reduction, but this is set against an intensified claim on natural and agricultural land.

5. Intensifying the separation of plastic household waste for recycling under currently available technologies is not very promising from a welfare perspective. Separating plastic waste in households does not solve the problem of litter or plastic soup. Most of the recycled plastic waste consists of 'mix' (a mixture of different types of plastics) and 'foils' for which the application possibilities are only limited. The market price of the 'foils' and 'mix' is low and sometimes even negative—the latter because discarding them costs money. Recycling plastics from separated household waste is currently still very expensive. The costs of collection and processing of this 'mix' are therefore substantially higher than the market price, which is mostly determined by its limited application possibilities, as well as by the low price of primary plastic (oil price and CO_2 price). Increased recycling, for example, due to a greater focus on the amount of residual waste per household, is expected to lead to an even larger flow of a product with limited market possibilities. This, in turn, may lead to stock formation, or to incineration of the already separated waste material, which has a negative impact on the environmental benefits. Recycling provides no solution to the problems of litter and plastic soup, and at this point only contributes to CO_2 emission reduction to a limited degree.
6. The quality of the recycled plastics, and thus the application possibilities, could be expanded by improving the currently available sorting techniques. However, this will make processing more expensive. Current financial incentives push towards the highest possible output, though, instead of the highest possible market price. Organising the instruments to have a greater focus on quality could improve the environmental benefits of plastic waste recycling. This should be studied more closely.
7. A side effect of a focus on the amount of residual household waste is that this increases the chances of polluting other waste flows, such as biodegradable waste. Plastics in compost in the Netherlands is a major source of the plastics that end up in surface waters and thus, ultimately, in the plastic soup.
8. Expansion of the deposit-refund system is a type of policy that directly links to the prevention of litter and thus to a reduction in the Dutch contribution to the plastic soup. Over 90% of plastic litter consists of packaging. Expansion of the deposit-refund system provides users with the incentive to collect waste instead of discarding it into the environment. The question of whether the related benefits would outweigh the costs was not considered in this study.
9. Government policy may also contribute to combatting other sources of the plastic soup; for example in the field of regulation, possibly mostly in the international context (e.g. banning the use of plastics in cosmetics or artificial grass made of car tyres). Other areas would be stimulating innovation to improve techniques to filter wastewater (e.g. to remove particles from washing textiles) and reducing the pollution of biodegradable waste. The question of whether the related benefits would outweigh the costs was not considered in this study.
10. The main conclusions above were drawn from an analysis based on the current state of technology. Technological developments could, for example, improve the quality and reduce the costs of recycled plastics. The government may contribute

to this process by stimulating innovations through subsidies, green deals and fiscal measures.[3] Another option would be to internalise the external effects into taxes.[4] This last point may provide innovative sustainable initiatives from within society with the necessary financial scope to achieve full development.

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Annemiek Verrips is a project lead and senior researcher at the CPB Netherlands Bureau for Economic Policy Analysis. She studied both Chemistry and Economics at VU University Amsterdam. Annemiek is a leading policy advisor for sustainability policies. She has been involved in the cost–benefit analyses of wind farms on land and sea, water safety, mobility as well as the economic wrongs and rights of plastic recycling.

Sander Hoogendoorn is a project lead and senior researcher at the CPB Netherlands Bureau for Economic Policy Analysis. In this role, he combines the management of a wide variety of policy-

[3]See Acemoglu et al. (2012).

[4]Aalbers, Renes, and Romijn (2016) indicate that the CO_2 price that should be used by the government to achieve the two-degree climate target should be over 60 euros per tonne, for all economic activity. The current CO_2 price within the Emissions Trading System (ETS) is around 6 euros per tonne and applies to part of the economy.

oriented studies with academic research in economics and business. His key objective is to foster the decision-making process of both policymakers and politicians. He received his Ph.D. from the University of Amsterdam, the Netherlands. His academic research has been published in leading scholarly journals such as Management Science, Journal of Economic Geography and Organisation Science.

Krista Jansema-Hoekstra was a researcher at the CPB Netherlands Bureau for Economic Policy Analysis. She was trained as an economist at Groningen University, the Netherlands. She has co-authored several CPB studies on the economic effects of policy platforms for political parties in the advent of national elections. Recently, she co-authored an influential policy brief on the employment effects of tax greening. Krista sadly passed away in 2019.

Gerbert Romijn is program leader of the programme Benefit–cost analysis and sustainability at CPB Netherlands Bureau for Economic Policy Analysis. Gerbert is trained as an econometrician and economist at the Erasmus University Rotterdam, the Netherlands, where he also received his Ph.D. Gerbert has been a senior policy advisor in many fields of economic policy analysis including taxation, housing, transportation, carbon prices and the circular economy. He is an authority on methodological matters relating to cost–benefit analysis.

Chapter 5
Mismanaged Plastic Waste: Far Side of the Moon

Lincoln Fok, Irene Nga Yee Cheng and Yau Yuen Yeung

Abstract Plastic is one of the most efficient materials and was designed to be strong, light, resistant to degradation and highly moldable both chemically and physically. Due to these advantageous properties, plastics are used in all walks of life. We are currently living in the 'Plastic Age' where the presence of plastic is ubiquitous. However, effective methods and technologies to deal with end-of-life plastic products have not been developed and applied. The net result is the generation of an ever-growing amount of plastic waste. Part of this waste can escape the waste management system and enter the environment, accidentally or otherwise. Once in the environment, mismanaged plastic wastes will degrade fragment into smaller and smaller pieces, and pose a notable threat to the health of our environment, in particular to the biota. At present, plastic debris has been found in numerous marine organisms, including those intended for human consumption. Because direct human health risks associated with mismanaged plastic waste have yet to be established, statutory controls on the use plastics in general, will be difficult and at best, piecemeal. Nonetheless, mitigation measures of this pervasive issue should progress from an end-of-pipe approach to preventive strategies, with a final goal to eliminate all single-use plastic products.

Keywords Marine debris · Microplastics · Waste management · Education · Preventive strategies

5.1 Age of Plastics

Nowadays, the word 'plastic' itself has a derogatory connotation, which is of being cheap, fake, expendable and sinister. This is partly due to plastic being a central material supporting a 'throwaway' lifestyle that has thrived during the past few decades. This throwaway concept was first promoted in an article published in LIFE

L. Fok (✉) · I. N. Y. Cheng · Y. Y. Yeung
Department of Science and Environmental Studies, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: lfok@eduhk.hk

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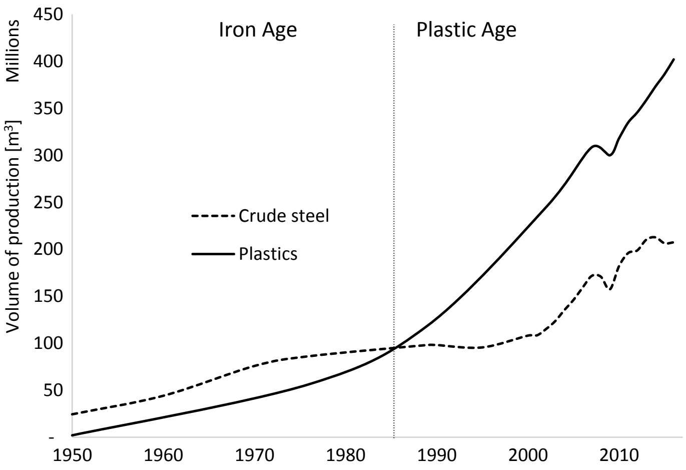


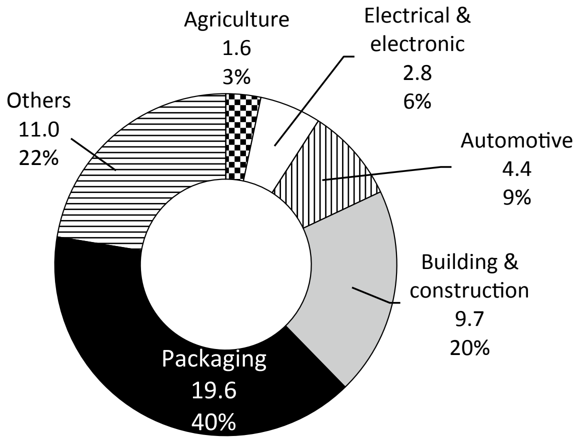
Fig. 5.1 Global volume of production of crude steel and plastics, 1950–2016. Production data in weight from the World Steel Association (2017) and PEMRG (2018). Assuming densities of steel and plastics being 7.85 and 1.20 g/cm^3 respectively

magazine in August 1955, entitled 'Throwaway Living' (Life magazine, 1955). In this article, the use of disposable plastic household items and utensils was celebrated for their ability to liberate housewives from excessive cleaning. Since then, cultures of disposal and planned obsolescence have slowly and now firmly taken hold in our society.

Today's capitalistic economy is largely driven by consumption, with household consumption contributing to 58.4% of global gross domestic product in 2016 (World Bank, 2016). To meet the demands of mass consumption, mass production is needed and to support the latter, inputs of raw materials are required. In terms of volume of production, plastics have exceeded steel, an iron alloy, since the mid-1980s, and have since become the most-used material of modern day society (Fig. 5.1). Archaeologists traditionally use materials, which artefacts are made of, to categorize historic time periods such as the Stone, Bronze and Iron Ages. Shall this chronological framework be adopted, humans are now living in the Plastic Age. Considering the fact that plastics have only been mass-produced since the 1940s (Thompson, Swan, Moore, & vom Saal, 2009), the rate of increasing human reliance on this material is astonishing. In 1950, the global production of plastic materials was a mere two million m^3. This figure has increased by almost 200-fold in the last 56 years (2016: 402 million m^3, Fig. 5.1).

Plastics are now used to fabricate all sorts of everyday objects, including the obvious ones such as distilled water bottles sold in vending machines and common writing instruments; along with more subtle ones such as the inner coating of milk cartons and garment sewing threads. Nonetheless, plastics are most often applied to single-use packaging, and this application alone accounts for approximately 40% of all plastic uses in Europe (Fig. 5.2; PEMRG, 2018). As a plastic user, one may won-

Fig. 5.2 Plastic materials demand by market sector in Europe, 2015 (PEMRG, 2018). Labels show the demand in million tonnes and percentage of total



der why plastics could conquer the world so swiftly. To address this question, one needs to appreciate the properties the material offers, relative to other alternatives, such as natural fibres, wood, glass and metals. Plastics are produced from feedstocks originating from fossil fuel refining, including naphtha from crude oil and hydrocarbon gas liquids from natural gas, which are derivatives from the process of making fuels, such as gasoline and liquid petroleum gas. In other words, plastics are complementary rather than competing materials. This side-product nature of plastics renders the material relatively inexpensive, as their production does not require a separate extraction process. Second, given a similar structural strength, they are relatively low in density, compared to alternative materials. Third, they are highly versatile, as they can be processed to take different colours (including being transparent) and to possess outstanding barrier properties, moisture and oxygen included. Ninety percent of all plastics produced belong to a class called *thermoplastic*, which refers to plastics that soften into a viscous liquid when heated. This property allows them to be easily moulded into different shapes. Last but not least, plastics are, by design, very resistant to biodegradation: the polymer itself can take hundreds of years to biodegrade. When subjected to the forces of nature, metals oxidize and timber decomposes, but all of the plastics ever created have remained as plastics, though progressively fragmenting into smaller pieces over time.

Once again, peoples' feelings towards plastic materials are mixed: as much as they are disdained at times, they keep being used all the more. These mixed feelings actually do the material no justice. A recent study analysed the negative impacts from raw material production, manufacturing, logistics, using and end-of-life phases of plastic consumer products and packaging (Lord, 2016). According to this product life cycle study, although the environmental cost of plastics per unit weight (estimated at US$1,654 per tonne in 2015) is higher than alternative materials (US$1,558 per tonne), the replacement of plastics by the latter is even more costly. This is so because, on average, it takes four times more alternative materials to perform the same function offered by plastics. The total environmental cost of plastics was valued at US$139 billion; and had it been replaced by alternative materials, US$533 billion. These amounts are significant as they are equivalent to 0.2 and 0.7% of global GDP in 2015, respectively. The findings of this study, much to our surprise, illustrated that plastics are actually 'greener' than their alternatives. Having said that, when we cast our disdain on plastic products, think again holistically. Smelting of aluminium from ore or transporting glass bottles actually costs more energy to do so compared to the same process using plastics. The issue is less about plastics themselves and more about our ways of consuming them! Of all the plastic ever produced, 60% has been disposed of (Geyer, Jambeck, & Law, 2017). This high proportion of disposed plastics is largely a result of our single-use applications of the material.

5.2 At What Costs?

So, what are these environmental costs of plastics that we have been discussing? In the broadest sense, they are referred to as all of the negative externalities produced, or the costs imposed upon a third party, throughout the life cycle of a plastic product.[1] These costs arise because they are neither borne by the producer nor the end user. They encompass a wide range of adverse effects including but not limited to greenhouse gas emissions, air, land and water pollution incurred during production, use and end-of-life phases of plastic products. The production phase includes processes of resource extraction, manufacturing and product distribution to markets; while the end-of-life phase includes waste management processes such as recycling, energy recovery and disposal; as well as the plastic products being disposed of and have escaped the waste collection and management systems. Interested readers should refer to the Trucost report for life cycle analysis of plastics (c.f. Lord, 2016). Nonetheless, only a few have practiced this holistic approach of cost evaluation.

The evaluation of negative impacts of plastic consumption has traditionally been focused upon the end-of-life phase, in particular on the costs with reference to various waste management strategies including recycling, energy recovery (incineration) and disposal (landfill). Bernardo, Simões, and Pinto (2016) reviewed 20 life cycle assessments of plastic waste over the last decade. In general, they concluded that recycling has the least environmental impact concerning the potential for global warming and energy use.

While waste management of plastics has always been a worthy topic of investigation, this chapter focuses on an often-neglected aspect of plastic waste: 'mismanaged' plastic waste. This term herein refers to the portion of plastic waste which has escaped from our waste management system, deliberately (littering) and accidentally. The equivalent old Cantonese saying in English, 'out of sight, out of mind', applies to waste that has escaped the management system, or in practice, the jurisdiction of statutory bodies to manage waste. Very often, this mismanaged waste is

[1] Interested readers should refer to the Trucost report for life cycle analysis of plastics (c.f. Lord, 2016).

left untouched, remains and becomes part of the natural environment. One example the media often cites is the debris that entered the Pacific Ocean due to the 2011 Tohoku Tsunami in Japan. The International Pacific Research Center modelled the movement of this floatable debris, much of which was plastic, in the Pacific over time (IPRC, 2012). Some of it travelled across the Pacific and arrived on the West Coast of the USA beginning in 2012. Much of the floatable debris, however, remained in the North Pacific Gyre, one of the five great gyres in the world's oceans. These gyres are where ocean currents converge and form slow, colossal swirls of water, and are known to collect floatable debris (Moore, Moore, Leecaster, & Weisberg, 2001). The presence of plastic debris in ocean gyres is sometimes referred to as plastic 'soup' (e.g. Jabr, 2011) or the 'great garbage patch' (e.g. Kostigen, 2008), although the highest observed density of plastics was merely 0.89 pieces per square metre of ocean surface (Eriksen et al., 2014). Nonetheless, these sensational media references have catalyzed the public's attention to plastic pollution in our oceans.

Investigations of marine debris significantly rose over the past decade. It was recently estimated that the annual terrestrial input of plastic waste into the oceans amounted to 4.8 to 12.7 million tonnes (Jambeck et al., 2015), thus rendering marine litter a pervasive issue. Through fragmentation and biofouling (accumulation of organisms on wetted surfaces), floatable marine plastics can become negatively buoyant and sink. Therefore, plastic pollution is found not only on the sea's surface, but it also accumulates in the water column (Doyle, Watson, Bowlin, & Sheavly, 2011) and benthic sediments (Van Cauwenberghe, Vanreusel, Mees, & Janssen, 2013). Eriksen et al. (2014) estimated that there are 0.25 million tonnes of floatable plastic debris on the surface of the world's oceans. Among these floatable plastic pieces, 92% (in terms of count) were tiny debris particles with diameters less than five millimetres. This fraction of mismanaged plastic waste is known as 'microplastics' (MP) (Thompson et al., 2004). The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) classified MP into two types: primary and secondary. The former refers to the small plastic particles directly released into the environment (e.g. microbeads and pellets), while the latter are the fragmented plastic particles from large marine debris.

There is no doubt that plastic pollution is entirely anthropogenic, and therefore the spatial distribution of its extent is associated with population centers. In the last few years, the author's research team completed a baseline survey on MP in the Pearl River estuary located in Southern China. The findings exhibited that MP abundance in the region is one of the highest in the world, with abundance in excess of 3,000 items per m^2 on sandy beaches (Fig. 5.3). In addition, a higher abundance of beached MP has been observed on the western side of Hong Kong compared to its eastern coasts. This spatial distribution is particularly apparent during the wet season. This suggests that the Pearl River is a potential source of the region's MP pollution, in particular when the debris is transported by the high volume of discharge into the coastal areas (Cheung, Cheung, & Fok, 2016). The author's findings are consistent with similar studies in the South China Sea (Qiu et al., 2015). The Pearl River Delta in Guangdong is the largest urban area in the world, and home to nearly 60 million people (World Bank Group, 2015). In 2015, 5.8 and 78 million tons of plastic raw materials were

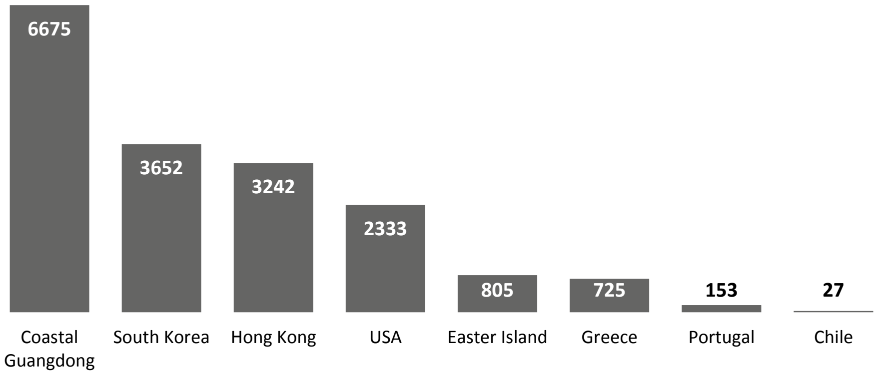


Fig. 5.3 Average abundance (items per m^2) of microplastics on beaches. *Data source* Coastal Guangdong (Fok, Cheung, Tang, & Li, 2017); South Korea (Heo et al., 2013); Hong Kong (Cheung et al., 2016); USA (McDermid & McMullen, 2004); Easter Island and Chile (Hidalgo-Ruz & Thiel, 2013); Greece (Kaberi et al., 2013); Portugal (Martins & Sobral, 2011)

produced in Guangdong Province and Mainland China respectively (NBS, 2017). In addition, waste collection in rural areas of China is at best rudimentary, and often non-existent (Wang et al., 2017). Being less dense than water, the plastic debris generated on land can be carried by runoff and eventually enter waterbodies such as rivers. A recent study estimated that the Pearl River annually carries 100,000 tonnes of plastic waste into the South China Sea, which ranks third in regard to plastic emissions by major rivers in the world (Lebreton et al., 2017). As a result, a significant amount of marine litter has been observed in the South China Sea (Zhou et al., 2011).

There is evidence that plastic debris affects over 170 marine species (Vegter et al., 2014), ranging from large animals (Fossi et al., 2012) to zooplankton (Cole et al., 2013). Potential physical impacts are entanglement and ingestion. Entanglement of marine mammals and sea tortoises has been frequently reported by the media, usually with images of a wounded or dead animal tangled by plastics alongside, such as derelict fishing gear. A study by the NOAA indicated that more than 200 species worldwide were documented to be impacted by entanglement (NOAA Marine Debris Program, 2014), whereas ingestion of debris by organisms may lead to suffocation, food intake reduction or starvation. The high mobility of marine plastic debris also allows it to be an effective vector to disperse invasive species across oceans (Gregory, 2009).

The effects of large plastic debris on marine macrofauna have received wide media coverage due to their conspicuous nature, whilst relatively less attention has been given to the effects of MP, which can also be ingested. The size of MP lies within the food range of many marine organisms, including those intended for human consumption. For example, Murray and Cowie (2011) found that 83% of Norway lobsters had ingested plastic filament and fragments. Even worse than its macro counterpart, MP can contain harmful additives, and carry organic pollutants and microorganisms, including endocrine disruptors and pathogens (Kirstein et al., 2016).

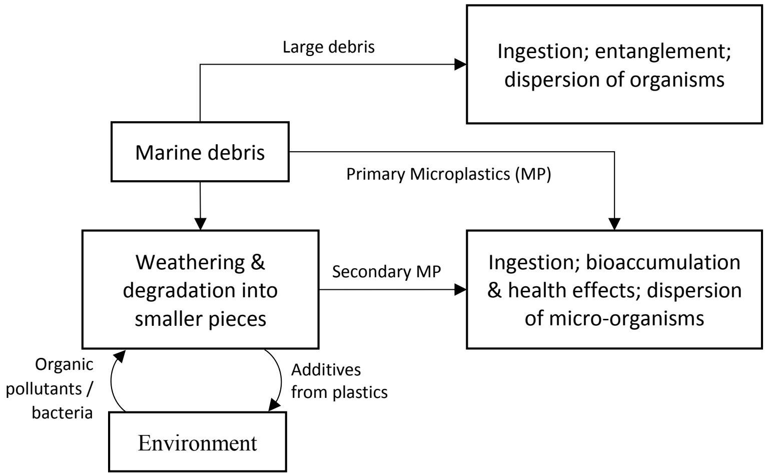


Fig. 5.4 Potential impacts of marine debris on marine organisms

These pollutants can dissociate from the debris after ingestion and may lead to adverse health impacts to the organism, including developmental and reproductive effects. In addition, the trophic transfer of plastic particles has also been documented (Mattsson et al., 2015). Thus, MP poses an even higher risk to organisms. For instance, a study showed that bisphenol-A in plastic products can affect the hormonal and reproductive systems of crustaceans, mollusks and fishes. When the contaminant enters the food chain, there is potential for biomagnification (Teuten et al., 2009). Figure 5.4 summarizes the potential impacts of marine debris on marine organisms.

Although MP was first reported in oceans, its presence has also been detected in all types of aquatic environments, including rivers (e.g. Mani, Hauk, Walter, & Burkhardt-Holm, 2015), lakes (e.g. Fischer, Paglialonga, Czech, & Tamminga, 2016), and recently, even in tap water (Kosuth, Wattenberg, Mason, Tyree, & Morrison, 2017). Because of its pervasive presence and potential impacts, the United Nations Environment Programme listed MP as an emerging issue of environmental concern (UNEP, 2016). As mentioned previously, science has begun to reveal the pollutant's potential impacts on marine organisms; however, direct evidence with regard to human health risks posed by marine debris is yet to be uncovered. This would first require an estimation of the level of human exposure to marine debris, in particular to MP, in various food sources, among which, seafood naturally comes to mind.

Globally, a number of studies have observed average occurrences of MP in around one-third of fish samples. In a study of fish from the English Channel, (Lusher, McHugh, & Thompson, 2013), found that MP occurred in 37% of samples, with an average abundance of 1.9 pieces per individual. The same study also detected no difference in the occurrence of MP in pelagic and demersal species. Five species of commercial fish caught in the Adriatic Sea were studied by (Avio, Gorbi, & Regoli,

2015) and where plastics were found in 28% of their samples. Similarly, Rochman et al. (2015) found the presence of MP in 28% of their samples. The author also observed MP in 60% of wild grey mullet samples obtained in Hong Kong (Cheung, Lui, & Fok, 2018). A global study reported 68% of bogue fish (Boops boops) ingested plastics, with abundance as high as 3.75 items per individual (Nadal, Alomar, & Deudero, 2016). This study can be regarded as the high-end of occurrence of MP ingestion. For the low end, only 9.2% of the fish from the North Pacific Subtropical Gyre had ingested plastics (Davison & Asch, 2011). A similar low occurrence (9% of samples) was observed in two estuaries in Brazil (Vendel et al., 2017), and the same study also observed no correlation between MP abundance versus functional group of fish and its size. For fish samples collected in the North and Baltic Seas, MP was only found in 5.5% of the fish, and the occurrence of ingestion for pelagic species was higher than that for their demersal counterparts. These studies were all in agreement on the fact that the majority of ingested particles consisted of fibre. The above studies of physical exposure to MP by fish illustrate that ingestion may be influenced by the abundance of MPs in the environment, but there has been no agreement on the influence of fish living in different habitats. A point to note here, is that MP is detected in the stomach of fishes, and human beings usually remove the stomach before consumption. Therefore, the risk of physical exposure to plastics from seafood is higher for the species we consume whole, such as shellfish.

Data with regard to physical exposure to MP in shellfish is relatively scarce. Many species of shellfish are filter feeders which obtain their food by circulating seawater through their system. Because oysters and mussels are intended for human consumption in many parts of the world, they have been a focus for scientific attention. In the southern hemisphere, Santana, Ascer, Custódio, Moreira, and Turra (2016) found MP in 75% of their mussel samples. In coastal China, an average of 4.6 plastic items were detected in wild mussels (Li et al., 2016). Furthermore, in the Atlantic Ocean and the North Sea, both mussels and oysters were detected to contain plastics (Van Cauwenberghe & Janssen, 2014). The same study also estimated the physical exposure to MP by European seafood consumers, ranging from 1,800 to 11,000 pieces per year, depending on the individual's diet.

Nonetheless, the above studies only scratched the surface of the problem with relation to human health risks, as it depends not only on the level of exposure, but also the potential impacts on human health. In addition, because humans ingest (usually) very tiny amounts of plastics through indirect channels such as seafood consumption, the potential health impacts are more associated with the *chemical* rather than the *physical* exposure to plastics. This is a very complex issue[2] that depends on many factors including (i) which type(s) of pollutant are associated with the ingested plastic particles, (ii) how long a particle stays in an organism, (iii) how fast (rate) and how much (extent) the concerned contaminant may be released from the particle, (iv) the rate and extent to which plastics may transfer from the digestive system to other tissues of organisms and (v) the rate and extent to which the concerned contaminant

[2]Interested readers are referred to Galloway (2015) and Crawford and Quinn (2017) for a synopsis of this particular issue.

may transfer from the consumed organism to human being. Note that the above factors naturally vary across different types of pollutant, types of organism and geographic locations where the organism is obtained.

5.3 Solutions and Resolution

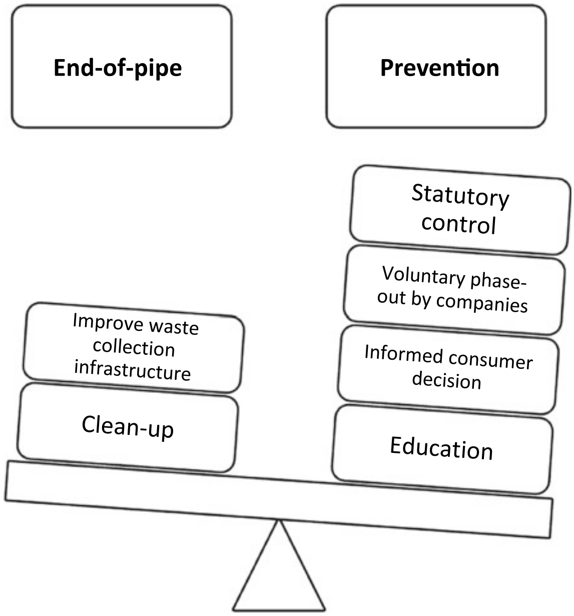
The above discussion suggests that it would be inappropriate to draw conclusions at this time on the human health risks associated with mismanaged plastic waste as we would to other well-established pollutants such as mercury and DDT. The reason being is that toxicity studies of MP in human beings are not currently available. Without robust supportive scientific evidence, there will be no human health standards developed for MP. And without a standard, there will be no basis for statutory bodies to control this particular pollutant. In other words, at this moment, it is premature to call for statutory controls as it would likely be futile.

This, however, does not mean we cannot do anything about this issue. The solution to any issue can be defined into two broad classes: end of pipe and preventive (Fig. 5.5). End-of-pipe solutions involve a higher long-term cost and are unable to deal with the root of the issue; however, they are easier to execute and therefore can be carried out immediately. On the contrary, preventive solutions are more difficult to accomplish but should be valued over shorter term solutions. Moreover, the individual solutions mentioned in the followings should be considered as a collective package and they are not mutually exclusive.

The cleaning up of solid waste in the environment is by far the most common strategy taken to mitigate the plastic waste issue. Internationally, volunteer actions have been coordinated by the Ocean Conservancy (oceanconservancy.org) under the International Coastal Cleanup (ICC) initiative over the last three decades. Locally in Hong Kong, there is a Hong Kong Cleanup Challenge which is a competition for volunteer teams to collect wastes from the local environment, and beaches are one of the popular locations. Over the years, the event has successfully removed millions of pieces of garbage from the environment. More recently, there have been propositions to clean up the ocean using technology. Among them, the Ocean Cleanup (www.theoceancleanup.com) led by Boyan Slat, is considered to be the most ambitious engineering project to deal with the marine plastic issue. It involves the design and construction of an automated mid-ocean incinerator with stationary floating nets to guide floatable debris into the central machine, in which plastics will be converted into energy to run the whole system. Nonetheless, the design has been challenged due to its potential ecological impacts of substantial bycatch of marine organisms by the collection mechanism (Martini, 2014).

Improvements in waste collection and management infrastructures can reduce the amount of waste leakage from the management system. This is particularly crucial for the case of rural China, where as previously mentioned, waste collection has been rudimentary at best as domestic wastes have often been removed by open burning and dumping into rivers. The issue was identified in the 13th Five-Year Plan of China, and

Fig. 5.5 Solutions to mismanaged plastic waste



actions to setup and improve domestic waste disposal facilities in rural China will be implemented by 2020 under the ‘Beautiful countryside’ initiative (KPMG, 2016). In fact, this issue is also relevant to China’s cities such as Hong Kong. Locally, rural domestic wastes were collected from some 800 village-type refuse collection points (RCPs) and 1900 village bin sites (FEHD, 2017). Compared to the urban RCPs, these village-level waste collection sites are relatively small. From the author’s observation, when the bins of the collection sites are full, domestic waste will often be placed on the ground next to them. This can increase the chance of waste leakage, in particular during storm periods. A potential solution includes increasing the frequency of waste collection and increasing the storage capacity of the village collection sites.

At the preventive end of the solution spectrum, environmental education has been the foundation of preventive strategies in the last decades. Using Hong Kong as a case study, almost every youngster can recite the ‘3Rs’ (Reduce, Reuse and recycle) of waste management owning to decades of environmental education campaigns funded by the government. For instance, Yan Oi Tong’s (a local NGO) ‘Reduce Your Waste and Recycle Your Plastics Campaign’ promoted plastic recycling in local schools from 2011 to 2013. To create a recycling-friendly environment where students can practice their eco-behaviour at will, plastic recycling bins and collection services have been made available to all schools by the Hong Kong Government (ECC, 2017). Due to the lack of outlets for plastic recyclables in Hong Kong, local education with reference to solid waste management has begun to move from recycling centric to reduction priority. A recent initiative restricting the sale of plastic bottle beverages on a university campus is one such example in Hong Kong (HKU, 2017). This, however, is only a good starting point, as single-use plastic products are ubiquitous and interwoven into our daily lives. The ultimate goal of education for plastic waste reduction is to reject single-use plastic products entirely. This would involve a paradigm shift in the public's household consumption pattern.

Educators usually believe in the so-called 'information-deficit model' of behavioural change which assumes that people's inaction is due to not knowing what they should do, or how to do it, and that behavioural change can be achieved by provision of knowledge about the behaviour of concern (Schultz, Khazian, & Zaleski, 2008). Lessons learnt from environmental education research revealed that behavioural change is not a direct result of filling the knowledge gap, as other influential factors including social norms, psychology and emotion may alter the way information is used to change attitudes and behaviour. With regard to waste reduction behaviour, the author believes that there are six consecutive stages to make a habit stick. First, being *aware* of the behaviour; which is followed by *understanding* the behaviour; third, *accepting* and agreeing with the behaviour; followed by *adoption* of the behaviour; fifthly is to *maintain* practicing the behaviour and finally to habituate the behaviour and *integrate* it into our daily life. With reference to plastic consumption behaviour in Hong Kong at present, a gap exists in the fourth stage: adoption.

Although the goal or end point is to reject single-use plastic products, the process for achieving this goal can, and should be progressive. Due to the extensive occurrence of single-use plastic products, it is almost impossible to ask people not to consume plastics at all in the beginning; it is easier instead to ask them to consume less. Nonetheless, there is no readily available information to inform this behavioural change. Taking reference from electricity consumption, the energy efficiency label system has been applied to many household appliances in order to aid consumers in achieving energy efficiency. Similarly, had a plastic packaging label been adopted for consumer products, one could make an informed decision regarding their purchase. One such label has been developed by the author for local food products using their packaging data, namely the *Plastic Packaging Environmental Index* (PPEI; ppei.hk). The index classifies food products into four classes according to the efficiency of their plastic packaging. It is believed that the adoption of this index could initiate a graduate change in the behaviour of consumers. This can push forward a change in the pattern of demands of food products packaged with plastics, and consequently and gradually, producers will voluntarily phase-out inefficient plastic packaging to meet this demand.

To sum up, mismanaged wastes is a global issue that has only come to light very recently. Like other global issues, its resolution requires local action. This chapter has outlined several directions of remedial action to be taken: First, the development of scientific evidence of the human health impacts, if any, of plastic debris including MP; Second, the development of ecofriendly methods of removal of plastic debris from the environment, in particular, the oceans. Third, the adoption of a plastic packaging label to inform a change in the behaviour of eco-conscious consumers.

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Lincoln Fok is an Associate Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong. He is a believer of, and practices experiential learning. By training, his research focuses on hydrology and geomorphology with a particular concern on the impacts of water and sediment quantity and quality along with their implications on the environment. More recently, his research has also been extended to marine debris, ecotourism, protected area management, environmental consciousness and education for sustainability.

Irene Nga Yee Cheng is an Assistant Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong. Research interests of Dr. Irene Cheng include geographical education, interdisciplinary curriculum and teacher knowledge and development. As an experienced teacher educator, her teaching foci relate to the development of interdisciplinary subjects, including General Studies, Environmental Studies, Geography, as well as integrating pedagogical content knowledge and curriculum and methods of the subjects outlined above. Dr. Cheng is also the Chair of the Geography Curriculum Development Committee under the Education Bureau, Hong Kong since 2014; and the Hong Kong Geographical Association from 2017 to 2019.

Yau Yuen Yeung is a multidisciplinary scholar in two distinct academic disciplines, namely science and education. As a scientist, his research areas have been mainly related to the atomic spectroscopy of transition metal and rare earth elements, computational science and materials science. As a teacher educator, he actively conducts research in various fields of information technology and science education. The foci of his current research interest include energy technology in luminescent materials, crystal field theory, molecular dynamics simulation, science/STEM education, technology-enhanced learning and social network analysis in education.

Chapter 6
Hong Kong Needs to Embrace a Holistic Approach to Waste Management

Edwin Che Feng Lau

Abstract Hong Kong's waste problems are challenging and have become increasingly intractable. The city relies on landfilling as its core approach to handling over 10,000 tonnes of municipal solid waste every day (2015 figure). Most of Hong Kong's recyclables were used to be exported to the mainland and other Asian cities. However, since early 2018, mainland authorities have tightened the regulations over imported wastes. As a consequence, an increasing volume of locally generated waste is now going into the landfills. The projected early saturation of the three strategic landfills has intensified the waste management problem in our land-scarce city. The chapter examines the crux of the waste problem from multiple perspectives, including the government's position, the business sector's approaches and the general public's individual behaviour. In order to cope with the waste problems successfully, there is a need to adopt a holistic waste management approach. Public education is an extremely challenging task that requires continuous investments to produce desirable results. However, such investments have proven to be seriously inadequate in Hong Kong. Although recycling bins have been put up in public places for over 20 years, non-recyclables and contaminated items are still often found in the recycling bins. Without an effective public education programme, the provision of hardware by itself will only yield a half-baked solution. To solve our city's waste problem, a fundamental change in people's mindset on waste is absolutely necessary. We need to strive for a zero-waste economy by treating waste as a resource, and we need to find a way to extend the lifespan of consumables rather than constantly replacing workable gadgets with trendy new products.

Keywords Holistic waste management · Recycling · Zero-waste economy · Producer responsibility

E. C. F. Lau (✉)
The Green Earth, Hong Kong SAR, China
e-mail: edwinlau@greenearth-hk.org

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6.1 An Overview

6.1.1 Current State of the Waste Problems

To most members of the public, waste management is merely a straightforward government task to remove refuse from our streets and rubbish bins. Most people don't even consider that they have responsibility for the trash they produce, let alone having to pay for the treatment of their waste according to the Polluter Pays Principle. In the 1960s–70s, our government probably held a similar view that it had the role of efficiently removing waste from our streets and burying it in places far from our living environment to prevent hygiene problems that are hazardous to public health. Hong Kong's municipal solid waste has increased by nearly 80% in the last three decades, while our population growth has only increased by 36% for the same period (Environment Bureau, 2013). This reflects extraordinarily high growth in waste disposal whereby the existing waste management facilities, not to mention government policies, have been unable to cope with over 10,000 tonnes of municipal solid waste (MSW) being dumped in our landfills every day (Environmental Protection Department, 2016b).

Hong Kong had several incineration plants in the past to treat our solid waste before disposal, but they had rather poor emissions standards that created hazardous air pollution problems, so the last one was closed in 1997. Today, the core measures to handle our MSW have become quite a single-focused solution—landfilling. Although the city's three strategic landfills started operation between 1993 and 1995, landfilling of untreated waste exerts heavy pressure on Hong Kong, which is a small city with scarce land for housing or its many other needs. Therefore, the government's plan for expanding the landfills to cope with our waste growth is an interim but not a sustainable solution. As the average per person MSW disposal rate has kept rising since 2006, from the lowest level of 1.27 kg in 2011 to reach 1.39 kg in 2015, unfortunately, the MSW recycling rate dropped to 35% in 2015 from a relatively higher level of 48% in 2011 (Environmental Protection Department, 2016a). That means Hong Kong has disposed of more waste, while less waste has been recycled in the last 10 years. The situation is somehow related to our affluent lifestyle and new modes of business operation coupled with changes in the import policies of mainland China.

The mainland has been for decades at the receiving end of recyclables generated in many western countries as well as Hong Kong, from used paper to metal to plastic. The mainland could absorb nearly all of Hong Kong's recyclables due to its strong development in the manufacturing industries. For instance, plastic and paper are the common packaging materials used to protect and pack products made in factories. And many products require plastics as their basic raw materials. However, in 2013, the Chinese government launched 'Operation Green Fence', a policy to tighten the import of recyclables into the mainland, as it did not want to continue being the trash dump for other countries. Therefore, only processed recyclables, especially plastics, that have been shredded and cleaned were accepted. Plastic scraps packed into cubes without cleaning were rejected. Because of this policy change, the price of our waste plastics has dropped significantly, and some recyclers even stopped accepting local plastic scraps as they did not have the processing facilities. In February 2017, the mainland government launched another campaign called the 'National Sword 2017', aimed at further preventing unclean or illegal wastes from entering the mainland.

So, where will such unprocessed plastic scraps go? If they were not bought by buyers from other Asian cities, our landfills will probably be the destination. Although green groups have lobbied the government for years to implement more environmental policies, Hong Kong is yet to have relevant legislation that mandates producers to recycle their product packaging waste. In the case of used plastic bottles for beverages and personal care products, producers could continue making profits by selling their products, but need not be responsible for collecting their scrap plastic bottles in the community, while the taxpayers have no choice but to share the waste disposal costs.

6.1.2 Trends of Waste Disposal and Recycling

The waste disposal trend will be affected by several factors, such as lifestyle, business operation mode, public environmental awareness, product design, repair and reuse support, recycling facilities, etc. First, let us look at the long-term trend of waste disposal in Hong Kong.

Between 1997 and 2015, the highest per capita MSW daily disposal amount was 1.4 kg in 1999, 2000, 2002 and 2003, while the lowest per capita MSW daily disposal amount for the same period was 1.27 kg in 2011. This figure rose to 1.39 kg in 2015. Such waste disposal amounts showed a decline from 2006 for a couple of years but have then gradually increased again since 2011. To further consider the differences in domestic waste and commercial and industrial waste per capita daily disposal during the same period, there was a slight drop in domestic waste from 1.04 to 0.89 kg, a drop of 14.4%. However, the commercial and industrial waste increased from 0.29 to 0.51 kg, a rise of 75.9%. (Fig. 6.1).

Although the waste charging policy is not yet in place, people are more cautious about waste produced at home than in the workplace or public places, and therefore have put some efforts into reducing domestic waste by doing better waste recycling, reuse or avoidance. All public rental housing estates have installed the three-colour recycling bins since October 2005 to allow about 29% of the Hong Kong population to recycle their daily waste (Transport and Housing Bureau, 2015). The Hong Kong Housing Authority has also jointly launched a long-term community environmental programme named Green Delight in Estates with three green groups since mid-2005 to encourage its public rental housing residents to protect the environment with waste reduction as one of the main themes. The 11% drop in the per capita domestic waste disposal amount from 1 kg in 2005 to 0.89 in 2015 has somehow reflected the result of the continuous engagement with public housing residents.

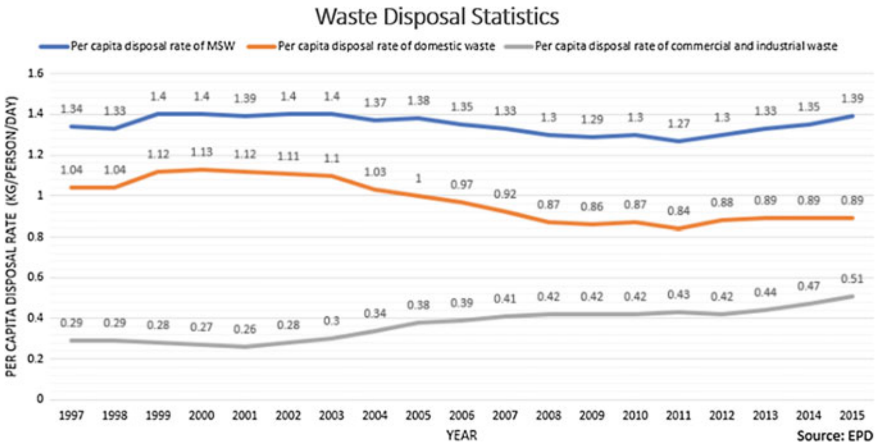

Fig. 6.1 Per capita disposal rate of MSW. *Data source* EPD

The rise in waste disposal in the commercial and industrial sector has triggered the government to consider policies and voluntary schemes to reverse the waste growing trend. But not much has been done in this sector except for the Food Wise Hong Kong Campaign that was launched in May 2013 to promote food waste reduction. The campaign has made some achievements after 2 years of work, as the food waste disposal amount recorded the first ever drop in 2015, a drop of 7.1%, from 3,640 tonnes/day in 2014 to 3,382 tonnes/day in 2015, while the bigger drop came from the domestic sector again.

As the first 200-tonne capacity organic waste treatment facility is still in the final stage of the building process, the city only has one large-scale commercial operator which runs a low-capacity food waste recycling plant at the government's EcoPark. As a result, most of the food waste generated in our city is dumped in landfills, so the food waste reduction result is probably due to the government campaign and the efforts of non-government organizations who are devoted to promoting food waste reduction and regularly collecting surplus food from restaurants and hotels.

Waste recycling has been operating as a commercial activity in Hong Kong for over 100 years (Heaver, 2017), while the government has kept its distance from this business, albeit realizing the waste reduction efforts that large-scale waste recycling companies and the many small street-level recycling shops have contributed.

Waste recyclers operate their businesses purely based on a revenue-driven motive, and therefore the more valuable the recyclables are, the more that will be recovered from the waste stream. In other words, recyclables with relatively low value will be left for the government to dispose of in our landfills. But even low-valued recyclables can be turned into useful raw materials to make new products. For example, used glass bottles have a very low market value, so recyclers do not bother to collect them, even if there are large numbers of them, for example at bars and hotels, but used glass bottles can be washed and cleaned for reuse, or they can be finely ground for use as a

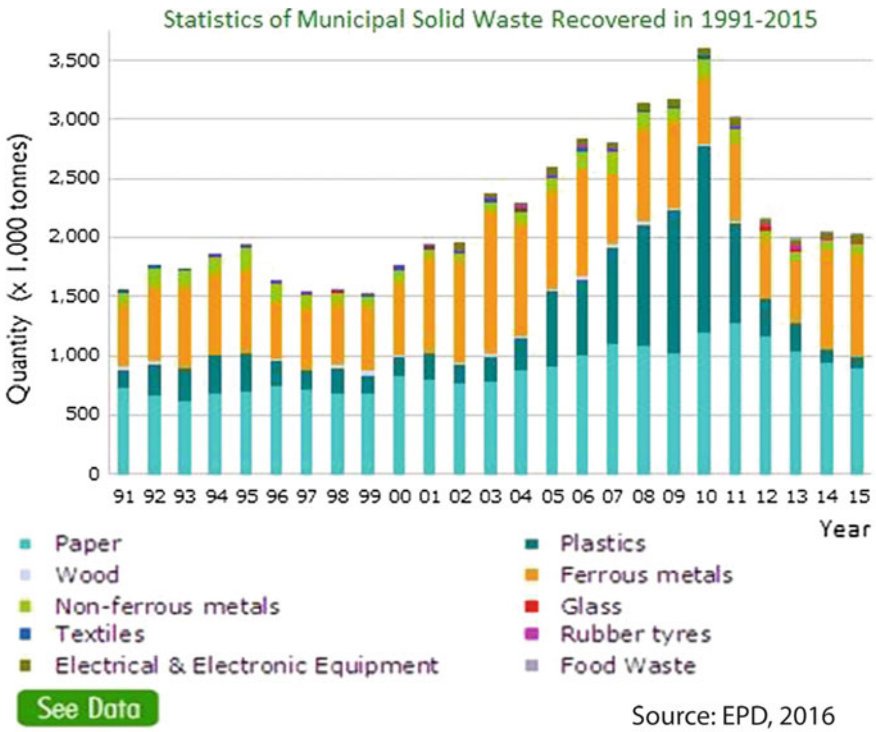

Fig. 6.2 Statistics of MSW recovered in 1991–2015 (EPD, 2016c)

construction material for building roads and buildings. Although the government is aware of the disposal of recyclables in landfills, it has not changed its policy mindset to create an artificial price for the low-valued recyclables as it is afraid that this will become a long-term financial burden on the government.

Paper, ferrous metals and plastics are the most common recyclables in Hong Kong. The recycling rate of paper was 52.1% and for metals, it was 91.7% in 2015. The recycling rate of plastics fluctuated most among the three types of recyclables from the early 90s to 2015. It reached a peak of 69% in 2010, with over 1.5 million tonnes being recycled, but this rate dropped to 10.5% in 2015, the lowest in the period, with only 93,900 tonnes recycled (Fig. 6.2). The drastic drop in the recycling rate for plastics could be attributed to the 'Operation Green Fence' policy launched by the Chinese government in 2013. The drop in plastic recycling started in 2014.

The world economy also affects the market value of recyclables. The world financial crisis of 2008 has slowed down the world economy and a deep recession has happened in many jurisdictions globally. In the same year, oil prices dropped from USD156 in June to USD45 in June 2017 (Macrotrends LLC, 2018). The price of virgin plastic materials also dropped accordingly; hence manufacturers in the mainland saw little incentive to buy recycled plastic materials, which has further affected the price of scrap plastics in the second-hand market. When less plastics are recovered for recycling, more will end up in landfills. Government waste monitoring reports showed that in 2010, each day 1,941 tonnes of plastic were dumped in landfills; this amount increased to 2,183 tonnes per day in 2015, a rise of 12.5% in 5 years (Environmental Protection Department, 2011).

6.1.3 International Experiences

It is interesting to compare Hong Kong per capita domestic waste generation with other Asian cities due to their similar levels of development. Among the four Asian cities of Seoul, Tokyo, Taipei and Hong Kong, an average Tokyo person generates 0.77 kg of domestic waste, followed by Seoul (0.95 kg), followed by Taipei city (1 kg), with the highest level of 1.36 kg for Hong Kong (Environment Bureau, 2013).

It is not encouraging at all to make known to others that Hong Kong has earned the top rank in domestic waste generation. Over the years, the Legislative Council has more than once raised questions for the government about the continued rise in the city's MSW, and the government has responded by saying that due to the vast numbers of tourists visiting Hong Kong and the economic growth, the city's MSW is bound to increase (HKSAR Government, 2016). Is there a real relationship between the number of tourists, the economic growth and the MSW amount? The following graphs (Figs. 6.3 and 6.4) show the two sets of figures and give us an idea that they do not have any correlation. In other words, more tourists visiting Hong Kong or the city's economic growth do not necessarily generate more daily per capita MSW. Comparing the similar data of other cities with similar economic development levels, it is interesting to note that their MSW amount also did not show any correlation with the numbers of visitors or their economic growth (Figs. 6.5 and 6.6).

6.2 Government Measures and Their Effectiveness

6.2.1 Evolution of Government Measures: Late 1980s–2010s

The Environmental Protection Department was set up in 1986 and it released its first policy paper named 'White Paper: Pollution in Hong Kong: A time to act' on World Environment Day 1989, which set out its vision and direction for tackling Hong Kong's pollution problems (Environmental Protection Department, 1989). Regarding the topic of waste, its direction for the following 10 years from 1986 was to build bigger landfills with higher environmental standards and to close the incinerators that were operating with rather poor emission standards. It did not spell out any immediate plans for the government to address waste avoidance or recycling as it considered that direct participation in waste recovery and recycling was inappropriate

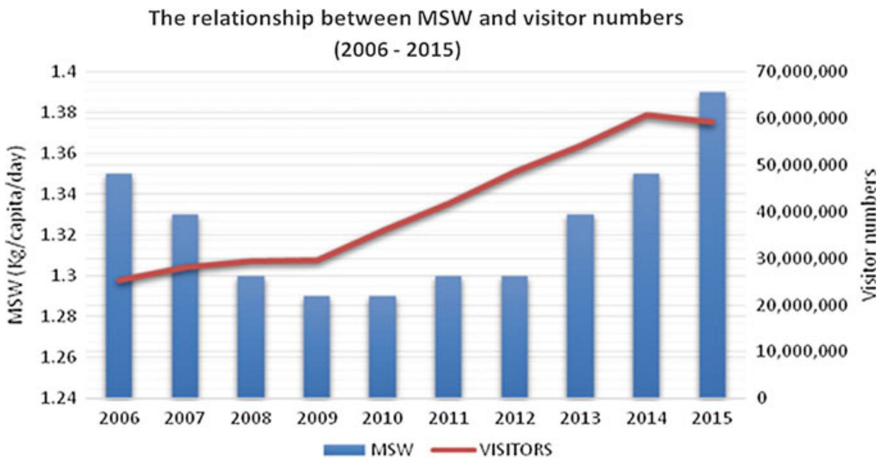

Fig. 6.3 Hong Kong visitor data: Zhong (2016), Hong Kong MSW data from EPD (2016)

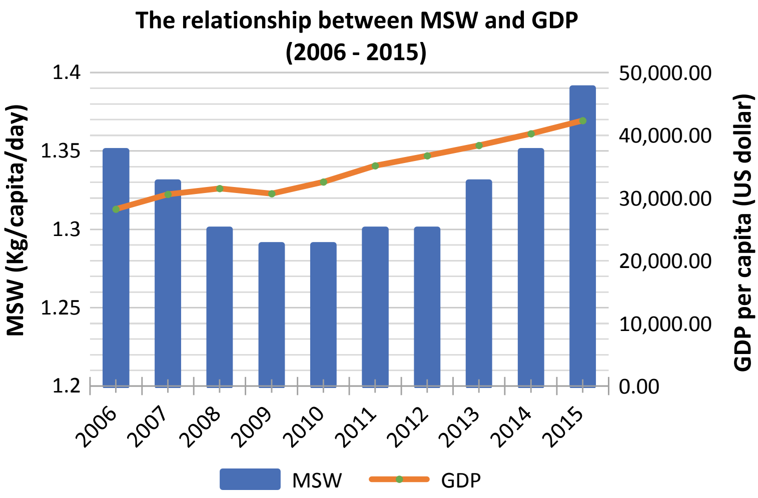

Fig. 6.4 MSW data from EPD (2016). GDP data from The World Bank (2015), Hong Kong Census and Statistics Department (2018)

for the government. However, it claimed that it would explore measures to limit waste generation and encourage recycling. This reflected that the waste management direction in that era focused mainly on one end-of-pipe solution instead of on multiple solutions, even if they were all end-of-pipe solutions. Moreover, the government did not see that it could also play a role in helping Hong Kong preserve our land and achieve more economic gains by recovering recyclables from the waste stream. It is considered that the government mindset of that era was quite narrow and short-sighted.

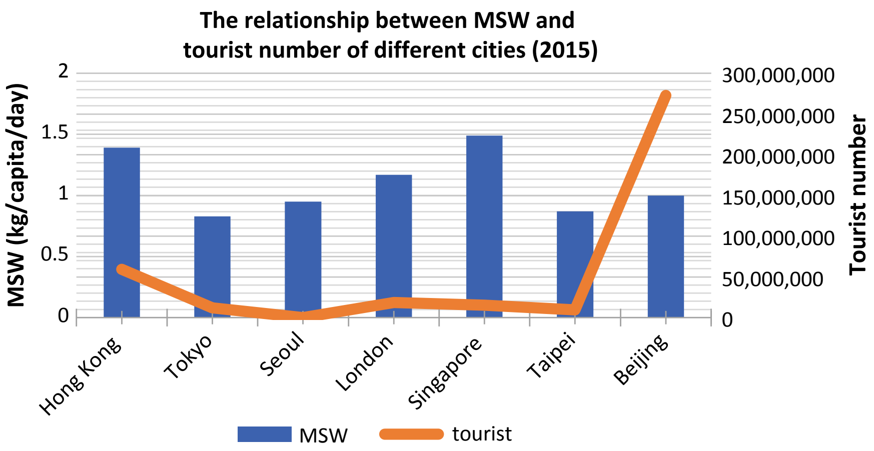

Fig. 6.5 MSW data from EPD (2016), Environmental Protection Bureau, Macao (2017), London Data Store (2016), Clean Authority of Tokyo (2016), Anonymous (2015), Nate (2018). Visitor data of Beijing from Zhong (2016), Tokyo Metropolitan Government (2017), Won (2017), London & Partners (n.d.), Greater London Authority (2015), Singapore Tourism Board (2016), Department of Information and Tourism, Taipei City Government (2016)

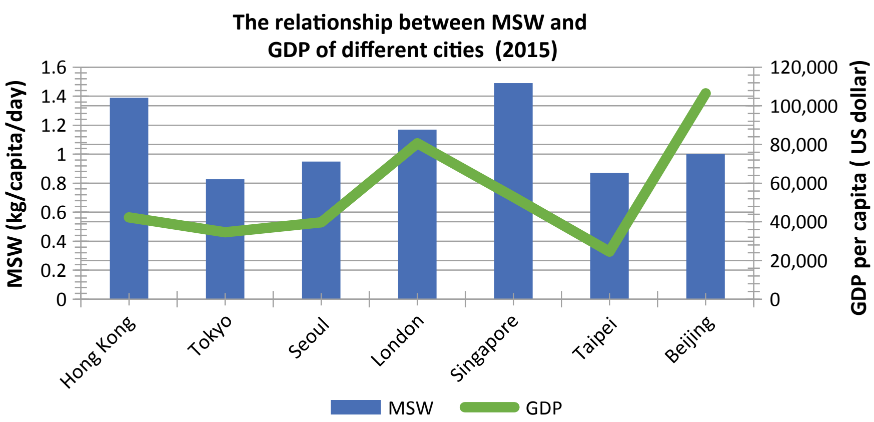

Fig. 6.6 MSW data of different cities from EPD (2016), Statistics Division, Bureau of General Affairs, Tokyo Metropolitan Government, Clean Authority of Tokyo (2016), Anonymous (2015), Nate (2018). GDP data of different cities from The World Bank (2015), Hong Kong Census and Statistics Department (2018), Greater London Authority (2015), Trading Economics (2018), Worldometers (2018), kuaiyilicai (2015). Wikipedia (2017), Read 01 (2016), Beijing Municipal Bureau of Statistics (2016)

Around a year after the handover of Hong Kong to the Chinese government, the Waste Reduction Framework Plan (1998–2007) as the first 10-year plan tackling waste problems, was developed by the Hong Kong SAR government. This plan emphasized that reform of the current institutional arrangements and operational practices could save resources and help promote waste reduction. The objectives of the plan included aspects such as minimization of waste that needs disposal, increases in the waste recycling rate, and conservation of the earth's non-renewable resources. It was quite a breakthrough in the government mindset regarding a greener waste management approach that no longer relied on bigger landfills as the only viable solution to cope with the city's waste.

This was followed by 'A Policy Framework for the Management of Municipal Solid Waste in Hong Kong (2005–2014)' unveiled by the former Secretary for the Environment, Transport and Works, Sarah Liao Sau-tung, in 2005, which set out a wide range of policies covering waste avoidance, recycling and pipe-end solutions such as incineration (Environmental Protection Department, 2005a). In this plan, the timeline for each of the policies proposed was clearly stated, and it is believed that it was Liao's intention to avoid slippage of policy development progress. This was considered to be the most comprehensive plan compared with the other previous plans released by the colonial government or the SAR government.

Should all of Liao's proposed policy measures have been implemented according to the timeline stipulated, the waste problems of Hong Kong would have come under control, even if they had not been totally resolved. However, the policy framework has not been treated seriously and many of the policies stated were not followed through by the responsible Principal Officials when Liao stepped down from her position in mid-2007. The public perceives that any of the government's unveiled policy plans are meant to be a blueprint that it will act upon, irrespective of changes in the respective Principal Official. Officials stepping down due to retirement or transfer to another bureau often happens in the government; however, such changes would not and should never affect the implementation of the announced policies. The case in discussion is somehow different. The successor to Liao was Yau Tang-wah, who headed the Environment Bureau from 2007 to 2012. Yau seems to have picked and chosen some specific things from Liao's plan to work on.

Liao was fully aware that Waste Charging and Producer Responsibility legislation would bring significant waste reduction effects if implemented; she, therefore, included in the framework plan six types of products to be covered by the Producer Responsibility legislation including electrical and electronic equipment, vehicle tyres, plastic shopping bags, packaging materials, beverage containers and rechargeable batteries. The timeline for introducing the MSW Charging Bill was between 2007 and 2008 (Environmental Protection Department, 2005c). Yau did not start any public consultation process for Waste Charging when he took office, and only a few months before the expiry of his tenure did he launch a public consultation for Waste Charging. So, a delay in the legislative development of the law was expected and left for the next administration to follow.

Wong Kam-sing was Yau's successor, and he commissioned the Council for Sustainable Development to conduct the second phase of the consultation regarding the implementation framework of the proposed Waste Charging law in December 2012. To the public, there seemed to be a delay in enacting the law, while some even felt that undergoing more consultations showed a lack of confidence in the government's ability to sell its plan to the public and legislators (Philip, 2013). Wong did not come from the civil service, but is an architect by profession who is well known for designing green buildings in Hong Kong. His mindset is quite open when engaging with him in a discussion of possible solutions to our environmental challenges. Wong believes solutions to environmental problems such as waste are multiple. He accepts applying software and hardware, that is education, legislation and technologies, to cut down the city's waste. Wong's mindset is similar to that of Liao and is quite different from that of the colonial government which had a strong belief in relying on hardware to manage our waste.

One of the cases worth mentioning is the Food Wise Hong Kong Campaign aimed at reducing food waste and with an icon called the Big Waster, which was launched in 2013. Wong was bold to invest resources in developing a creative campaign to address food waste, which constitutes the largest portion (33.3% in 2015) of MSW in Hong Kong. He believes that food waste could be reduced through public education, and as such the government needs to not merely pour money into building food waste plants to tackle it.

Quite a big change in the government mindset and strategies in certain aspects of waste management from the 80s to the present was reflected by Wong. Technology enhancement and higher public environmental concern are factors propelling such changes; however, there are areas that still require breakthroughs in the government mindset, if bigger improvements are to be achieved.

6.2.2 Two Types of Measures—Hardware and Software

The Environmental Protection Department was acquainted with applying proven engineering solutions, which are mainly hardware, to tackle our solid waste from day one. Landfills and incinerators were the main types of hardware to manage our solid waste, although the standards of this hardware were lax compared with today's standards. However, with the public's increasing environmental and health concerns, the last incinerator located at Kwai Chung was closed in 1997, and all the city's solid waste was then absorbed by the three strategic landfills based on the advice of technical consultants employed by the government.

Our government was criticized for its strong reliance on advice given by external consultants, for example, the full reliance on a single solution—the landfill to deal with our solid waste—is one of the classic examples of failure in holistic waste management. Consultants in that era usually offered technological solutions as most were engineers; engineers will inevitably recommend engineering solutions as they are not environmental advocates. The government trusted the consultants' advice that by building three strategic landfills it would be able to manage our waste for several decades. However, our waste disposal continued to rise, thus shortening the life of the landfills, but the government offered no other solutions and it also feared that incinerators were unwelcome to the public and environmentalists.

In the waste management hierarchy, recycling is in the middle level; it can be facilitated by hardware coupled with software—education. The government designed the three-colour recycling bins and has put them in public places since 1998. These bins were designed originally to collect waste paper, cans and plastic bottles, and the shapes of the 'mouths' give hints to the public about what items they collect. However local green groups are quite vocal and their software approaches have included campaigns advocating waste reduction such as No Plastic Bags, No Foam Boxes, etc. Government officials had no experience of promoting environmental messages to the public, but they were aware of the effects of environmental campaigns and education. The government, therefore, launched a quasi-NGO called the Environmental Campaign Committee (ECC) in 1990 supported by EPD officials who play the role of secretariat. It also appointed environmentalists, representatives from NGOs and commercial bodies to sit on the Committee to play a role in promoting environmental awareness in society, as the government realized the success of green NGOs in raising public environmental awareness that has filled the gap that hardware approaches cannot. The ECC also handed out grants to support NGOs doing environmental programmes to echo the annual ECC theme of enhancing the educational effects. Since then, most of the software approaches have been handled by the ECC instead of the EPD which continues to focus on pollution control and law enforcement.

Wong Kam-sing was appointed Secretary for the Environment in 2012 and he believes that both software and hardware approaches are needed to tackle the critical waste problems. He released two long-term plans addressing the city's waste problems, namely the Hong Kong Blueprint for Sustainable Use of Resources (2013–2022) and A Food Waste and Yard Waste Plan for Hong Kong (2014–2022) in 2013 and 2014, respectively. He made a change to the perception of waste within the government, considering it as a resource; thus, the government should have policies to ensure that such resources be used in a sustainable manner.

Wong persuaded the Legislative Council to pass an amendment to the Plastic Shopping Bag Levy Scheme to cover all retailers in Hong Kong effective 1 April 2015, as the first phase only covered some 3,000 retailers. Other software approaches have included the legislation related to Producer Responsibility for glass beverage containers and waste electrical and electronic equipment (WEEE), whereby a levy will be added to beverages packed in glass containers and eight types of electrical and electronic equipment. The government will then have the money to employ contractors to recover glass bottles and WEEE in the community. Another effective software approach is the Waste Charging law where Wong told the public that the government is committed to launching a new law to charge the domestic and commercial sectors for waste disposal based on quantity. He expected that the law will take effect in the second half of 2019 at the earliest. There are uncertainties as to whether the law can be passed by the Legislative Council as some political parties have stated that they do not support the idea of waste charging.

In terms of hardware, three major waste treatment facilities have been built in recent years. First, the T-park is a large-scale sewerage treatment facility operating since 2016. Second, the 200-tonne organic waste treatment facilities (OWTF) will begin accepting food waste in the second half of-2018. Third, the WEEE treatment plant also began its operation in the fourth quarter of 2017. The 3,000-tonne integrated waste management facilities (IWMF) proposed in Liao's framework plan was planned to be completed by 2014, but it has suffered serious delays. The timeline of the IWMF stated in Wong's Blueprint is between 2019 and 2022. The government claimed that it is a state-of-the-art waste treatment facility that will greatly reduce the volume of MSW before landfill disposal, but many environmentalists have commented that it is just a cleaner incinerator that might destroy materials if no comprehensive pre-sorting mechanism is included in the facilities. As Wong was appointed Secretary for the Environment again by the new administration in July 2017, there is an advantage of continuity, which will save time for the Secretary to get acquainted with the government operation. Under the Principal Officials Accountability System, the public is expecting Wong to deliver according to the targets and timeline stated in the blueprints, whether they are hardware or policies.

6.2.3 Responses from Society

Have any significant improvements been made because of government policies? This is a question often raised by legislators, media and the public. In terms of policies, there should be two that are related to charges which made quite noticeable improvements. The first is the Construction Waste Disposal Charging Scheme and the other is the Plastic Shopping Bag Levy Scheme.

6.2.3.1 Construction Waste Disposal Charging Scheme

The Construction Waste Disposal Charging Scheme was initially enacted in 2005 with the aim of reducing the disposal of construction waste in landfills by encouraging reuse through financial disincentives. For each tonne of construction waste dumped in landfills, the charge was HK$125, and was increased to HK$200 in 2017 due to the rebound of construction waste dumped in landfills in the last couple of years. Under the revised charging scheme, if putrescibles such as timber are removed from the construction waste, contractors can pay only HK$71/tonne to dispose of such inert construction waste at Public Fill Reception Facilities (Environmental Protection Department, 2017a).

Before implementing the waste charge, Hong Kong generated over 58,767 tonnes of construction waste per day in 2005. When the waste charge was implemented from January 2006, the amount dropped to 29,884 tonnes per day in the same year, which is a significant drop of 49.1%. This significant drop in construction waste being dumped in landfills indicated that if contractors make an effort to prevent the mixing of waste at construction sites and to reuse the sorted materials, then almost half of the construction waste could be reduced (Fig. 6.7). As the charge increased in

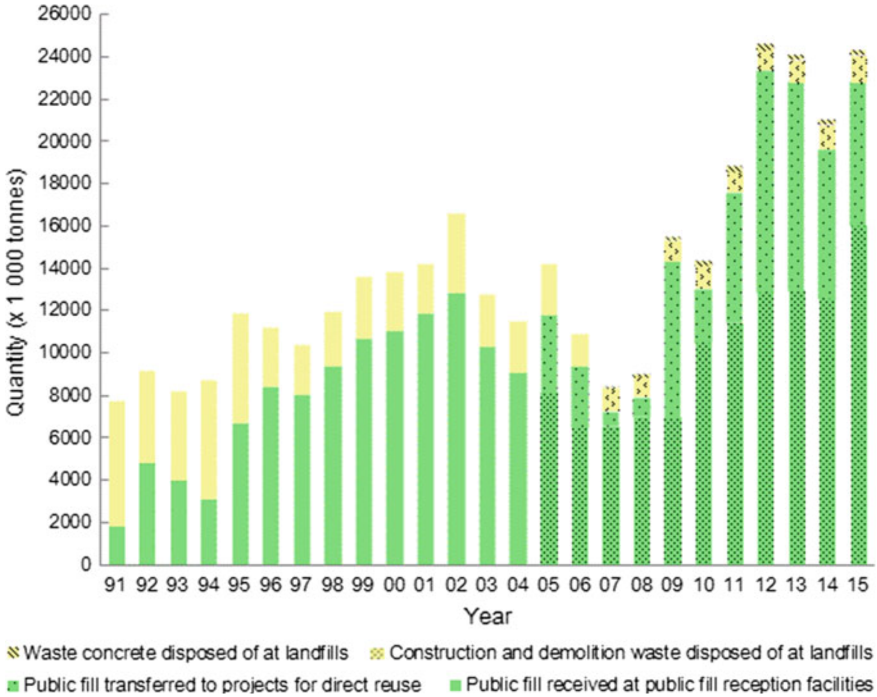

Fig. 6.7 Quantity of construction waste (1991–2015), (EPD, 2016a)

2017, there should be further reduction in construction waste disposed of in landfills; however, we can only learn the outcomes when the relevant data from the Monitoring of solid waste in Hong Kong 2017 report is unveiled by the government later in 2018.

6.2.3.2 Plastic Shopping Bag Levy Scheme

Hong Kong people were criticized for decades for using plastic shopping bags excessively and beyond our actual needs. According to a government landfill survey in 2005, around 8 billion plastic shopping bags were disposed of at landfills every year. This was equivalent to an average of more than three plastic shopping bags per person per day. The government and green groups have separately launched various campaigns in an attempt to lessen the use of plastic bags. However, since all the campaigns were voluntary approaches, the reduction in bag usage was insignificant. Green groups kept pushing the government to develop legislation to tackle this problem. Finally, the Plastic Shopping Bag (PSB) Levy Scheme was endorsed by the Legislative Council, and from 7 July 2009 some 3,000 registered stores, including mainly supermarkets, were required to charge customers 50 cents per plastic shopping bag.

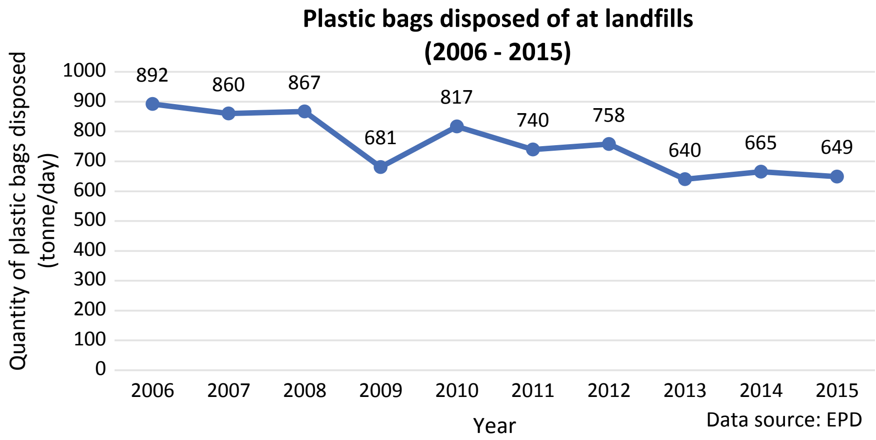

Fig. 6.8 Quantity of plastic bags disposed of at landfills. *Data source* EPD

To understand what differences the PSB Levy Scheme has brought to shoppers, through observation in supermarkets, it is found just 50 cents had made a difference in the behaviour of Hong Kong people. Most maids, housewives and men did not take a plastic shopping bag that was once given for free by the supermarkets. Some brought along their own shopping bags or trolleys, others just held two bottles of milk in their hands. This somehow reflected that financial incentives yield immediate and better results than voluntary approaches.

The government claimed that after the first year of the PSB Levy Scheme, the plastic shopping bags distributed by those registered retailers had reduced by 90% based on its landfill survey done in mid-2010 (Environment Bureau, 2011). But the government later found that there was a bounce back to the decreasing trend of bag distribution by the registered retailers during the first quarter of 2011. The plastic shopping bags distributed by the registered retailers amounted to 12.4 million between 1 October 2010 to 31 December 2010, and that amount rose to 13 million for the first quarter of 2011. In view of the problem, government enhanced the legislation to cover all retailers to bring more effective improvements. The amended legislation took effect on 1 April 2015. The daily amount of plastic bags disposed in landfills started from a relatively high level of 892 tonnes in 2006, dropping to 681 tonnes in 2009, but with a rise to 817 tonnes in a year's time, which was followed by a descending trend to 649 tonnes in 2015 (Fig. 6.8). Some other common waste items such as paper and PET (polyethylene terephthalate) bottles did not show any significant reduction over the last 10 years as no government regulations were launched to address such items. PET bottle waste even showed an apparent growing trend (Figs. 6.9 and 6.10).

The majority of the businesses in Hong Kong, in particular, the larger ones, adhere to government policies but they do not like over-control by regulations as they believe running businesses effectively needs a certain level of flexibility. When the Plastic

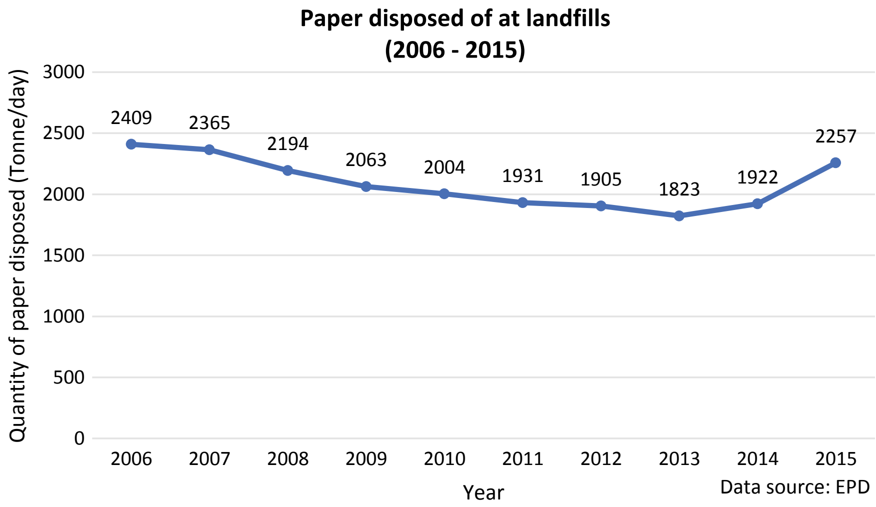

Fig. 6.9 Quantity of paper disposed of at landfills. *Data source* EPD

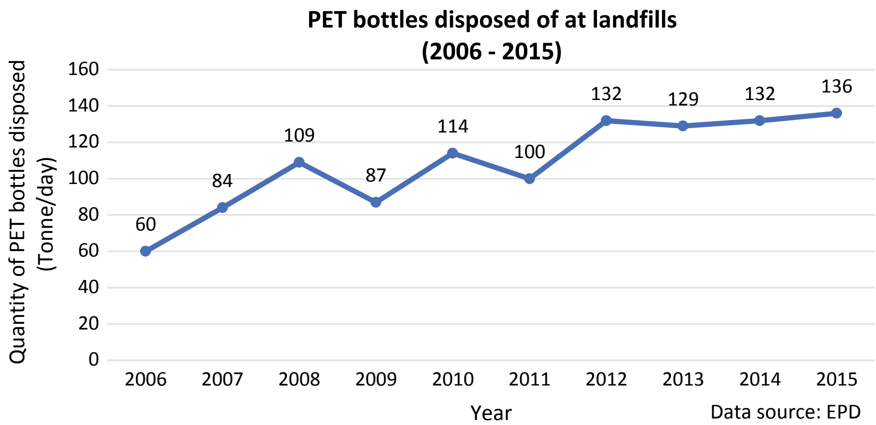

Fig. 6.10 Quantity of PET bottles disposed of at landfills. *Data source* EPD

Shopping Bag Levy Scheme took effect, registered retailers put up government produced posters and cards at the cashier counters to inform customers of the mandatory bag levy. Soon after the bag levy took effect, a new type of bag appeared and became popular. It is the non-woven bag, which the bag producers and retailers tactfully gave the nice name: 環保袋 (Environmental Bag) which made it sound environmentally friendly. However, it is just a thicker plastic bag that people are supposed to use over and over rather than using it just once and disposing of it. Under the first phase of the bag levy law, non-woven bags were exempted from any bag charge. Companies foresaw that the law would cover more retailers in the future, so they reacted swiftly to the law by changing from giving out single-use thin plastic bags to more durable non-woven bags to customers. However, not just retailers, but many events and conference organizers also changed to giving out non-woven bags at their events, thus creating another kind of bag problem. Today, every person probably has five or more non-woven bags at home or in the workplace.

The other retailers that were not covered by the plastic shopping bag levy law simply did business as usual by giving out free plastic bags to customers until they were regulated, even though most of the big businesses had corporate environmental policies stating clearly their environmental responsibilities. To address the rebound of the plastic bag disposal problem, the bag levy was strengthened on 1 April 2015 to cover all retailers in Hong Kong to enhance its strength in cutting the use of plastic shopping bags. A couple of large fashion retailers had their own way of dealing with the upgraded bag levy; Uniqlo and H&M separately announced that they had decided to change to paper shopping bags to replace the existing plastic bags. This means that they were not prepared to echo the law which was expected to bring improvements in waste reduction. They did not offer a reason for the change, but it is quite apparent that their decision was made purely based on business consideration. It is believed that they were afraid that if no free shopping bags were offered to the customers, it might affect their company's bottom line.

Recognizing the decision of these two retailers, the author wrote repeatedly to persuade them to change their decision by emphasizing the harm and damage plastic shopping bags have brought to the environment. H&M replied with their reasons why its shops in Hong Kong decided to use paper shopping bags to replace the existing plastic bags. Uniqlo replied via email on the morning that the bag levy came into effect, saying that it will charge the same amount of 50 cents for the plastic bag and the paper bag. Seems Uniqlo had already produced a lot of paper bags, so charging for both types of bag was a viable solution that would prevent wasting the bags. Re-observation has been made on 1 April 2015 to observe if there was any change in the two shoppers' behaviour. Uniqlo had put up signs at the cashier counters reminding customers of the bag charges, while H&M had not put up any similar signs. Most of the shoppers at Uniqlo used their own shopping bags to carry the products they had bought or simply refused to take a Uniqlo bag to avoid paying the 50 cents. Shoppers at H&M simply used the free H&M paper bags to carry the products they had bought. Well, the difference is apparent in this case, but the story has not yet ended.

The government and NGOs often use quite different approaches to make environmental improvements. The government uses the approach of legislation, and guidelines when legislative control is not applicable, whereas NGOs use the approach of lobbying, applying public pressure and education. While persuading the two fashion retailers through written communications, the author also expressed the views and comments openly regarding their decision via the media, which might be given them some kind of pressure. Having gained a small victory in persuading Uniqlo to change its business decision at the last minute to echo the bag levy legislation, the author kept communicating with H&M's Hong Kong office and even wrote to its head office in Sweden. In mid-March 2016, H&M Hong Kong office wrote to inform the author that its shops in Hong Kong will start charging 50 cents for each shopping bag distributed to customers despite its paper shopping bags not being regulated by the law. Environmental policy is a form of legislative measure; government officials can only enforce it when legislation is in place, and it was not the tradition for officials to persuade commercial firms to change their business decisions, even if such a decision goes against the policy goal. Legislative measures are often more effective than voluntary approaches; however, when the public or businesses try to get around legislative measures, non-government organizations can always play their role through education and motivation to make some achievements.

6.3 How to Resolve Our Waste Problems?

6.3.1 Finding a More Sustainable and Holistic Solution

As the city's waste problems are becoming more critical, the public expects the government to come up with practical solutions and to lead the whole society to resolve the problems together, instead of launching piecemeal campaigns and voluntary schemes. The holistic waste management approach is the direction our society should embrace; it is an approach encompassing 'Avoidance', 'Reduction', 'Reuse', 'Recycling', 'Treatment' and 'Disposal'. At the same time, we need to use the Waste Hierarchy as the guiding principle and put heavy emphasis on its upper levels such as waste avoidance, which will yield the greatest outcome with the minimal effort (Environmental Protection Department, 2005b).

Our government is well aware of the Waste Hierarchy, but the unveiled policies so far and the waste disposal trend of Hong Kong over the last decade reflect that the government has not put enough emphasis on the upper levels of the Waste Hierarchy. Green NGOs have urged the government for years to implement Waste Charging by applying financial disincentives to drive behavioural change, but such effective policy has gone through only repeated public consultations and is still on the administration's drawing board. We are all aware that education takes a long time to come to fruition, but once people are motivated and have converted to a green mindset, reducing waste will become their daily habit, whether there is legislation or not, which can be considered as the most sustainable solution.

Environmental education is not a core subject in schools, and the Environmental Protection Department has not actively reached out to educate students, the working class and housewives on the various issues related to waste reduction. Therefore, even though the public's environmental awareness, in general, is relatively higher today, most people still have misunderstandings about the appropriate ways to reduce and recycle waste. A closer look at plastic recycling bins placed in public places will reflect the misunderstandings of the public regarding waste separation at source and clean recycling (Photos 6.1 and 6.2).

Photo 6.1 With permissions from The Green Earth

Photo 6.2 With permissions from The Green Earth

6.3.2 The Government's Roles

There has been no shortage of strategic framework plans and blueprints developed and launched in the last two decades by the Hong Kong SAR government to address the city's solid waste issues. However, it needs the genuine buy-in by the large civil service team of the entire government, in particular, the relevant departments, to work hand in hand with the Environment Bureau to take those plans forward according to the stated timeline. However, this seems to be a difficult part in our government since cross-departmental collaboration on environmental policies rarely happens. Each department has got a clearly defined scope of work for its officials to follow.

Policy plans have been announced, but the change of Environment Minister under different administrations seems to have affected the continuity of the plans. Take 'A Policy Framework for the Management of Municipal Solid Waste for Hong Kong (2005–2014)' as an example; many of the items stated in the plan did not get worked out according to its proposed timeline. The MSW waste charging legislation was supposed to take effect between 2007 and 2008, however, its draft legislation was not submitted to the Legislative Council before the end of the term of the last administration headed by former Chief Executive Leung Chun-ying. The previous Environment Ministers had already unveiled a spectrum of solutions to Hong Kong waste problems; what we really needed was the commitment of the Principal Official to drive and complete these policy measures which were experiencing serious delays.

Engaging the public to get them to understand why an environmental policy is needed to tackle the city's waste crisis is a must-do step and cannot be treated lightly. When the public and political parties have lots of misunderstandings and concerns about a proposed policy, it is unrealistic to expect them to buy-in and vote for it at the Legislative Council. The proposed MSW charging legislation is a classic case of great concern for the public and political parties since it was proposed by the previous administration. For such legislation that is relevant to every citizen and business in Hong Kong, organizing merely two public forums to give more details will not be sufficient to ease the public concerns and misunderstandings. Instead of sensible questions raised during the forum the author attended, many grievances were raised by the audience, and the time constraint has prevented more interactions from taking place to iron out misunderstandings. Such a cosmetic consultation just allowed the officials to report that they had done public consultation, but this has not earned greater buy-in from society.

It is expected senior officials and not just the Environment Minister to reach out to the 18 local districts at different times to engage the public and businesses as a core exercise to earn the necessary public support for passing the legislation. This effective legislation does not require huge capital investment in infrastructure; it only requires the government officials' time and genuine efforts to convince the public to embrace the legislation. In the current political environment, government officials are often criticized by some people or political parties during public consultations of various topics; therefore, it made some officials unwilling to face the public.

6.3.3 *The Private Sector's Roles*

It is strongly believed that the private sector should play a key role in tackling Hong Kong's waste problems, or at least to take care of its own waste including product packaging waste and products when they reach the end of their life, the private sector, in general, has seldom made a move voluntarily unless required by legislation. The private sector is well aware of the city's serious waste problems; unfortunately, businesses tend to act lightly or tinker on the edges to show the public that they have contributed their part for the environment. In most cases, businesses prefer to take part in high-profile campaigns run by government or green NGOs, because they know they stand a chance of gaining some publicity in return. For instance, there are several local beverage companies doing business in Hong Kong, and their main or sole aim is to sell more beverages to gain a larger market share for more profits. Though the public can see sustainable policies covering waste management or climate change topics on their official website, it is hard to identify any significant environmental actions or plans conducted by these companies. What you will see are some small scale or ad hoc activities carried out within a limited number of schools or shops, which can in no way resolve their own waste problems.

Hong Kong's waste problem is mainly the waste generation that seems to keep growing without any sign of slowing down; therefore, what we need to do is reduce waste generation at the source instead of just concentrating on recycling used plastic bottles in the case of the beverage industry. However, to reduce waste generation at source means selling fewer products, which is against the beverage companies' profit-making aim. It is unrealistic to think that the private sector will share the government responsibility for tackling our waste problems, unless there are some business opportunities. For example, the government issued tenders inviting the business sector to manage the public recycling bins, and such waste management service will become a business opportunity for successful bidders to make profits by providing regular services to collect recyclables from the public bins. It has turned out to be a profitable business as our government pays the contractor around HK$9,000 for each tonne of recyclables collected from the public recycling bins (Audit Commission, 2015). Recyclers who run their business without government support can in no way earn such a high amount from collecting and selling recyclables of paper, plastic or even metal. Recycling companies act similarly to the mainstream businesses as they won't do businesses that yield zero profit. That is why low-value recyclables, such as glass bottles, were not collected by recyclers, and the destination is the same as that of other trash—landfills.

To give a legitimate role to the private sector to manage waste, the government must develop legislation to mandate businesses to act, and one of the effective policies is Producer Responsibility. When such a policy is in place, producers must take care of the waste they produce using their resources instead of shifting their responsibility to the government. For example, in 2005, the EU mandates that between 55 and 80% by weight of all packaging waste be recycled by the end of 2008, which has clearly required the producers to shoulder their responsibility (U.S. Environmental Protection Agency, 2007).

6.3.4 The Individual's Roles

The spirit of Producer Responsibility is to put the responsibility on producers whereby they have due responsibility to take care of the waste (including packaging and end-of-life products) they produce, and this applies to product manufacturers. Another principle is the Polluter Pays Principle, where consumers must pay for the cost of treating their waste. When the majority of the public is aware that their lifestyle has strong connections with waste disposal and are being reminded of ways to reduce and channels to recycle, they will probably assume a greater role in waste reduction. On average, each person in Hong Kong produces 1.39 kg of waste every day (2015 level). If we see ourselves as socially responsible citizens, then we should at least find out whether we have produced less or more than that average amount, as well as our waste composition. It could be a simple and interesting exercise for family members to conduct for a week to identify what types of waste they produced most and whether part of the waste is avoidable and recyclable.

Individuals are believed to be much easier to motivate to reduce waste than businesses and the government because individuals need not be concerned about the corporate bottom line and the complex official procedures. If you are an environmentally conscious person and a responsible consumer, you will choose products with less packaging and only shop when there is a real need. You will do your best to avoid using one-off disposable products, bring your multiuse drinking water bottle and a shopping bag whenever you go out, and you won't buy take away food to avoid generating waste at source. When you finish reading the newspaper or magazines you will put them into the paper recycling bin. The main part of waste you might generate in a day would probably be the food waste generated from meals. And if you cook only what your family members can consume comfortably, even if you do not have food waste recycling facilities at your residential building, the amount of waste should be minimal.

It is not difficult to establish a waste-conscious mindset and culture in society if people of all ages are educated about the topic of waste and the environment while the government also keeps promoting waste reduction via traditional and new media channels aided by attractive campaigns. The Big Waster campaign that the Environment Bureau launched in 2013 with the aim of reducing food waste is considered a successful case. Two years after the launch of the campaign, the government reported that the food waste disposal amount of 2015 had reduced by 7.1% compared with that of 2014. As the success is by no means due to mandatory requirement, the campaign should continue to let the key messages of food waste reduction be heard continuously to motivate more people and businesses to take actions to tackle our waste problems together.

6.4 Conclusion

Holistic Waste Management is not just jargon for government officials to talk about when approached by the public or media; it is a strategy the government should uphold and implement to develop policies and hardware for waste management that can effectively suppress waste generation at source and reduce waste disposal at the end. The upper levels of Holistic Waste Management require education and motivation to achieve and sustain; however, it seems that the majority of Hong Kong people do not practice waste avoidance, reuse and recycling regularly for various reasons. Therefore, it is vital for the government to devote resources to promoting and facilitating waste avoidance, reuse and recycling in the business sector and community.

Many cities in Southeast Asia, the EU and the US are aware of the importance of Holistic Waste Management and therefore have developed legislation, technologies and systems coupled with promotions to manage their solid waste and recover resources from it. For instance, the Taipei government has implemented a waste charging policy, named ‘Per-bag Trash Collection Fee Program’ since 2000, which is based on its Pay As You Throw (PAYT) system. Before implementing the policy, the government organized over 740 briefing sessions for the public and waste collection staff of buildings to get more to buy-in the policy. In 2003, the government implemented another recycling programme addressing household kitchen waste to further enhance the effectiveness of its waste charging policy. As a result of the combined effects of several waste reduction policies, the waste reduction rate reached 66.7% and the recycling rate reached 56.38% by December 2014 (Ecologic Institute, 2014). In 2013, the Environment Bureau of Hong Kong SAR government led a delegation with scholars and green NGOs to visit Taipei to learn Taipei’s success in waste management.

The Packaging Ordinance implemented by the German government as early as 1991 is another good reference for the world. The Ordinance requires manufacturers and distributors to take back their product packaging for reuse or recycling. Germany is also known to be one of the advanced nations in developing and applying technologies to sort mixed recyclables, which has achieved much greater efficiency compared with places where waste sorting is performed manually by workers (Skoda, 2018). The Chinese government bans the import of 24 types of foreign waste from 2018 has given the world a clear message that every nation should handle its waste within its boundary and China is no longer the waste dumping ground for other nations. Hong Kong and other countries who have been relying on the mainland to process our waste should immediately examine our waste management direction and should not take it for granted that developing countries will forever receive waste that does not belong to them. Hong Kong is a developed and wealthy city in Asia with very efficient systems for transport, telecommunications, finance and banking, etc.; the government should, therefore, speed up the development of all other measures needed to support Holistic Waste Management to make waste management one of the efficient systems in Hong Kong that we can all be proud of.

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Edwin Che Feng Lau is Founder and Executive Director of The Green Earth. Mr. Lau has been actively engaged in environmental protection work since the late 1980s and founded The Green Earth in early 2016. He keeps motivating the business sector and public to tackle pressing issues related to waste management, air pollution and climate change by acting green. Mr. Lau sits on several government advisory committees to offer advice on waste reduction, water conservation, public environmental education, etc. In 2009, Mr. Lau. was awarded the Medal of Honour by the HKSAR government in recognition of his long-term contribution to the cause of environmental protection and education.

Part II
Environmental Programmes from Schools and Universities, as well as Community Education for Waste Management

Chapter 7
Community and School Education on the Subject of Waste Management: Experiences of Romania, The United Kingdom and Germany

Karin Kolbe

Abstract Waste management practices can help to conserve energy and resources, reduce carbon dioxide emissions and safeguard human health. Community and school education should help to increase knowledge, awareness and understanding regarding these practices. In the current chapter, three different European countries will be examined regarding their community and school education regarding waste management: Germany, Romania and England. Germany has an advanced waste management system in which only a small fraction of inert waste is landfilled. However, the quantity of waste that is produced per person is very high. Romania joined the EU in 2007 and translated European environmental legislation into national law. The country has made immense progress regarding environmentally sound waste disposal and waste management options. However, the largest fraction of municipal waste is still landfilled. Whether and to what extent waste management is covered in schools depends primarily on the individual teacher's motivation and interest regarding this topic. Community education often focuses on 'basic' waste management approaches such as the negative effects of fly-tipping and the correct use of recycling facilities. In England, which is part of the United Kingdom, a range of community and school education initiatives exist to support sustainable waste management. As a result of the Brexit—the United Kingdom leaving the European Community—fears have arisen that recycling and landfill reduction targets might be changed into more lenient targets in the future. This could also reduce the emphasis being put on community and school education regarding waste recycling and waste reduction.

Keywords Waste management · Education for sustainable development · Waste reduction · Recycling · European Union

K. Kolbe (✉)
Faculty of Mathematics and Sciences, University of Koblenz-Landau, Universitätsstraße 1, 56070 Koblenz, Germany
e-mail: kkol4786@uni.sydney.edu.au

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7.1 Introduction

The United Nations proclaimed that 2005–2014 will be the decade of education for sustainable development (UNESCO, 2005). Waste management is an essential part of sustainable development and education on this matter is vital to conserve resources for future generations, reduce carbon dioxide emissions, protect the environment and safeguard human health. Waste management itself differs largely in different countries, and community and school education initiatives should help the population to understand the problems associated with waste and how their behaviour can help to improve the management of waste, for instance, through the correct separation of waste materials or their choice of easily recyclable materials. Education regarding waste management is consequently interrelated with regional or national waste management systems.

Within the European Union (EU), targets are set for waste recycling and landfill reduction. How these aims are achieved is the responsibility of the member countries. However, it is now widely accepted that environmental education is a vital precondition for a well-working waste management system (Hasan, 2004; Palmer, 1995). Countries of the EU—as well as many other countries around the world—have, therefore, introduced different educational programmes that should help the population to live in a more sustainable manner (Aegee, 2017; Foundation for Environmental Education, 2017; Knowlton Cockett, Dyment, Espinet, & Huang, 2017).

The concept of the waste hierarchy defines a priority of actions regarding waste management (European Parliament and European Council, 2008). The best option, according to this hierarchy, is to not produce waste at all. The second-best option is to reuse waste, followed by recycling, incineration and finally disposal in landfill sites. All EU member countries support the waste hierarchy since it is seen as the best option to save a maximum of resources and energy.

Education at the school level is particularly successful if carried out in a manner that addresses the young generation. Pupils act as 'multipliers' in their homes, which is why the effort and money that is invested at this level can lead to effects beyond the pupil generation itself (Armstrong, Sharpley, & Malcolm, 2004; Boerschig & De Young, 1993; Larsson, Andersson, & Osbeck, 2010). However, school education alone does not suffice. Every person within a community needs to be addressed through community education programmes. The three countries that are analysed in the current chapter illustrate in an exemplary manner the development of education on waste management, taking the improvement of the waste management situation into account. Romania is a country in which waste management that is in line with the EU vision is still at the beginning, the United Kingdom (UK) is in the phase where the largest improvements in waste management are currently being achieved and Germany is a country where waste management has already been optimised to a high level. While education on waste management has not yet been developed in Romania, most of such programmes have already disappeared in Germany since waste is no longer perceived as a problem. In the UK, where recycling, composting and landfill targets that were laid down by the EU still need to be reached, a vast

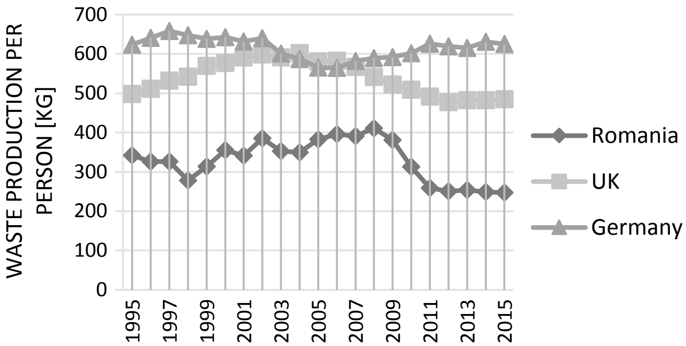

Fig. 7.1 Waste production per person in Romania, the UK and Germany between 1995 and 2015. *Source* Eurostat (2017)

range of education programmes exists to encourage citizens to participate in, and to understand, waste management activities.

In the next section, an overview of the development and current situation of waste management in the three countries will be provided. Hereafter, in more detail what problems are associated with waste in the three countries and which specific education initiatives exist at the school and community level regarding waste management will be shown.

7.2 Background

In the current chapter, community and school education in three different EU countries which joined the Common Market at different times and with different pre-existing conditions in the environmental sector are compared. To understand what community and school education can achieve, it is necessary to know what the main challenges of waste management are in the three countries. Figure 7.1 shows the amount of waste that is produced in the three countries. It can be easily seen that Germany is producing the highest amount of waste per person. Within the European Union, only citizens from Cyprus and Switzerland, which is not part of the European Union but within the geographical area of the EU, produce more municipal waste per person. Romania, on the other hand, produced less than 250 kg of waste per person in 2015 and thereby only around 40% of what an average person in Germany produced. In the UK, waste production has decreased slowly since 2006. In 2015, the average citizen in the UK produced 485 kg, which is 9 kg above the EU average of 476 kg (Eurostat, 2017).

However, as can be seen in Fig. 7.2, the little waste that is produced in Romania is primarily landfilled. Over 70% ended up in landfill sites in 2015, compared to around 22% in the UK and almost no landfill in Germany.

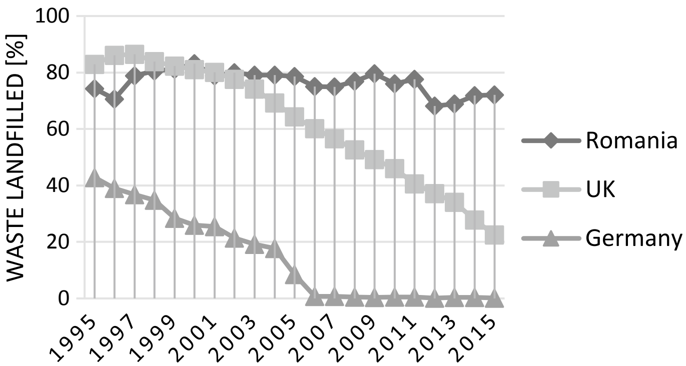

Fig. 7.2 Percentage of municipal waste that was landfilled in Romania, the UK and Germany between 1995 and 2015. *Source* Calculated from data provided by Eurostat (2017)

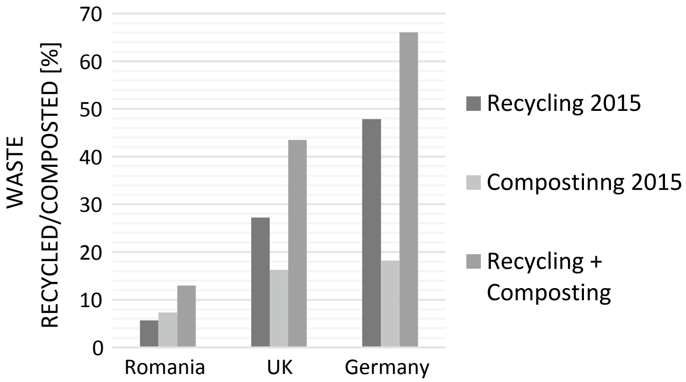

Fig. 7.3 Recycling and composting rates in Romania, the UK and Germany in 2015. *Source* Eurostat (2017)

Equally, Romania has very low recycling and composting rates of less than 10%, as can be seen in Fig. 7.3. In Germany, over 65% of municipal waste is recycled or composted. Germany is consequently one of the countries with the highest recycling/composting rates within the European Union. It has already achieved the EU target of recycling 65% of municipal waste by 2030 (as was specified in the EU Waste Framework Directive).

7.3 Romania

7.3.1 Current Situation Regarding Waste Management

Romania joined the EU in 2007. During the negotiations preceding EU membership, the so-called acquis communautaire (entry requirements) played a key role. In this document, legislation regarding the EU is formally compiled. For Romania, the environmental chapter of the acquis communautaire, of which waste management is one part, was one of the most difficult chapters (Orban, 2006). Before 1989, environmental protection played no significant role in Romania's national legislation. Economic and social benefits were sometimes linked to environmental factors, but there was no public awareness of human behaviour threatening the environment itself (Turnock, 2002).

Waste management in Romania is still a 'work in progress'. While each citizen in Romania produces significantly less waste than do citizens in the UK and Germany (see Fig. 7.1), the little waste that is produced is managed in a manner which is questionable for the environment. Romania's water, air and land quality has been deleteriously affected because of environmental pollution, such as is caused by the smelting of non-ferrous metals, the extensive use of nitrogenous fertilisers, pollution of water resources by the petrochemical industry and improper disposal of waste by the building industry as well as the near universal use of landfill. Human health and environmental standards have declined significantly in some areas as a result (Zinnes, 2004). Moreover, it can be expected that waste production in Romania will increase in the future as a result of Western-style consumption patterns and a higher level of wealth. The European Commission concluded in a working document on the recovery of the Romanian economy after the recession in 2008/09, that higher consumption is first highly desirable to improve the local economy and second is a sign of the improved economic situation of households and the country as a whole (European Commission, 2010). Current research indicates that with the increase in waste production which is expected, the problems associated with waste will equally increase. Inglezakis, Ambãrus, Ardeleanu, Moustakas, and Loizidou (2016) found that there is a severe lack of waste management infrastructure, separation facilities and (at least in some areas) a lack of capacity. Not only the very high percentage of waste that is landfilled is a problem, but in particular small, uncontrolled landfill sites (Orlescu & Costescu, 2013). The 'Operational Programme Environment' for the period between 2007 and 2013 was an EU-funded programme that aimed at reducing uncontrolled landfill sites and the conservation of resources through higher recycling rates (European Commission, 2017). Despite these investments, recycling rates are still low.

The participation of the public is vital in order to increase the overall level of environmentally sound management of waste. By now, it is widely accepted by the Romanian public that waste management is a huge problem impacting the environment and human health (Budica, Busu, Dumitru, & Purcaru, 2015). As many as 82% of Romanians believe that their country is producing too much waste (TNS Political & Social, 2014). If environmental attitudes are considered, a study conducted by Crumpei, Boncu, and Crumpei (2014) showed that most Romanian students have pro-environmental attitudes that were ethically motivated. However, when confronted with a social dilemma, up to 50% of the questioned students chose the option which favoured economic over environmental aspects. Iojă, Onose, Grâdinaru, and Serban (2012) analysed 457 educational institutions (among them pre-schools, primary schools, secondary schools, high schools and special schools) in Bucharest regarding their waste management approach and the available possibilities. The authors found that 49% of the schools did not have segregated waste collection facilities. Around 47% of the respondents reported a severe lack of information regarding waste management. Compared to the other European countries, citizens in Romania are least likely to recycle paper, plastic, glass, hazardous waste, electric and electronic waste and garden waste (TNS Political & Social, 2014).

7.3.2 Romania—Community and School Education

There is little education on waste management in Romania at any level, despite the fact that a range of scientists and legislators have highlighted the need for high-quality environmental education regarding this issue (Blaga, 2010; Petrescu, Ciudin, Isarie, & Nederita, 2010). Luca and Ioan (2014) concluded that 'a big disadvantage that Romania has compared to other European countries is that there is no education […] in the public educational system' regarding separate waste collection. According to the authors, the 'lack of formal environmental education […] is a sore spot with long term effect'.

However, initial educational programmes have been introduced in some communities and in some schools. These normally concentrate on the correct sorting of waste materials and the negative effects of fly-tipping. For instance, the programme 'Every Can Counts' organises information campaigns in public places and schools regarding the recycling of cans to raise awareness of the benefits of can recycling. The organisation also organises a festival in which professional and non-professional artists can show what they have constructed out of used cans (Magsi, 2017). 'Let's do it Romania!' is a non-profit organisation that organises different community events, of which some directly address waste management, for instance, the cleaning-up of areas outside cities on a specific annual 'national clean-up day' where everybody can participate in clean-ups of fly-tipping (Let's do it Romania!, 2016).

Whether waste management is covered in the curriculum at the school level primarily depends on the teachers' interest and the general management of the school. Many schools still lack the possibility to separate waste into different bins (Iojâ et al., 2012). A study conducted by Kolbe (2014) showed that awareness levels are very high among the Romanian student generation. This is in accordance with findings from Budica et al. (2015), who see the generation born up to the year 2000 as being more concerned about waste management. However, Kolbe also found in a questionnaire-based survey that only around 30% of the students separated cans and glass whenever possible at home. One major reason named for this low rate was the lack of specific facilities for recycling.

Currently, there are only a few programmes that address students directly. One very successful programme is the ‘Recycling Patrol’, which was initiated by the RoRec organisation to raise awareness in schools regarding the recycling of electric waste and batteries (RoRec, 2017). School classes can register for this programme and rewards are given to the groups that collect the highest amount of waste materials. In 2017, 95 school classes enrolled in the initiative (Nistor & Nedelea, 2017). RoRec also organises information days for university students, information days for pupils, and electronic media flashmobs regarding recycling electric and electronic waste.

Overall, there are a few education initiatives that focus on waste management at the community and school levels. Further programmes are urgently needed together with an improvement in the recycling infrastructure so that every citizen in Romania is not only aware of the problems associated with waste but also with the options for improving the waste management situation.

7.4 United Kingdom

7.4.1 Current Situation Regarding Waste Management

The United Kingdom joined the European Community in 1973. In the same year, the Community’s First Environmental Action Programme was put into action. At that time, the country was relatively modern and proactive in the area of environmental protection (OECD 2002: 125). Scientists often conclude that this led to a ‘first-mover disadvantage’: because the UK’s environmental legislation was very advanced, it paid little attention to the transformation of EU environmental policy. Possibly as a result of this, the UK had high landfill rates, low recycling rates and almost no composting facilities in the 1980s (Jordan, 2004; Sharp, 1998).

In addition to the Landfill Regulations, which represent a clear-cut translation of the EU regulations, landfill tax was introduced as the first ‘green tax’ in the UK (Morris & Read, 2001) in 1996 to decrease landfill rates. It must be paid in addition to other waste-related fees and thereby reduces landfill by making this method of disposal more expensive than alternative routes of management such as recycling or incineration. While in 1997 over 85% of waste was landfilled in the UK (see Fig. 7.2), this amount has fallen steadily during recent years. In 2015, only around 22% of waste was landfilled while over 43% was recycled or composted. This is not least an achievement of campaigns and initiatives which increased public awareness. In particular, the need to comply with EU recycling and landfill reduction targets increased the effort that was put into environmentally sound waste management (Price, 2001; SLR Consulting, 2015). Since the decision to leave the European Union, some stakeholders have proposed to reject EU waste-related targets (Priestley, 2016).

This would probably retard the further reduction of landfill and inhibit the increase in recycling and composting.

7.4.2 Community and School Education

Most communities had or have programmes which focus on correct waste sorting, waste recycling or waste reduction. Nationwide programmes encompass, for instance, the programmes of the Waste and Resources Action Programme (WRAP). WRAP conducts surveys and publishes reports on recycling behaviour, barriers to recycling, food waste collection and waste reduction. The results of these reports help communities to improve their collection services.

Many UK local authorities are proud of their achievements in the waste management sector. Recycling rates or achievements in landfill reduction are often covered in the local media and communities get some pride from announcing that they had the highest recycling rates in the region. Many councils had or currently have one or more of the following programmes or incentives to increase recycling rates: staff who talk face-to-face with households that do not sort their waste correctly, recycling crews that leave written information explaining why they did not collect waste that was not sorted correctly, newsletters for households, resident surveys and reward programmes for households that sorted their waste correctly. DEFRA carried out a household incentive pilot scheme in 2005/06. Different categories of incentives, namely charitable donations, community rewards, school rewards, personal (non-financial) rewards, prize draws and cash rewards were analysed regarding their effectiveness. The final report concludes that the best solution may in many cases be to offer additional services or infrastructure but that incentives—if communicated correctly—can help to reduce barriers for participating in new or existing schemes. They are therefore useful in 'maximising the efficiency of waste management infrastructure and service provision that is already available to households' (DEFRA Waste Strategy Division, 2006). Holmes, Fulford, and Pitts-Tucker (2014) found an average increase in the recycling rate of 8%, accompanied by a 4% reduction in the landfill in authorities that operated an incentive scheme compared to those that did not.

At the school level, waste management is also well covered. While there is no national curriculum requirement which forces all schools to cover this issue, a range of education programmes exists which are specifically designed for schools and/or teachers. The primary aim of these programmes is to educate pupils as to why recycling and waste reduction are beneficial and what they can do regarding these issues. A range of online resources is available and various educational approaches can be chosen. Roleplay, word search puzzles, the production of artistic objects from waste materials, testing magnetic characteristics and class discussions are proposed and promoted for school classes (The Guides Network, 2017).

Many councils offer free visiting speakers to schools to inform pupils about waste management and recycling—or offer home composting bins for schools at reduced prices. Waste management organisations and consortia equally offer their services for organisations in the education sector (Crawleys, 2017; Veolia, 2017). In some cases, teachers or other educational personal can participate in training courses or the industries provide speakers who visit schools and explain specific aspects of waste management to the pupils. WRAP equally covers education on waste management and provides a step-by-step approach to setting up action programmes at schools to improve recycling rates (WRAP, 2016).

Overall, there is a wide range of community and school education programmes available in the UK emanating from governmental agencies, non-governmental organisations and private companies. While it is difficult to estimate the specific performance of each of these programmes, questionnaire-based research indicates that students in the county of Essex, England are very knowledgeable about waste and recycling. They participate in recycling behaviour and are eager to reduce waste (Kolbe, 2015b).

7.5 Germany

7.5.1 Current Situation Regarding Waste Management

Germany is a founding member of the EU. It has an advanced waste management system in which high rates of recycling and composting and low landfill rates have been achieved. Since December 1991, packaging waste has to be taken back by manufacturers, distributors, or retailers (Bundesministerium der Justiz, 1998). The Duales System Deutschland (DSD) has helped industries to free themselves from their obligation to take back packaging materials. The DSD finances itself through fees for the utilisation of its trademark, the Green Dot. However, it is important to recognise that the Green Dot is not an eco label; it does not identify the packaging materials as being environmentally friendly. Currently, there are approximately 19,000 companies that use the Duales System Deutschland.

Since June 2005, landfilling of untreated waste has been prohibited. Recycling rates are among the highest in Europe. However, waste quantities are equally among the highest in Europe. Each citizen in Germany on average produces around 625 kg of municipal waste. While the German population is still perceived as extremely environmentally conscious and eager ‘to recycle a teabag’ using four different rubbish bins (Schulte-Peevers, 2013), the loss of resources and energy through waste production is immense and the best practice according to the European Waste Hierarchy—waste reduction—is currently not reflected in the waste production statistics. Ironically, 40% of households in Germany believe that their waste production is already at a minimum and that they cannot reduce it anymore (TNS Political & Social, 2014).

7.5.2 Community and School Education

In the 1980s, environmental problems associated with landfill became a widely known problem and many landfill sites had to be cleaned up to limit the negative impact of leachate on the environment and human health (Bilitewski, Härdtle, & Marek, 2013; Köster, 2017). These problems were also covered in schools and led to public awareness of the problems associated with landfill sites. As a result of public pressure, the landfill of degradable waste was completely prohibited from 2005 onwards. In the years that followed, the landfill has almost completely disappeared and recycling and composting rates have increased (Eurostat, 2017). Compared to the extensive treatment that landfill demanded, recycling became a cheap option. Today, waste is managed in a manner which does not pose a threat to human health or the environment. However, few if any community education programmes can be found nowadays concerning waste management.

The city of Duisburg has constructed a waste management trail. Interested citizens can find information on the waste hierarchy as well as practical help and advice concerning waste recycling and waste reduction. Different stops on the trail offer information on recycling and composting techniques and the problems associated with landfill and fly-tipping. The trail is built close to a recycling centre, which can be visited on a guided tour (Expo Fortschrittsmotor Klimaschutz GmbH, 2017).

The federal state of Brandenburg initiated a day of action against the illegal dumping of garden waste in woods and forests to raise awareness of the importance of correct garden waste disposal. A range of flyers and initiatives were provided for the public as part of this promotion. For instance, advisory signs were erected in wooded areas where garden waste was regularly illegally disposed of (Krause, 2014).

The German Railway Network provider DB regularly displays posters at its stations to discourage littering on the railway platforms. It provides bins with segregated compartments for the separate collection of different waste material categories.

Probably as a result of the generally effective and efficient waste management system, the subjects of waste management and waste, in general, have disappeared from the educational curricula. For instance, the curriculum of the Federal State of Baden-Württemberg covers sustainable development in various ways, for instance, in physics, chemistry, biology and geography. However, waste management is only covered very superficially as one aspect of product life-cycle analysis in the school subject of engineering—which is not a mandatory subject in German schools (KM Baden-Württemberg, 2016).

This is a direct result of efficiently working waste management. Waste is no longer perceived as a nuisance or a problem. This was confirmed by a questionnaire that was circulated in schools in Germany. Only 75% of the students clearly stated that waste should be reduced—in similar questionnaires in England and Romania, almost all students perceived the reduction of waste as being an important goal (Kolbe, 2014, 2015b). Moreover, not even half of the German students recycled 'whenever possible', and around one-fourth recycled 'almost never' (Kolbe, 2015a). While this is problematic from an environmental point of view, this attitude also leads to high costs arising for waste management since separate collection at source is not performed.

Currently, only a few cities offer programmes for pupils that focus on waste management. They are not mandatory and it normally depends on the available time and commitment of the tutors or teachers. In the city of Mönchengladbach, education programmes on waste management and recycling for kindergarten and primary school children are offered free of charge (Mags, 2017). In Berlin, an educational institution which is supported by the German Environmental Foundation offers programmes for young children from kindergartens and primary schools. Children can learn playfully which waste materials are disposed of in which bin, which materials can be easily recycled and what the function of the Green Dot is (Trebeß, 2013). In Frankfurt, the local waste management company offers hands-on educational courses for pupils of all ages on waste management and recycling. Students can, for instance, separate different waste materials and produce paper from recycled fibre (Umweltlernen in Frankfurt e.V., 2013).

Overall, there are a few education initiatives that focus on waste management. Other aspects of education regarding sustainable development have started to dominate the curricula in schools, such as renewable energies. While some education initiatives still exist, these normally only occur sporadically. They do not address large parts of the German population or school pupils.

7.6 Discussion

In this chapter, three very different countries were compared regarding their community and school education on the subject of waste management. The three countries demonstrate as examples of the direction that waste management and education on waste management can take. Within this development, Romania is still at the beginning of introducing a functioning waste management system and suitable education programmes. The country joined the EU in 2007 and at that time, environmental awareness played only a minor role. Kerbside collection services and recycling facilities were almost non-existent. Education programmes on waste management are rare and normally organised by non-governmental institutions that do not work for a profit. It remains to be seen how far community and school education programmes will be introduced in the future that can help to increase awareness and participation in recycling schemes. This will be vital to further decrease landfill rates, to safeguard resources and to achieve EU recycling and landfill reduction targets.

The UK is in a transitional state—which is characterised by impressive improvements in the waste management sector: In 2001, the UK still landfilled over 80% of its waste. In less than 15 years, the complete waste management system has been transformed. In 2015, only around 22% of waste was landfilled. Today, a range of educational programmes exist that shall help citizens to further reduce and recycle waste. It remains to be seen whether the importance that is put on education of waste management will continue beyond EU membership.

Germany is at the end of the developmental process: It landfills almost no waste at all and has high recycling and composting rates. Waste management works so efficiently that waste is no longer perceived as being an environmental problem. Hence, it has almost completely disappeared from the educational agenda. While this might seem logical and environmentally beneficial at first glance, a deeper analysis shows that Germany produces extremely high levels of waste. Municipal waste production per person is among the highest in Europe. Evidence from questionnaire-based research revealed that many German students do not see any reason why waste should be reduced—since it is managed so efficiently. This is highly deleterious to the environment. The most important aim, waste prevention, has little priority or backing. It seems unlikely that there will be more importance being put on this issue through community or school education in the near future. While the developments in the waste management sector that took place in Germany led to almost no waste at all being landfilled, these developments triggered a disappearance of relevant education programmes. The few programmes that exist nowadays, some of which were detailed in the current chapter, do not address large parts of the population. There are no national or large-scale programmes that every student or every citizen can participate in. Further improvements that could have been achieved—namely to reduce waste production—are, therefore, unlikely to happen. Moreover, due to the lack of education at an early age, it is questionable whether the current high standards can be kept in the future. There is also a danger of going backward since the problems associated with high consumption patterns and the waste that arises as a result is no longer communicated to the public.

7.7 Conclusion and Future Research

Three different countries were compared in the current chapter. The three countries can be seen as being good examples of the developmental process in the area of waste management and are closely connected to education on waste management. While at the beginning of this development, countries with little waste management infrastructure need to develop educational programmes that interact with the existing or developing waste management infrastructure, this interplay can improve waste management significantly. However, once a certain point is reached and waste management functions well, interest in further improvement declines and education is neglected in favour of other (environmental) issues.

Future research needs to establish ways to further increase awareness of the importance of waste management beyond the point that has been achieved in Germany. Waste reduction is vital and all developed countries should search for options to increase the willingness of citizens and stakeholders to further reduce waste and thereby safeguard resources for future generations. Moreover, best practices for Romania need to be established to increase recycling rates and waste management practices in the whole country. Education in communities and schools is one very important tool—the specific programmes, however, still need to be developed and tested. In the UK, it will be of major importance how far the achievements of the past years can be transferred to the future. Other countries can learn from the example of the UK and consequently promote incentives to improve waste management through educational initiatives.

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Karin Kolbe studied at the University of Sydney, Australia, the University of Essex, UK and at the University of Koblenz-Landau in Germany. She did research in the area of waste management systems in different European countries, waste reduction initiatives and education for sustainable development. She is currently working in the area of education for sustainable development.

Chapter 8
Waste Management Education: Chinese Perspective and Experiences

Yu Huang, John Chi Kin Lee and Y. T. Jin

Abstract This chapter examines education for waste management practices in China. The chapter first entails the introductory section, which outlines the kinds of waste followed by the discussion of waste management policies in some developed countries such as the United Kingdom, Germany, and Japan. Then the current situation of waste management in China is described. Three case studies of ecological schools with practices of waste reduction from various parts of China are analyzed. Overall speaking, waste management and education are strongly supported by international trends of sustainable development, education for sustainable development, sustainable consumption, and education for sustainable consumption. China's waste education is currently subject to the level and needs of waste management, with a focus on waste reduction and classification. The pilot project Waste Reduction Schools as a part of Eco-school project in China shows successful practices on promoting reducing, recycling, and harmlessness of domestic wastes. But in terms of waste education, there is much room for improvement and more measures are suggested for implementation in the future. With the development of Chinese society, waste education can be further promoted to building citizenry behavioral norms and environmental ethics.

Keywords Waste management education · Waste reduction project · Eco-school · Case study · China

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Y. Huang
Beijing Normal University, Beijing, The People's Republic of China

J. C. K. Lee (✉)
The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: jcklee@eduhk.hk

Y. T. Jin
Centre for Environmental Education and Communications, Ministry of Ecology and Environment, Beijing, The People's Republic of China

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8.1 Introduction

For the past few decades, the management of waste has increasingly become a central global issue related to environmental protection and the realization of sustainable development which necessitates insights and inputs from multiple disciplines and collaboration of different stakeholders. Moreover, the success of waste management counts on not only the advancement of technology, the legislation of policies and measures of reducing waste but also on the cultivation of environmental citizenry and the role of school in promoting education for waste management. Waste refers to the disposal of any garbage that is valueless and unrecyclable to the society which is generated from human consumption, social activities and construction work. Wastes are largely discharged from municipalities, industries, and urban construction projects. They can be grouped and classified in terms of its sources, shape, and degree of hazard. Urban wastes are mainly generated from garbage disposals of households, hospitals, business enterprises, and constructions. Each urban citizen on average disposes of 1–2 kg of wastes per day. The amount of wastes disposals is responsive toward citizens' living standard, habit, sense of waste recycling, and social construction work. This chapter mainly focuses on urban waste as well as its management and education. This chapter draws upon international trends of waste management including experiences from the United Kingdom, Germany, Japan, and China. Then the status of school rubbish reduction project in the People's Republic of China would be examined. Finally, case studies of Eco-Schools with practices of waste reduction are discussed in the paper.

Eco-Schools is a growing phenomenon, which encourages young people to engage in their environment by allowing them the opportunity to actively protect it. It starts in the classroom, it expands to the school and eventually fosters change in the community at large. Through this program, young people experience a sense of achievement at being able to have a say in the environmental management policies of their schools, ultimately steering them toward certification and the prestige which comes with being awarded a Green Flag. The Eco-Schools programme is an ideal way for schools to embark on a meaningful path toward improving the environment in both the school and the local community while at the same time having a lifelong positive impact on the lives of young people, their families, school staff, and local authorities.

Other than urban waste, there is an agricultural waste. Using agricultural engineering as an example, the utilization of organic waste (OW) has become an important agenda in worldwide waste management as it is closely linked with the dynamics of the agricultural system (Soliva et al., 2007). For the support of the development of the agricultural system and land management toward equity, stability, and sustainability (Conway, 1985), it requires multidisciplinary research and agricultural education. Farmers and related stakeholders, such as environmental protection bureau officers, students, agricultural co-operative members, industrial production officers, need to get acquainted with new knowledge of plant growth, soil science, and waste transformation technology as well as novel practices of waste reduction, composting, and environmental actions in combating agricultural pollution.

As waste management industries are growing globally, more personnel are involved in the processes of waste collection, treatment, and management (Davis, 2008; Davis & Read, 2007). Therefore, there is a demand and call for education and training. There have been waste management programmes designed by experts and associations. An "integrated waste management (IWM) curriculum" proposed by the National Recycling Coalition in the United States (Conn, 1993) entails four main objectives: developing college or university students' "environmental literacy"; educating IWM specialists; enhancing the training of IWM skills; and providing IWM experiences to nonspecialists. In the United Kingdom, in addition to accredited university courses and modules by the Chartered Institutions of Wastes Management (CIWM), the CIWM offered training courses ranging from "Underpinning knowledge—implications of waste legislation," "The management of refuse collection and kerbside recycling," "Practical management and control of landfill gas," and "Integrated recycling and waste management operations" (Davis, 2008, p. 1871).

Higher education institutions where higher education and research takes place have tremendous potential to promote sustainable development and foster social transformation (Stephens, Hernandez, Román, Graham, & Scholz, 2008). Zhang, Williams, Kemp, and Smith (2011) reviewed why sustainable waste management has become the focus of Higher Education Institutions (HEIs). They took the University of Southampton (UOS), one of the largest universities in Southern England, as an example to illustrate how a four-stage waste management strategy has been developed for more than 15 years for a safe, sustainable, and practically staged solution to manage the waste and protect the environment. At each stage, political, economic, social, technological, legal, and environmental (PESTLE) issues are thoroughly analyzed following the ISB models (infrastructure (I), service delivery (S), and behavior change (B)) proposed by Timlett and Williams (2011). Based on the PESTLE analysis, the ISB model and the waste hierarchy, the strategy for sustainable waste management was developed for HELs to encourage reducing, reusing and recycling.

In basic education, Giovanni (2005) states that a wider spread of environmental education can foster the enhancement of waste management. He further suggests integrating waste education into the current preschool or primary school curriculum. Not only can the 3R education (Reduce, Reuse, and Recycle) encourage children to take part in waste management; it can also raise the awareness of taking up social and civic responsibility to protect the environment by energy conservation and recycling and reducing waste. It is believed possible to become the children's lifelong responsibility and daily practice.

At an international level, the concept of, sustainable consumption and production (SCP) was brought about at the Oslo Symposium in 1994. SCP was referred to the minimization of the use of resources primarily for meeting basic needs as well as the reduction of toxic materials, waste emission, and pollutants "so as not to jeopardize the needs of further generations." (Sustainable Development Goals, n.d.). In 2015, the United Nations (2015) announced the report "Transforming our world: The 2030 agenda for sustainable development" (《新的征程和行动——面向2030》). That report mainly explained the planning and prospects of global development for

2015 and thereafter and in particular “Sustainable Development Goals and targets.” There was Goal 12. Ensure sustainable consumption and production patterns under which it is aimed toward “By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse” (United Nations, 2015, paragraph 12.5). Therefore, different countries could consider implementing waste management and reduction policies and at the same time launching initiatives on education for waste management so as to achieve the future sustainable development goal.

8.2 International Trends of Waste Management

8.2.1 United Kingdom: Leading “Duty of Care” into Waste Management

As one of the top waste-producing countries, the United Kingdom led “duty of care”, which originated from the tort law, into Environmental Protection Act of 1990, becoming one of the regulations in waste management, leading the U.K. to become a pioneer which adopted “duty of care” as a regulation in waste management. Regulated by the Environmental Protection Act of 1990 of the U.K., any importers, producers, carriers, keepers, treaters, or disposers of controlled waste are given “duty of care” to manage the waste properly. After that, “duty of care” was renewed in The Environmental Protection (Duty of Care) Regulations 1991 (The Environmental Protection (Duty of Care) Regulations of 1991), and recently the revised Waste Duty of Care Code of Practice: Statutory Guidance (Department for Environment, Food & Rural Affairs and Environment Agency, 2018)

“Duty of care” in respect of waste imposes a duty on any person, who is involved in controlled waste management to take all measures to make sure the waste is treated recycled safely and sensibly, preventing harmful effects on the environment and human health. “Duty of care” is involved in every part of waste management, from waste production to treatment. Respective parties in different processes, such as collection, storage, recycling, transport, and treatment, are obliged to bear the duty. Overall, “duty of care” is bidirectional, imposing duty on both waste holders and waste receivers.

Basic obligations of waste holders involve the following, namely, identifying controlled waste and providing detailed descriptions on the nature of specific waste, ensuring safety of waste and transporting waste to authorized receivers; meanwhile, basic obligations of waste receivers include making separate collection of recyclable waste, obeying the waste management regulations, and obeying the hazardous and special waste regulations.

In the U.K. waste management system, “duty of care” leads waste management in the U.K. to a sequential and structural development, laying the foundation for structuring and establishment of other systems in waste management. First, “duty of care” prevents contravention of specific provisions of the Pollution Prevention and Control

Regulations, aiming at clean production, which is related to the Environmental Protection Act 1990, regulating waste management problems in financial development. As circular economy promotes in the U.K. waste management legislation, "duty of care" can be refined without contracting to the existing legislative system, leading the U.K. to transform from terminal handling to recycling, from pollution control to pollution prevention, manifesting compliance and vitality.

Second, "duty of care" strengthens the foundation of extended producer responsibility, "duty of care" of different parties involved in the waste management, including producers, importers, carriers, treaters, agents, and traders, is reasonably distributed in terms of waste production, waste transfer, waste recycling, and waste treatment, depending on their effects on environment and human health caused in the process of controlling waste. The rationale of distributing responsibility allows every possibly hazardous party to bear their own responsibility.

Lastly, "duty of care" promotes the collaboration of different parties' involved in waste management, reflecting the principle of collaborative management. On one hand, the market players fulfill their duties to waste management regarding the regulations of "duty of care". Administrative control is not heavily involved when the parties are fulfilling their duties. On the other hand, to set a minimal control by laws for market players and reserve the authority of establishing correction measures and direct intervention when self-regulation and public welfare targets cannot be achieved, the Environment Agency promulgated a number of regulations, such as setting standards of waste recycling and circulation and ways to enduing administrative authorization. With these, proper regulation to market players fulfilling their "duty of care" can be achieved. As regards education for waste management, some organizations or schools have initiated programmes and activities. For example, the project recycling our waste and reducing our landfill was implemented in a school in the U.K. which involved parents, staff, and students and covered the range of measures from providing colored bins for paper, plastic, tin, and card to organizing curriculum-related activities and school assembly as well as using noticeboard and an e-book. The results showed that the annual payment of £15,000 for waste to go to landfill was reduced to £3,500 a year (UNESCO, n.d.a).

8.2.2 Germany: Characteristics and Operation of Electronic Waste Management

Concerning the philosophy of electronic waste management, Germany has been adjusting and working on its ideology in electronic waste management since the 70s. From random disposal, end control to resource regeneration, the idea of material circulation has contributed to the vision and direction of electronic waste management in Germany, which the German relied much on when promulgating new policies.

Concerning the legal system, the recycling, treatment, and management of electronic waste are ensured strong legal assurance by legal provisions in the German government's policy on electronic waste, Waste Management Act and related pollution control measures. In order to embody the management principle of electronic waste, which is to recycle materials, the policy on electronic waste aims at preventing hazardous waste produced by electrical and electronic appliances as well as promoting the ideas of reusing electronic waste, recycling materials and material regeneration in any other forms, so as to reduce the quantity of management of electronic waste and the formation of harmful substances possessed in the electronic waste. According to the differences in management requirements, the end-of-life management of electronic waste involves three objectives, namely, separate recycling of electronic waste, promotion of resources revival, and prevention of damage caused by pollution to human body and environment. Corresponding management tasks, such as reaching and fulfilling the minimum amount of recycling, the rate of recycling utilization and the requirement of pollution control, are configured to achieve the above objectives.

Concerning the recycling of electronic waste, the policy on electronic waste requires electronic waste to be segregated from domestic waste and placed separately. These legislations clarify the responsibilities of respective stakeholders in electronic waste management, safeguarding an effective implementation of electronic waste management in Germany through rules and regulations of states and districts.

Implementing the polluter-pays principle, the German government, while sharing responsibility with the producers, clarifies responsible stakeholders and their responsibilities in recycling, treatment, and management of electronic waste. The standard of measure, clear shares, and a rigorous link among stakeholders, regulated by the producer responsibility, guarantee material regeneration in the circulation of electronic waste. Providing an institutional platform and regulatory support, which are based on law and regulations, sensible collaboration, power, and responsibilities, a complete organizational system is formed by various institutions, namely, the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Federal Environment Agency, state capitals, local government, related environmental protection departments, the local authority waste management services and clearing agencies, and so on.

Regarding the implementation mechanism, identification, distribution, accounting and monitoring of electronic waste management are established depending on the well-developed separate collecting facilities of electronic waste, scientific statistical methods, an effective statistical system and adequate communication. All of these contribute to the separation of responsibilities of electronic waste producers and processors, leading to a beneficial complicity of producer responsibility and marketization of electronic waste management.

Concerning refinement of the policy on electronic waste, communication and exchange of ideas among stakeholders and the feedback mechanism ensure the effectiveness of the policy instruments (Cave, 2017). Both the general public and evaluation of policies are legally involved throughout the processes of establishing and revising laws, regulations, policies, plans, and schemes in Germany. With these, opinions of stakeholders and evaluation of policies regarding the effects of implementation are prevented to be neglected.

8.2.2.1 Operation of Electronic Waste Management System in Germany

The federal states of Germany are the executive party for the Waste Management Act, responsible for the promulgation of regulations of different states and appointment of state administrative departments and the local authority waste management services. State administrative departments are responsible for setting up the rate paid by producers to the local authority waste management services while the local authority services are responsible for management and operation of waste recycling, transport, treatment, and disposal. In order to refine different states' regulations, rural, urban areas and the municipal governments are responsible to promulgate regulations of districts. Examples of such district regulations are clarifying recycling frequency, methods, sites, and payment of fees to name but a few.

Domestic consumers must sort their garbage, separate, and place the electronic waste into collecting containers. They are also forbidden from making agreements with the third party about waste recycling and treatment. According to the principle of extended producer responsibility, producers are responsible for the end-of-life management of its electrical and electronic appliances. In Germany, regarding extended producer responsibility, electronic product producers have to bear their responsibility by doing the following things: attaching a separate recycling reminder label, doing registration, transporting, and managing electronic waste as well as reporting obligation and providing a financial guarantee.

The local authority waste management services, according to the policy on electronic waste, are legal institutions, which are responsible for collecting domestic electronic waste, managing and operating electronic waste collecting sites. They complete their responsibility by the time they transfer the collected domestic electronic waste to its producers or management agents. To be more concrete, the local authority waste management services bear the following obligations: collecting domestic electronic waste, reporting obligation, providing separate storage of electronic waste, and free transfer.

Due to the needs for the establishment of extended producer responsibility (CalRecycle, 2018), clearing agencies are set up under the policy on electronic waste. They are set up for coordinating and monitoring the direction of electronic waste, defining and assigning responsibility to producers as well as monitoring and providing evidence for producers bearing and completing their responsibility.

The best technology should be used for managing electronic waste to make sure the management can achieve the legal recycling and reuse rate. Regarding electronic waste management, the policy on electronic waste, Waste Management Act, regulation for specialized waste management companies and pollution control act provide a related legal basis for different stakeholders.

8.2.3 Japan: Legal System of Waste Management and Recycling

In 2000, Japan established the Basic Act for Establishing a Sound Material-cycle Society (Basic Recycling Act) (Ministry of Environment, Japan, 2014). In addition to the Green Purchasing Act (2000), different laws were established involving the Act on the Promotion of Sorted Collection and Recycling of Containers and Packaging (Containers and Packaging Recycling Act, 1995), the Act on Recycling of Specified Kinds of Home Appliances (Home Appliance Recycling Act, 1998), the Act on Promotion to Recover and Utilize Recyclable Food Resources (Food Recycling Act, 2000) and Act on Recycling of Construction-Related Materials (Construction Recycling Act, 2000), to name but a few. The promulgation and establishment of the Home Appliance Recycling Act were a pioneering case worldwide, indicating the existence of law/act and a well-constructed management system (Ministry of Environment, Japan, 2014). In 2003 and 2004, Japan introduced the Environmental Education Promotion Law and the Environmental Awareness Promotion Law respectively (Regional 3R Forum in Asia and the Pacific, 2009). The Japanese government and local provinces devoted a lot of efforts to promote students and citizens' environmental awareness and behavior (Lee, 2010).

Using electronic waste as an example, producers, sellers, and consumers of electrical and electronic appliances are equally responsible for material recycling. Consumers will be heavily fined if they are found illegally disposing of the electronic waste, such as burying and throwing the waste away privately. This kind of after payment involves consumers since they also gain benefits and consume energy and resources when using the appliances they buy. Also, consumers' sense of management and recycling of electronic waste can also be fostered through taking part in the process of recycling and reuse of electronic waste, carrying out environmental education for the general public.

To examine the effect of the implementation of Home Appliance Recycling Law, the Association for Electric Home Appliances is the responsible organization. Regarding the operation of electric waste recycling, the home appliance recycling coupon system is established. Regulating the operation of recycling and reusing four types of electronic waste, the Home Appliance Recycling Coupon Center (Recycling Ken Center, RKC) is responsible for the system.

Besides the regulation of the Association for Electric Home Appliances, social media also plays a role in examining the implementation effect of electronic waste management. Environmental conservation highly promoted in the society, it takes up an important part in the media, newspaper, on the Internet and even in advertisements. Japanese citizens are highly concerned and involved in environmental conservation because of the serious environmental pollution, leading to man-made diseases, which happened years before. Owing to the environmental education of electronic waste management, most of the electronic waste collecting sites entertain citizens to visit. High school students and families are all welcome to go and the working staff will introduce the legal system and flow of electronic waste management in detail using

PowerPoints, and even lead the students to visit the disassembling sites while explaining every step of disassembling and even every type of valuable disassembled part. The success of waste management and recycling in Japan counts on not only the policies and infrastructure but also the linkage of initiatives with schools and communities. For example, school lunch leftovers are arranged for composting and direct communication of source separation of waste messages involving communities and schools are highlighted (Hotta and Aoki-Suzuki, 2014).

These above-developed countries showed that waste management and reduction has been placed at a priority with the enactment of laws and support of technology and community participation. School education is an area which deserves attention and now we turn to.

8.2.3.1 The Role of Education for Waste Management

Education for waste management plays a significant part on both environmental and sustainable development education. Environmental education lays emphasis on the aspect of personal and organizational changes in knowledge, skills, experiences, attitudes, and behaviors which also include the education about environment, education in the environment and education for the environment (Tilbury, 1995). According to the UNESCO (n.d.b), educations for sustainable development (ESD) sanction learners to make knowledgeable decisions and responsible actions for developing a society involving environmental quality, sustainable financial development, respect, and equity. ESD is all-around and transformative education which puts emphasis on learning content, pedagogy, learning environment, and the changing society.

Concerning the content, waste management education involves sustainable consumption and production (SCP), addressing student-centered and interactive learning, owing to transformative learning which based on exploration and action. The societal transformation allows people to lead an environmentally friendly and sustainable life through lifelong learning and practice. Consequently, a behavior of reducing, recycling, and reusing can be fostered, equipping people with skills for green jobs and leading to greener economies and societies (UNESCO, n.d.b). This transformation of green education draws attention to critical and systemic thinking, collaborative decision-making skills and bearing responsibility for the present and future generations (Lee, 2010).

Taking Taiwan as an example, environmental education in primary school is comparatively desirable (Lee, Wang, and Yang, 2013). While in secondary school, environmental conservation in life is addressed (Wang, 2004, pp. 91–92), “recycling, reducing lunch boxes and reusing resources” are some of the activities organized. However, there are still differences in schools, some schools rather join the volunteer scheme organized by the Environmental Protection Bureau. Students participate in cleaning and recycling in the neighborhood, promoting environmental education in regions.

In addition, taking Hong Kong as an example, different environmental conservation campaigns have been organized. A campaign “Reduce Your Waste and Recycle

Your Plastics Campaign 2012" was jointly organized by the Environmental Protection Department (EPD), the Environmental Campaign Committee, the Education Bureau and Yan Oi Tong EcoPark Plastic Resources Recycling Centre (Waste Reduction and EcoPark Group Environmental Protection Department, 2011). Aiming at raising students' awareness of waste reduction, students are encouraged to participate in the campaign with their families. Moreover, EPD also collaborated with CECTL Child Education for Teaching & Learning to launch the Early Childhood Education Pilot School Campaign "Prevention First before Reuse and Recycling", aiming at cultivating a green culture starting from the younger generation by delivering the 3R concepts, which are "reduce, reuse and recycle" (Child Education Centre for Teaching and Learning, Hong Kong Institute of Vocational Education, n.d.).

Waste reduction education and campaigns are being held all over the world. Since 2001, Canada has been running the Waste Reduction Week, which is a national-level waste reduction campaign, owing to increases awareness of schools and the public toward sustainable and responsible consuming behavior, waste management, and preservation of the environment and natural resources (Waste Reduction Week in Canada, n.d.b) Waste Reduction Week is held in October every year, supported by numerous environmental organizations. Organizations provide support to the campaign by holding different activities and offering resources, to mention but a few, providing educational resources for schools, teaching the schools and students' families to pack a waste-free lunch, leading students to pay a visit to a material recovery factory and encouraging schools, families, and offices to join a recycling scheme named Terra cycle Canada. In the U.S., the Wisconsin Department of Natural Resources (2012) provides schools with a guide on recycling and waste reduction. In Wisconsin, electrical and electronic appliances like calculators, printers and televisions are illegal to be incinerated or put in the trash. To promote the sense of recycling, the E-Cycle Wisconsin program is advocated in schools and districts, suggesting schools to set goals related to the waste prevention, donation, and recycling (Wisconsin Department of Natural Resources, 2019). Besides, Sustainability, Victoria and Victoria State Government (n.d.) encouraged the seven-step development of "Waste Smart Schools" under "Resource Smart Schools" (Sustainability Victoria and the Metropolitan Waste and Resource Recovery Group, 2016) which echo some similar five-step procedures such as waste audit/assessment, action plan and review promoted by "Recycling and Waste Reduction" school guidelines (Wisconsin Department of Natural Resources, 2012).

8.2.4 Awareness of Waste Classification and Reduction in China: Current Situation and Policies

China has initially formed a series of laws and regulations based on the basic laws such as the "Circular Economy Promotion Law", the "Clean Production Promotion Law" and other special laws such as "Solid Waste Pollution Prevention and Control

Law" (hereinafter referred to as "Solid Waste Law") as the basic framework for waste management, which is also supplemented by other laws and policies of the waste management legal system. In the special legislation on waste management, China has adopted "safeguarding ecological security" as the legislative objective for the "Solid Waste Law" revised in December 2004 for the first time. It is clearly stated that the country is adopting the circular economy strategy through the introduction of Producer Responsibility Scheme, Compulsory Recycling System, and Solid Waste Import Classification Management System so as to preliminarily establish a waste management system. It can be seen that China has reached some consensus with other developed countries on sustainable waste management. First, China has realized the serious damage caused by throwaway culture and waste pollution as well as the importance of "turning waste into treasure." The principles of circular economy "reduce, reuse and recycle" has in fact been legislatively practiced that end pollution control system has been implemented. Second, China has established a relatively sound waste management system that is supplemented by an administrative licensing system, sewage charges, producer responsibility scheme, government's incentives, public participation system, to ensure the implementation of waste recycling.

However, there are still some problems with waste management in China. The strategy that mainly remains in the field of operational management and industrial management is yet to be in line with the market and social management. The market mechanism of waste disposal is also yet to be comprehensive and spontaneous. Without a sound waste recycling market, the recycling of waste will come to an end in a "no-sale-and-yield" way. Other than that, the focus of relevant laws and regulations are primarily on solid waste disposal and recycling of resources, rather than on course control over producers and sellers. The missing of a clear waste hierarchy has limited the operation of waste management. As regards education for waste management, the main approaches in China are to infuse the ideas of waste classification, reduction, and recycling through informal science education, tourism education, city district activities as well as extracurricular activities, integrated activities in school and school-based curriculum. Some education initiatives are discussed as follows.

The Litter Less Campaign is a joint initiative of the Wrigley Company Foundation and FEE, and was initiated in 2011. The Litter Less Campaign is implemented in schools through the Eco-Schools and/or Young Reporters for the Environment (YRE) programmes. It aims to engage and educate children and young people on the issue of litter, and encourage them to make positive choices. As a full-member of FEE, Centre for Environmental Education and Communications of the Ministry of Ecology and Environment (CEEC) implements education programmes of FEE in China exclusively. From 2011 to 2016, selective schools in China, nominated by CEEC were asked to promote and implement such project. (Eco-Schools, n.d.a)

In the domain of conducting waste classification and environmental educational activities on waste reduction throughout schools, the project could not only enhance teenagers the knowledge and ability in handling wastes as well as its reduction, but also drew positive impact toward families and communities in promoting recycling of resources. It served an important role in demonstrating and leading the society toward household waste reduction and recycling enhancement by simply imposing the waste classification.

8.3 Overview

All through the past 6 years, an average of 502 kg wastes have been reduced for every semester from each school with highly high participation from 24 provinces (including autonomous regions and municipalities), and approximately 300,000 teachers and students of 195 primary and secondary schools.

Students and teachers should have a better understanding of environmental and social issues were wastes occurred from their participation as well as improving their knowledge and ability in reducing waste productivity and possessing effective waste management. Throughout the implementation project, schools collaborated and exchanged views on different issues and thus fostered the establishment of education for sustainable development (ESD) further (Table 8.1).

Table 8.1 Distribution of schools participated in the Litter Less Campaign in China (Data from CEEC, and prepared by the co-author Ms. Jin Yuting)

Province	No. of schools participated in waste reduction project
Beijing	7
Anhui	2
Chongqing	3
Guangdong	26
Guangxi	3
Guizhou	1
Hebei	11
Henan	2
Heilongjiang	15
Hubei	9
Hunan	1
Jilin	1
Jiangsu	24
Jiangxi	4
Liaoning	2
Inner Mongolia	4
Shandong	26
Shanxi	3
Shanghai	22
Sichuan	5
Tianjin	10
Xinjiang	1
Yunnan	5
Zhejiang	8
Total	195

8.4 Implementation Strategy

Students were encouraged to conduct activities of Eco-Schools under the theme of waste reduction, by following the methodology of "Seven Steps towards an Eco-School" with teachers' guidance. The key points about the individual steps (Eco-Schools, n.d.b) are listed as follows:

1. Establish an eco-committee.
2. Conduct an environmental review.
3. Implement an action plan.
4. Monitor and evaluate the results.
5. Integrate with the curriculum work.
6. Inform and involve the stakeholders.
7. Develop an eco-code.

Taking an eco-committee of a primary school located at Shandong Province as an example. Its membership comprised of school management bodies, teachers, parents, and social representatives. Student members from the committee formulated an action plan with the review of campus environmental issue before launching the "Waste Reduction, Waste Recycle" activity. They proposed setting up a waste collection box and monthly monitoring the total weight of the recycled waste. In addition, they actively promoted families and communities the benefits of recycled waste. For the school, teachers were highly appreciated in educating their student's environmental issues during teaching, especially for subjects of language, mathematics, and visual arts. Last but not least, an Eco code was produced after various meetings, discussions, and modifications. It was necessary to continuously implement and improve subject to social trend.

Students and teachers were enhanced in the knowledge and ability related to the aspect of waste classification and reduction after their participation. They could join hands together and serve as a role model for families and societies to further promote waste and environmental awareness.

8.5 Case Study of Waste Management in China

According to the submission materials of Eco-schools to the CEEC, The People's Republic of China, three examples were chosen for illustrating waste management education in schools.

8.5.1 Case Study 1: Guangdong Primary School

School A is a primary school in Guangdong Province, the southern part of China which aims to establish itself as an international eco-school. One of the projects is "Action for reduction of rubbish." Seven steps, in line with the eco-school protocol, are adapted to drive the classification of rubbish and reduction of rubbish (Eco-Schools, n.d.b): (1) forming an eco-committee; (2) conducting an environmental review; (3) formulating an action plan; (4) monitoring the progress and evaluating the outcomes; (5) linking with curriculum work; (6) informing and involving school and community; and (7) producing an eco-code.

School A started the practices of sorting rubbish into different types and reducing the amount of rubbish since 2003. Every year, students are mobilized to utilize lucky red packets and moon cake boxes collected during the Chinese New Year and the mid-autumn festival, respectively, for creating artifacts for display in school. After the display, these old exhibits were destroyed at the technology lessons to make recycled paper for students to use in visual arts lessons. Through these activities, students were encouraged to make use of recyclable materials. At the same time, teachers adopted a paperless office policy and used electronic files and communication for daily business and operations. Used envelopes and teachers' handbooks were also recycled for a second use. The trash in the school kitchen was transformed into renewable resources. School A has also taken into account the situation of fallen leaves and food waste and bought machines for their treatment onsite. The school also established a "storage place for hazardous rubbish" for collecting used light pipe by electrician master, mercury thermometer and expired medicine by the school doctor, waste electronic appliances and printer cartridges by information technology teachers and maintenance company officers, respectively. This hazardous rubbish would then be managed by the school's General Affairs Office for their delivery and treatment by professional companies. Colleagues also kept a record of the amount of other kinds of rubbish collected each day from the established collection pool in school and then transferred to the nearby street collection station managed by the local government's environmental hygiene unit.

As regards student participation in environmental education activities, the school set up an eco-school committee and each class is represented by one student either through self-nomination, recommendation or election. Then at the school level, each eco-school committee student member was elected by at least more than 50% of class representatives. The eco-school committee also consisted of representatives from school management, teachers and parents as well as community members and local environmental organizations. While teacher and other representatives were mainly responsible for tasks such as the implementation of environmental education activities and infusion of environmental education elements into the school curriculum, student representatives were tasked for collecting other students' views of improving the environment and organizing activities and communicating the decisions of the eco-school committee to all class and grade representatives in the school.

In 2013, a competition was organized to select exemplary families in classifying rubbish and as a result, more than 500 families were chosen to be recognized. An eco-code was also formulated through the concerted efforts of teachers and students and selected through more than hundred eco-code submissions. The selected eco-code highlighted that “rubbish classification being a scientific task, rubbish reduction being a collective effort, plastic waste not being thrown away and being recollected for re-use; treasuring the food and don’t waste, reducing food waste; hazardous rubbish not thrown away and combating white pollution.” School A also made liaison and established networks with other schools promoting cross-school endeavors in reducing energy consumption and emission. The positive results revealed that the amount of recycled materials increased from 170 kg in March 2012 to 205 kg in June 2013. Other rubbish was reduced from 110 barrels to 92 barrels during the same period.

8.5.2 Case Study 2: Beijing Primary School

School B was a city-level environmental education school and green school. It has been recognized as a school with teachers and students having high environmental consciousness and awareness of saving energy. In order to enhance the overall level of environmental awareness and behavior, the school decided to become a “Saving School”. The following measures have been adopted. The first approach pertains to the establishment of a leadership team with clear responsibilities for various teams within the school. For efficiently and effectively promoting the classification and treatment of rubbish, a leadership team was set up led by the Principal as the chairperson in charge of teaching and learning and Vice-Principal as the Vice-Chairperson in charge of general affairs and logistics as well as heads of the departments of teaching affairs, general affairs, moral education, and project leader as members. This leadership team enables coherent planning, construction, propaganda education for waste management and reduction as well as facilitates collaborative action, consolidation, and review, clear division of labor and responsibility (Table 8.2).

In the second school, the researchers conducted an evaluation of the utilization of resources in school environment, the extent of meeting stakeholders’ needs and contribution of school endeavors to the enhancement of local environment. Based on the evaluation results and past school achievements in green education, a rubbish classification system and its implementation details are set up: (a) rubbish classification: categories of rubbish bottles, aluminum foil package, paper, and waste; (b) collection time and venues: separate collection and distribution of different rubbish and nonrecyclable rubbish centrally managed; and recyclable materials sent to school rubbish collection point on every Thursday; (c) Income of recycling would be sent back to each class; (d) check of rubbish recycling: The performance of each class including its cleanliness would be scored for interclass competition. The environmental group would check regularly every afternoon. If a class has incomplete sorting of rubbish according to categories, scores of that class would be deducted and immediate onsite

Table 8.2 Division of labor and responsibility within the leadership team (Data from the submission materials of Eco-schools to the CEEC)

Chairperson and members of the leadership team/department	Main role in waste management and reduction
Principal	Overall coordination; Responsible for mobilizing all staff and students Clearly defining different department's relevant tasks and realizing whole-school planning Responsible for securing and providing funding and venues for activities
Cadre Party Office	Coordinate and monitor the tasks of all departments and offices; Responsible for tasks of regular research, checking, and consolidation as well as managing raw data and documents Responsible for consolidating reports
Moral Education Office	Responsible for promoting environmental education for staff and students Organize various activities including talks and exhibition with a view to cultivating a culture that is conducive to fostering green concepts among school members Ensuring the cleanliness and hygiene of school campus and classrooms as well as central treatment of rubbish; reducing pollution of the of school campus and neighboring environment
Teaching Affairs Department	Responsible for infusing environmental education elements into school subjects, their teaching plans and teaching resources
General Affairs Department	Providing support for activities and tables/forms for keeping records

sorting and checking needed to be done before allowing waste to be put into the rubbish bin; (e) Implementation: the school campus provided different zones of garbage disposal responsibility so that each class would collect and classify different categories of garbage in designated sites while leaves, tree branches, weeds, and wooded products would be treated centrally.

The second approach to education for waste management and reduction in school B was propaganda education and training for staff and students. In a weekly assembly, teacher delivered a speech covering the school's environmental situation and the importance of rubbish classification. Other related messages were disseminated through school broadcasting, noticeboard, poster, and blackboard display. Videos were shown in the teaching and learning web links to educate students about the appropriate manners of throwing garbage, the importance of reducing rubbish, recycling rubbish as a resource and making rubbish nonhazardous. Through different activities such as quiz competition and talks as well as participation in rubbish collection and treatment, students developed better awareness and knowledge of waste management as well as engaged in reducing the rubbish.

The third approach was to implement rubbish reduction, recycling, and other measures of reducing energy. Staff and students had developed a routine to classify and throw rubbish according to three types into different kinds of rubbish bin: the first type as waste paper, used books, and newspapers; the second type as plastic bottle and bags as well as cans; the third type as nonrecyclable materials. The first and second types could be recyclable and their amount was recorded. Other types would be disposed of immediately. An environmental protection association was also set up by students through election and student "Little Environmental Guardian" was involved to guide students for garbage disposal. Regular monitoring by "School Environmental Cleanliness Inspection Team" was conducted to ensure environmental cleanliness and environmental actions of staff and students. Rubbish collection and classification was extended to school to families and an activity "I talk with my parents on environmental protection" was organized as part of the green education programme. The school also required students to go with their parents to visit an ecological education centre during the weekend or vacation. Comments or ideas were put forward through the collaborative efforts of students and their parents in reducing the rubbish and enhancing the environmental cleanliness (less spitting and sticky glue everywhere) in the tourist area and the school campus. In addition, School B signed an agreement with the local resident committee on "providing students an activity base for community service" so that students could be actively involved in the local community services for promoting environmental awareness and action and enhancing environmental cleanliness.

8.5.3 Case Study 3: Chongqing Primary School

School C conducted its waste reduction programme by implementing various policies and actions on 11th December 2016. To build up students' sense of environmental knowledge as well as the concept of waste classification, the school extensively worked on the promotion, education, and advocacy of such kinds of messages through different means, such as campus broadcasts and window showcases. Students were highly expected to participate in the programme such that they are competent enough to realize the importance of waste classification from the understanding of the drawbacks of wastes to the society. They should have the ability to perform waste classification in a routine manner. In addition, the school also arranged promotion and training of waste classification on a class-based level. Students were asked to conduct discussions with peers by using the data collected from the internet or observation. They could make use of this opportunity to exchange ideas and share information with each other. Awards were presented to outstanding classes for their great achievements.

It is necessary to widely conduct waste classification through practical issues. The school was suggested to design and implement such kinds of programmes with reference to students' ability. Different forms of programmes could facilitate more ideas, which imperceptibly generated a positive impact on environmental responsibility toward students.

Students were asked to classify wastes and place in the correct trash when disposing of in schools. Meanwhile, recycled waste bags or boxes were set up in each classroom for classification convenience. For instance, students could send the glass bottles to the waste collection point after consuming and collect monetary return for operation funding of class activities. Students were not only benefited from monetary terms, but also created their sense of environmental responsibility by doing actions good for the environment. On the other hand, the school could spend fewer expenses on the disposal of wastes and utilize more resources in recycling instead. As a result, pollution from wastes could be reduced. Conducting waste classification and reduction programmes in school could bring up students' sense of environmental responsibility and encourage 3Rs comprehensively. Each of us should have the role to join hands together and create a green society for a better living environment.

It was appreciated that there was a significant impact to waste reduction after a semester trial in the third School. Rewards were presented to awardees with outstanding performance. Students were encouraged to continuously support waste reduction and build a clean and comfortable environment in the future.

8.6 Analysis

The Environmental Education Unit of An Taisce was entrusted by Foundation for Environmental Education (FEE) and Wrigley Company Foundation in 2015 to conduct an observation on waste issues for 22 countries and 530 Eco-Schools (including 30 of those in China), there were 1,790 questionnaires received and (O' Mahony & McGroarty, 2015). As regards China's student scores on knowledge and perception and less littering, it ranked high among 22 countries. In addition, China's student scores on opinion leadership ranked the highest among all surveyed countries, revealing that students paid a lot of promotion and leadership efforts on less littering and more recycling. Below the table illustrated the pattern of some findings (Table 8.3).

Compared with some developed countries and places such as Wales, Australia, Canada, China's scores on average perception, average behavior, and average opinion leadership tended to be higher than their Western counterparts such as Canada and the United States. Nonetheless, it is noteworthy that relatively speaking, the average behavior score on recycling is slightly lower than their western counterparts.

The majority of eco-schools implementing environmental education in China were following the project planning and strategies on Eco-School formulated by The Foundation for Environmental Education (FEE). The methodology of "Seven Steps towards an Eco-School" was proposed in the project that aimed at paving the way for schools to carry out environmental education and education for sustainable development (ESD). On the other hand, different municipalities have implemented different kinds of education for waste management under the advocacy of China's government toward the goal of sustainable development. There are three main approaches. The

Table 8.3 Average ratings on students' perception, behavior and opinion on less littering and more recycling

Country	Average scores on knowledge and perception	Students' average behavioral ratings on waste reduction from selected countries			Students' average opinion leadership ratings on waste reduction promotion from selected countries		
		Behavior score on littering (BSL)	Behavior score on recycling (BSC)	Behavior score on both (BC)	Scores on littering (OPL L)	Scores on recycling (OPL R)	Combined scores on both (OPL C)
Wales	0.67	0.84	0.82	0.83	0.46	0.48	0.48
Australia	0.67	0.85	0.78	0.82	0.47	0.44	0.47
Canada	0.68	0.80	0.88	0.84	0.45	0.45	0.47
United States	0.75	0.84	0.79	0.82	0.47	0.48	0.50
China	0.86	0.86	0.76	0.81	0.67	0.68	0.70

Sources

Table 13 Survey 1 (S1) Average Perception Score (PS) per Country. O' Mahony and McGroarty (2015). Litter less Evaluation Summary Report. Ireland: Environmental Edu. Unit, Ireland

Table 14 Survey 1 (S1) Average Behavior Score per Country. O' Mahony and McGroarty (2015). Litter less Evaluation Summary Report. Ireland: Environmental Edu. Unit, Ireland

Table 15 Survey 1 (S1) Average Opinion Leadership Score per Country. O' Mahony and McGroarty (2015). Litter less Evaluation Summary Report. Ireland: Environmental Edu. Unit, Ireland first approach is to establish some exemplary schools to demonstrate ways of collecting and classifying daily living waste as well as to cultivate a good mechanism and habit for waste reduction. The second approach is to enhance student understanding of waste management through school-based environmental science thematic activities which encourage and engage students as ambassadors to design ways of reducing and recycling waste. The third approach is to arrange social practice and volunteering activities, which facilitate students to visit related institutions and participate in community waste reduction and propaganda activities.

8.7 Concluding Remarks

Despite continuous efforts over the past years, waste education in China is still in its initial stage. "Reduce", "reuse", and "recycle" (3Rs) were emphasized in environmental education. Furthermore, there could be a possibility that schools can consider adding more elements matching with "economic", "ecological", and "equitable" (3Es) with the 3Rs in educating students for promoting green consumption, so that they can have a more understanding on the way of protecting the environment. For example, choosing to use environmentally friendly products can bring less harmfulness and pollution to the environment. In addition, schools can consider practicing waste education from the aspects of four pillars of becoming "toxic-free", using "resources sustainably", producing "a green and healthy space" and integrating teaching, learning, and student engagements as becoming a healthy and sustainable school (Green Schools Initiative, n.d.).

Given that China has fast economic growth and commitment to achieve the goals of sustainable development in future, China could learn the good practices and adopt innovative approaches from other advanced economies through the provision of funds and resources as well as formulation and execution of waste management and related educational policies. There is already a good foundation at the policy level as keywords such as scientific outlook on development, environmentally friendly society and ecological civilization have been disseminated in official documents (Wang, 2012). Nonetheless, there is scope of enhancement of China's environmental citizenry through the following approaches: leading by examples and establishment of exemplars which reveal the realization of basic concepts of waste management education; infusing the ideas of sustainable consumption and production into existing curriculum across levels of schooling and teacher education programmes; promoting multidisciplinary approaches and multiple partner collaboration in research and development of innovative education for waste management; and enhancing opportunities of social participation and service learning as well as intergenerational learning especially through community- and district-based activities.

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Huang Yu is an Associate Professor in the Institute of International and Comparative Education at Beijing Normal University. He received his Ph.D. in Comparative Education from Beijing Normal University. His research interests cover fields like environmental education and education for sustainable development, higher education and sustainable development, geographic education, and tourism geography. He has published extensively in Chinese journals on his fields. His professional career outside of academia includes writing and editing textbooks and popular science books for a variety of publishers. He has also served consultancy to international NGOs.

John Chi Kin Lee JP, Vice President (Academic) and Chair Professor of Curriculum and Instruction, joined The Education University of Hong Kong (EdUHK) [formerly known as The Hong Kong Institute of Education (HKIEd)] since 2010. He is also the Director of the Centre for Religious and Spirituality Education (CRSE), Co-Director (Research) of the Centre for Excellence in Learning and Teaching (CELT), and Co-Director of the Centre for Education in Environmental Sustainability (CEES). He was Dean of Education and Professor of Department of Curriculum and Instruction at The Chinese University of Hong Kong (CUHK).

Y. T. Jin is Project Manager of Center for Environmental Education and Communications of Ministry of Ecology and Environment of the People's Republic of China. She took in charge of Litter Less Campaign, a waste management programme in Chinese schools. She graduated from the Department of Geography of Beijing Normal University and have been engaged in public environmental education in the Mainland China for more than 10 years. Her work especially focuses on environmental education for school children.

Chapter 9
Waste Management and Recycling Education in Taiwan

Tzu-Chau Chang and John Chi Kin Lee

Abstract Taiwan has implemented waste management and recycling education in schools since the 1980s and been recognized with her higher recycling rate than many developed nations worldwide, as reported by the Wall Street Journal in 2016. This chapter reviews the projects and policies of Environmental Education to investigate their impact on school waste management and recycling education in Taiwan. These influential projects include the Green School Partnership Network Project, Sustainable Campus Project, Environmental Protection School Award, and the National Environmental Education Award. Important policies are the Grades 1–9 National Curriculum Framework, Environmental Education Act and Grades 1–12 National Curriculum Framework. The chapter indicates that the development of waste management and recycling education in Taiwan consists of different stages: schoolyard cleaning activities; garbage classification and recycling; environmental management of school, curriculum and teaching; and practical practices in daily lives. The chapter concludes a set of waste management and recycling education elements: being relevant to daily life and achievable goals; following the global trend of environmental education; applying a systematic operation and a whole school approach; infusing waste management and recycling into the school curriculum and over-all learning; and considering responsibility and sustainable development. The chapter also proposes with a strategy for waste management and recycling education in schools: offering incentives, such as reducing costs of waste disposal, encouraging learning through activities, building networks to share and promote recycling education, infusing waste management and recycling into the school curriculum, awarding for systemic operation, and applying the whole school approach to recycling education.

Keywords Recycling education · Environmental education · Environmental education act · Green school partnership network · Sustainable campus project

T.-C. Chang (✉)
National Taiwan Normal University, Taipei, Taiwan
e-mail: tzuchau.chang@gmail.com

J. C. K. Lee
The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: jcklee@eduhk.hk

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9.1 Introduction: Background

Recycling in Taiwan has been recently highly praised by a number of journal reports (Global Citizen, 2016; Taiwan Today, 2016; Chen, 2016). In "The World Geniuses of Garbage Disposal," the Wall Street Journal highlighted Taiwan's brilliant recycling rate of 55%, surpassing the U.S.'s 35% and keeping abreast with a few other high recycling rate countries. The journal also used the subtitle "How the island, with landfill not far from capacity, became one of the world-wide leaders in recycling" to describe the endeavors of the Environmental Protection Administration (EPA) Executive Yuan in Taiwan and its local governments to build a waste management system and recycling operation. Statistics demonstrate the great recycling achievement of Taiwan, in which daily waste disposal per person decreased from 1.143 kg in 1998 to 0.387 kg in 2013, waste recycling rate increased from 5.9% in 1998 to 55% in 2015, and lead battery recycling increased from 68% in 2000 to 95% in 2014 (Chen, 2016).

Most reports have agreed that Taiwan's successful recycling performance is due to good policies, such as the introduction of the 4-in-1 Recycling Program of the Recycling Fund Management Board, and government-certified bags for the general disposal of household waste. The cost of a bag ranges from NT $1 to NT $43 for smallest to largest, respectively. In Taiwan, residents segregate trash into the following: general refuse, most of which is incinerated; kitchen waste, which is composted or fed to pigs; and recyclables, which includes cans, papers, and bottles.

Recycling education has been successful in Taiwan. The EPA Executive Yuan in Taiwan was established in 1987. Environmental education has since become an official duty with a certain budget and personnel in collaboration with the Ministry of Education. In 1998, the National Environmental Protection Plan was issued (EPA Executive Yuan, 1998). Section 11 on "environmental education and communication," stated that while the public's or students' environmental awareness of resource recycling and environmental cleanliness has been enhanced, realizing such awareness into daily practices and habits remains necessary. This chapter suggested that the government and waste recycling industries could jointly communicate the treatment and recycling of garbage into two types of resources and non-resources (EPA Executive Yuan, 1998).

Taipei's waste reduction achievements have surpassed those of other counties. In 1996, Taipei City led the policy implementation for keeping trash off the ground and organizing trash pick-up times and locations. The Per Bag Trash Collection Fee Policy was implemented in 2000, reminding citizens of the "polluter pays" principle and compelling them to exert increased effort for recycling and waste reduction. Since then, trash volumes decreased annually, dropping to 21% from 1999 to just 0.86 kg of waste per day per person in 2013. The recycling rate increased from just 9.78% in 1998 to 43% in 2013. This kind of environmental-friendly behavior catered to Taiwan's good reputation. The Hong Kong Special Administrative Region Central Policy Unit (2014) commissioned a report by the Chung-Hua Institution for Economic Research to evaluate the Taiwanese government's endeavor in advocating waste reduction, addressing climate change, and enhancing environmental industries. Relative to Taiwan's significant achievements in the aforementioned aspects, Hong Kong is recommended to consider the following: increasing the government's subsidy of recycled waste; improving the support for collection points and recycling/waste treatment facilities; enhancing environmental policy and education; and leveraging community resources through collaboration with environmental groups.

9.2 Waste Management and Recycling Education in Schools: International Perspectives

Municipal solid waste is an environmental challenge that emerged from urbanization and is encountered in many South Asian countries. Waste management education or solid waste management projects have been implemented in Southeast Asia to raise the environmental awareness of community members and students and to enhance their environmental behavior for reducing waste. Examples include the 3R project, which targets elementary and university students, as well as local residents in Hanoi, Vietnam; a community-based waste management project in Jakarta city, Surabaya, Indonesia; and a school waste bank in Thailand, as well as pilot projects at the University of Philippines and at a university in Malaysia (Hoang & Kato, 2016). Through the 3R project in Vietnam, elementary students enhanced their knowledge and concepts on "organic waste," "inorganic waste," and "recyclable and reusable waste" (Hoang & Kato, 2016, p. 285). These initiatives include limitations, such as student performance was not included as part of students' assessment and a lack of an official waste source separation policy that echoes students' environmental education activities in school.

Some developed countries, such as the United Kingdom, have experienced a burgeoning promotion of school waste education in some counties and districts. For example, the Warwickshire County Council (n.d) and New Forest District Councils (n.d.) supported school activities including organizing assemblies and workshops on recycling, reducing waste and reusing waste to composting. The Devon Waste Education Program is one of the UK's largest waste programs; the program has run for several years with strategic plans, such as "Waste education strategy for Devon Schools (2014–2017)" (Marlisco, European Union, n.d.; Recycle Devon, n.d.). According to a survey, about 70% of teachers indicated that topics on waste have been embedded into the school curriculum or work schemes (Marlisco, European Union, n.d.). In addition, recycling and composting rates increased and residual waste decreased in primary schools (Resource Futures, n.d.).

Longstanding programs in Australia include the Waste Wise Schools Program (Waste Authority, n.d.), which has two stages: "Becoming a Waste Wise School," (Waste Authority, 2018) and "Accredited Waste Wise School" (Cutter-Mackenzie, 2010). More than AUD$ 37,000 was devoted to 13 Western Australian schools for environmental education projects that aim to reduce waste, enhance recycling, and instill waste-related education in students. The schools' grants from the Waste Authority were spent on reusing coffee grounds from local businesses to grow crops; upgrading composting systems, recyclable wheelie bins, and vegetable gardens; purchasing a trailer to convey recyclables; and constructing an outdoor classroom (Government of Western Australia, 2017). The Waste Wise Schools Program is also part of the Sustainable Schools Program in Western Australia. Cutter-Mackenzie (2010) revealed that certified waste wise schools in Victoria, Australia tended to establish partnerships with external agencies and engage in other environmental education programs. Waste wise schools are also likely to participate in the following practices frequently: recycling paper and cardboard, reusing materials (such as for art), reusing containers, and regularly switching off lights and fans. The organization of package-free lunches and maintenance of sustainable school transport to school were observed to be less frequent practices. Teachers praised positive achievements of waste wise schools in certain aspects, such as the whole school approach and student empowerment. However, they also faced challenges, such as time shortage, inadequate teachers and management commitment, and cramped school curriculum. In some provinces and districts, such as Logan City Council (n.d.), Queensland, Australia, a free "School & Community Waste Education Program" is provided by experienced environmental educators. The program comprises of designed in-class and group presentations on topics, such as "Waste and Recycling," "Environmental Impacts of Waste," "Think Food – Rethink Waste," "Worm Farming and Composting;" and landfill facility tours, as well as the provision of the publication "Reducing Waste at Home: A resource book for English learners." (Logan City Council, n.d.) By contrast, the Eco-Schools international program (Eco-Schools, n.d.a), one of the programs of the Foundation for Environmental Education (FEE), adopted a holistic and participatory approach for environmental education. Under the Eco-Schools program, which has a seven-step framework (Eco-Schools, n.d.a), "waste" is one of the topics involving the five Rs: Refusing, Reducing, Reusing, Repairing, and Recycling (Eco-Schools, n.d.b; Kayihan & Tönük, 2012). A case study of primary Eco-Schools in Istanbul, Turkey, showed the effective implementation of litter management through litter bins and the reuse of school materials through social cooperation activities. However, the collection of waste and selection of recycled products, such as recycled cleaning products and stationary equipment, varied. Only a small percentage of schools participated in composting organic waste (Kayihan & Tönük, 2012).

From the above examples, it appears that

- For some developing countries in Southeast Asia, waste education projects tended to include agricultural waste (e.g., organic waste) and involve universities and communities;
- For some developed countries such as the United Kingdom and Australia, there were established waste education programs sponsored by local or international non-governmental organizations and/or local authorities. Some of the waste management also involved agricultural waste depending on contexts but schools tended

to introduce systematic programs on waste education and management that encompassed both formal and nonformal learning.

9.3 Studies on Factors of Waste Management and Recycling Performance and Education in Taiwan

Taiwan residents were not familiar with waste management and recycling in the 1980s. Environmental Protection Administration Taiwan (EPAT) was established in 1987 and began to strengthen the Waste Disposal Act to deal with municipal waste disposal problems. To raise resident's recycling awareness, the EPAT provided information on recycling and associated policies through multiple channels and also conducted outreach and publicity. Since 1990, to encourage recycling, EPAT and local Environmental Protection Bureaus installed recycling bins of four categories (paper, plastics, glass, and metal) in neighborhoods, local convenience stores and public places. According to empirical research, the factors of the successful recycling performance result from the EPAT's policies of municipal waste disposal (Chen & Huang, 2003), and the establishment of 4-in-1 Recycling Program played a crucial role to dramatically increase the recycling rate in 1997. The program required manufacturers and importers to pay a recycling fee for collecting waste to recycle from consumers. Offering economic incentives for recycling has been recognized as a key success factor of the high recycling rate in Taiwan. In addition to the 4-in-1 Recycling Program, the "Keep Trash off the Ground" policy was singled out as an important factor to affect resident's awareness of waste management (Chao, 2007). This study applied Time Series Analysis on the effects of refuse collection practice on the outcomes of recycling, and found out the "Keep Trash off the Ground" policy surpassed over the other two policies—Mandatory Garbage Sorting Enforcement Project and buying bag policy. Regarding the influences of demographic factors, Hu, Jan, and Lin (2014) pointed out that education was a significant factor of the solid waste recycling performance in Taiwan, and higher education degree residents apparently complied with recycling policies better than lower education degree residents.

The factors that influence people's waste management and recycling behaviors include personal environmental attitudes and incentives (Marans & Lee, 1993). In addition to environmental attitudes, self-efficacy was highlighted as a crucial factor to predict student's recycling behaviors (Li, Yeh, Huang, Tseng, & Shih, 2008). Since environmental attitudes are important to resident's recycling behaviors, applying value clarification learning strategy to improve student's environmental attitudes has been adopted and proved to be effective in waste management and recycling education (Yeh & Tang, 2006).

From the perspective of education, the studies of waste management and recycling focused more on students' behavior than knowledge, and more on school settings than communities. To investigate student's behavior of waste management and recycling, the researchers applied the "theory of reasoned action" (Ajzen & Fishbein, 1980) and "self-efficacy" (Bandura, 1977) to study their behavior intention on waste reduction for fifth and sixth graders (Tseng, Hsieh, Yeh, Lin, & Huang, 2011). In addition, the same research group extended their survey to junior high students and found out that in order to reduce waste, the students had higher intention on resources recycling and reusing by comparison to refusing, and more than 80% of the students recognized the meaning and importance of garbage reduction (Lee, Tseng, Yeh, & Huang, 2013).

9.4 Waste Management and Recycling Practices in Taiwan Schools

Environmental education has been implemented in schools in Taiwan since the 1980s. With its rapid economic growth, Taiwan, along with Hong Kong, South Korea, and Singapore (known as the Four Asian Tigers), face serious waste disposal problem. Hence, environmental protection received nationwide attention in Taiwan (Tan, Lee, Chang, & Kim, 2017). Garbage classification and recycling were implemented in communities and schools, not in curriculum but in practice. Students practiced recycling in their classrooms with a couple of boxes labeled recyclable and nonrecyclable. Separating their waste into recyclable and nonrecyclable became the students' daily routine. The competition was adopted to make the routine more efficient, raising students' recycling rate. To win the competition, students did not just recycle, they collected recyclable materials from their homes; students weighed their recyclable materials and recorded them to compete. Recycling was a very popular activity in the 80s and 90s, and is still a daily routine in many schools nowadays. In academic years 2010 to 2012, the EPA Executive Yuan and the Ministry of Education (2010) announced the 99–101 Academic Year "Three-year implementation plan of enhancing school environmental education in schools," which echoed the enactment of Environmental Basic Law No. 9 (Ministry of Education, Taiwan, 2010). The implementation plan included categories, such as "promoting campus environmental management," covering the treatment of waste materials arising from research and teaching; "implementing environmental teaching," involving the development of environmental education materials and the organization of activities; "promoting environmental protection in campus life," entailing waste reduction and recycling, green purchasing plans, and one green/vegetarian lunch per week; "establishing environmental education facilities," including the establishment of environmental centers in selected counties, such as Taoyuan, Tainan, Kaohsiung, and Hualien Counties, and the arrangement of visits to environmental facilities, as well as recognizing and "extending international horizons."

Waste management and recycling education in schools are not just about classifying waste and recycling values and non-values. In the implementation methods of garbage classification and recycling resource in the Wen-Ya Elementary School (n.d.) of Taichung City, the school centrally collected CDs, diskettes, glass, lamps, clean Expandable Polystyrene (Styrofoam), and large waste batteries. In the class level, waste materials such as aluminum and iron cans, papers, aluminum foil bags, carton/cardboard boxes, porter/pet bottles, including Yakult, milk, and salad oil plastic bottles, as well as small waste batteries are classified and collected. Junior environmental and resource recycling team volunteers help with waste collection and recycling activities weekly. The tentative price for collecting different kinds of waste are as follows: TWD$ 4/kg for iron cans, plastic waste TWD$ 3/kg for plastic waste, TWD$ 20/kg for aluminum cans, TWD$ 1/kg for paper, TWD$ 8/kg for PET bottles, and TWD$ 15/kg for waste batteries. About 90% of the income generated from recycling is allocated to fund class activities, whereas 10% is reserved by the school to maintain its recycling facilities (Wen-Ya Elementary School, n.d.).

In addition to the aforementioned types of waste for recycling, waste management was expanded to water reuse, fallen leaves and leftover compost, and battery and fluorescent lamp recycling. Furthermore, recycling does not just involve collected valuables and thrown non-valuables, but also the reclamation of the values of recycling materials. For instance, Kaohsiung Municipal Primary School (n.d.) reclaims the values of their recycling materials by transforming them into tabletop decorations, potted plants, storage boxes, and compost and organic farming materials and by upcycling old clothes. Another example is Kaohsiung Municipal Cianjhen Senior High School (n.d.) in Kaohsiung City with similar plans and strategies for constructing a sustainable campus and enhancing environmental education with components of waste management and recycling education (document). Furthermore, the recollection and reuse of teaching materials (reference books and uniforms), fallen leaves for composting, and kitchen food waste (document) were promoted.

He-Shun Elementary School (n.d.) in Tainan City implemented the policy of "prohibiting the use of disposable tableware," and collaborated with the local community for resource recycling. A study by Li, Lin, Lin, Yang, and Lu (n.d.) on the treatment and recycling of resources and materials in primary schools of Tainan City, a leading case in Taiwan, revealed that schools observed good practice in sorting rubbish, recollecting waste batteries, and composting fallen leaves. Common examples of rubbish and waste materials in Tainan primary schools were paper, used textbooks, notebooks, newspapers, advertisement papers, food and drink cans, and glass and plastic bottles. Most primary schools provide a recycling room to keep records and segregate waste materials. The funds generated from recycling were used to purchase brooms and other cleaning equipment. In addition, some students are aware of the advantages, similarities, and differences of different kinds of composting and using compost products (e.g., for organic farming and environmental planting). Some school-organized activities, such as handwriting, cartoon and essay competitions, as well as recycling bin and poster design contests enhance students' awareness of recycling waste batteries.

9.5 Development of Waste Management and Recycling Education in Schools

Waste management and recycling education has been transformed and upgraded since the 1980s. In its early stages, environmental education was often treated as an activity instead of a curriculum. Daily recycling and cleaning activities were recognized as the major contents of environmental education. The public's reception of recycling was attributed to its global trend. Following the global trend of environmental education, efforts in implementing environmental education in Taiwan have positive impacts in formal and nonformal education settings. In responding to the global trend of Education for Sustainable Development (ESD) and education for climate change, Taiwan implemented the Green School Partnership Network Project, Energy School Program, Disaster Preparedness Education Project, Taiwan Sustainable Campus Project, Campus Chemical Waste Disposal Program, and Environmental Education Act. Among these projects, the Green School Partnership Network, Taiwan Sustainable Campus Project (TSCP), Campus Chemical Waste Disposal Project, and Taiwan Environmental Education Act (TEEA), which considerably developed waste management and recycling education in schools. Recycling education was initiated by dealing with the daily issues of garbage disposal, conforming to global environmental protection trends, building a comprehensive garbage disposal projects, developing teaching modules infusing environmental education into the school curriculum framework, and finally, realizing awareness in daily life.

9.5.1 Waste Management and Recycling Education as Professionally Designed Activities—Green School Partnership Network

Waste management and recycling are regarded as a daily routine for students. Students are asked to do activities without knowing the significance and impact of waste management and recycling on environmental protection. However, some schools and teachers realized the importance of waste management and recycling in both theoretical domain and practical application. Teaching modules developed when students understood the significance and impact of waste management and recycling, and they properly practiced them in school.

The Taiwan Green School Partnership Network project initiated in 2000 highlighted sharing ideas and practices on environmental education among schools and teachers. In addition to teaching about the environment, the project endorses the importance of teaching in and for the environment. The project also argues that environmental education should have four components: policy and administration, building and environmental management, teaching and learning, and students' living in schools. This network encourages schools and teachers to share their teaching modules and student learning reports. Waste management and recycling education has been one of the top three popular subjects since 2000. The most popular subject is outdoor education and interpretation, second is environmental actions, and third is waste management and recycling with shared teaching modules and reports amounting to 10943, 8896, and 5358, respectively.

The 5358 teaching modules and reports on waste management and recycling education demonstrate its variety, abundance, and extension. Waste management and recycling education became a discipline with professional teaching module design, teaching, and practice through sharing among schools and teachers. The pedagogy and topics of waste management and recycling education continuously developed by examining the contents of the 5358 modules. In the 80s and 90s, instruction shifted from recycling skill-oriented teaching to comprehensive and complex teaching, which consisted of problem-solving, experiential learning, and issue investigation. The subjects of waste management and recycling education, as well as resources on recycling also increased dramatically. Garbage classification and recycling valuable goods became the core elements of waste management and recycling education, which gradually progressed or extended to ocean waste, fair trade, and circular economy.

9.5.2 Waste Management and Recycling Education as a Systematic and Theoretical Approach—Taiwan Sustainable Campus Project (TSCP)

The TSCP is supported by the Ministry of Education in Taiwan to promote sustainable development education (Lee, Wang, & Yang, 2013). The program encourages schools to transform their campuses into sustainable development with alternative energy, water conservation, material recycling, and health applications. The program highlights a whole school approach, which consists of administration, facilities, curriculum, and school life. TSCP emphasizes both hardware (equipment and buildings renovation) and software (learning for sustainability) and requires schools to develop teaching materials and learning activities on ESD (Chiang, 2004). Such educational practices greatly enrich subject matters in the school curriculum and offer rigid theoretical definitions and conceptual structures for these applications (Chang, 2010; Su & Chang, 2005, 2010). The application of material recycling is a fundamental base for sustainability, as well as the meaning and significance of waste management and recycling education.

TSCP focuses on reforming school campuses to fulfill the concept of sustainable development, including its physical construction and utility operation. The project also emphasizes the core development of ecological thought, humanistic concern, and active learning of ESD (Chang & Chou, 2005). The framework of the program has three components: campus ecology, sustainable technology, and environmental management. Campus ecology highlights ecological designs to address issues on biodiversity, native species conservation, water cycle maintenance, multilayer

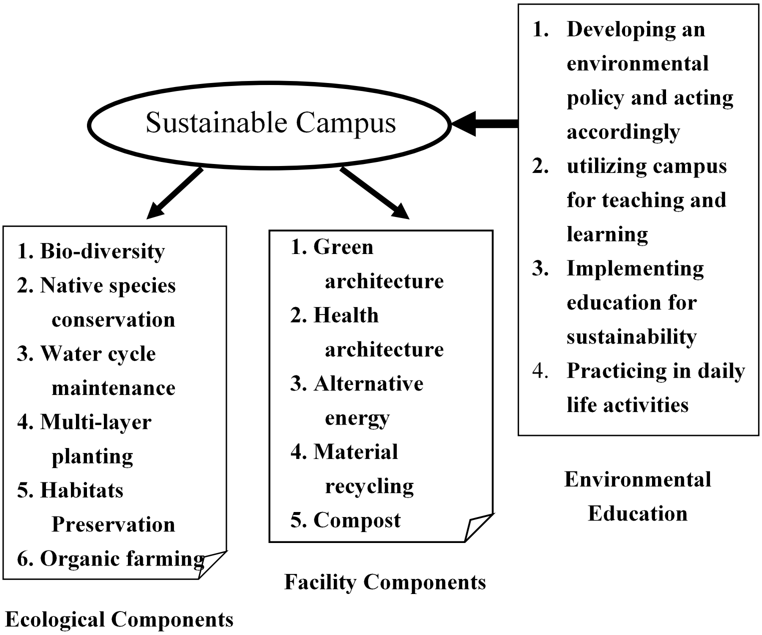

Fig. 9.1 A framework of Taiwan sustainable campus project

planting, habitat preservation, and organic farming. Sustainable technologies consist of green architecture techniques and evaluation, healthy architecture solutions, alternative energy and energy regeneration, material recycle equipment, and compost technology. The components of environmental management are the following: developing a school environmental policy and acting accordingly, designing campuses for teaching and learning, creating teaching modules and implementing education for sustainability, and infusing all the components into students' daily life (Fig. 9.1) (Ho & Chang, 2009; Yen, Ferng, & Liu, 2006).

The Taiwan Sustainable Campus Program (TSCP) was launched in 2002 to reform campuses into a safe, healthy, sustainable learning space. More than 1000 schools (about one-fifth of schools in Taiwan) are funded to transform their campuses into sustainable ones and improve education on sustainability. Schools implementing TSCP projects aim to enrich students' subject matter with information on sustainability. Instructional processes, teachers' reflections, and students' learning journals from the project reports of the TSCP schools are examined. The study finds that schools implementing TSCP projects enrich subject matters with information on sustainability by introducing important and contemporary concepts of sustainability, as well as constructing systemic knowledge and holistic perspectives on sustainable development. These sustainability concepts can be attributed to material cycles and resource recycling, eco-designs, habitat preservation, and a healthy environment. The systemic knowledge and holistic perspectives on sustainability are energy conservation and alternative energy, water cycle and conservation, material cycle and recycle, and eco-designs for campus biodiversity.

9.5.3 Waste Management and Recycling Education Infusion into the National Curriculum Framework

In addition to school activities, environmental education is infused into the school curriculum as suggested by environmental education scholars and practitioners. In 2001, environmental education, as an important issue, was required to be infused into the Grades 1–9 National Curriculum Framework. The curriculum was reformed in 2016 when environmental education was required to be integrated into the Grades 1–12 National Curriculum Framework as one of the four important educational issues. The three other issues are human rights, gender equality, and ocean education. The new Grades 1–12 National Curriculum Framework will be effective in 2018. Environmental education has been infused into school curricula for more than 15 years. The integration tremendously impacted school teachers and students, and its development clarified the goals and contents of environmental education in Taiwan.

The major activity of environmental education, according to teachers and parents, is recycling. Waste classification and recycling have been major parts of the environmental education project since the 1980s, although they are merely activities or projects and not included in the school curriculum. The consensus that environmental education was too important to be absent from school curricula was reached. When environmental education was infused into the Grades 1–9 National Curriculum Framework in 2001, the concepts of waste management and recycling education were incorporated into the curriculum. As a subject of the national curriculum, waste management and recycling education became a mandated discipline like Mathematics and Nature Sciences.

The goals, concepts, materials, and instructions of environmental education should be discussed and defined before it can be infused into learning fields. Goals and concepts of environmental education for the 2018 curriculum framework are developed, although teaching materials and relative pedagogy are still underway. Goals are expanded and included ensuring sustainable development for the entire world and its inhabitants. The framework primarily includes five concepts: environmental ethics, sustainable development, climate change, disaster preparedness, and sustainable use of resources and energy. Waste management and recycling are under the concept of sustainable use of resources and energy. The themes of waste management and recycling are described in the national curriculum framework as follows:

- Grades 1–6 should be
  - Aware of the importance of sustainable use of material and energy;
  - Aware that pollution and depletion are caused by the overconsumption of materials and energy;
  - Practice recycling in daily life.

- Grade 7–9 should be able to
  - Understand relations among energy flow, matter cycles, and the ecosystem;
  - Life cycle assessment, eco-footprint, water footprint, and carbon footprint;
  - Alternative energy, clean energy, and green energy.
- Grades 10–12 should be able to
  - Understand environmental cost, the polluter pays principle, green design, and clean development mechanism;
  - Understand international conventions on energy policy;
  - Practice green consumption and environmental-friendly lifestyles.

9.5.4 Waste Management and Recycling Education as Fundamental Environmental Literacy—Taiwan Environmental Education Act

TEEA was approved by the Legislative Yuan in Taiwan in 2010 and was implemented in 2011. All elementary, junior high, and high school students should attend 4 h of environmental education every year. TEEA requires the government to allocate appropriate funding to implement environmental education and to certify educators, institutes, and centers of environmental education. TEEA significantly influenced the implementation of environmental education in at least three perspectives since 2010: required 4 h of EE, allocating a certain amount EE fund, and certification of EE educators, institutes, and centers (Hsu, 2017).

According to EEA, every government worker, as well as every elementary, junior high and high school student, should attend 4 h of EE every year. The amount of people required to take EE is about four million, equivalent to 20% of the population of Taiwan. To ensure its quality, the EEA requires every government institute and school to assign an EE educator to design 4 h of EE. Moreover, the EE educator has to obtain certification. Some evaluation projects are initiated to measure the effects of the 4-h EE.

Four hours of EE was mandated to every school in Taiwan, and its content is recognized as citizens' environmental literacy. The topics and contents of the 4 h of EE can represent how schools and teachers view the purpose and importance of EE. Waste management and recycling education are received and applied to the 4 h of EE.

9.6 Conclusion

The contents and pedagogies of waste management and recycling education greatly developed as seen on the impacts of the policies of environmental education and the development of waste management and recycling education for the past 30 years in Taiwan. Furthermore, a strategy for implementation can be proposed.

9.6.1 Contents and Pedagogies of Waste Management and Recycling Education in Schools

Waste management and recycling education started with simple practices of garbage classification and recycling valuables. A whole school approach policy is currently adopted, and professional teaching modules are developed. In addition, evaluations and field studies are applied. The waste management and recycling education became creative and comprehensive in schools. For instance, Jhih-Sync Elementary School (n.d.) in Hualien County launched a 3-year plan to enhance environmental education echoing government policy. The school adopted a multipronged approach to integrate parental and community resources and to enhance the environmental citizenship competencies of teachers and students. Measures, such as green purchasing and green consumption, were utilized to match the county's environmental policies in "zero rubbish disposal, full resources recycling." Waste management and recycling education became part of the whole school's environmental plan, and a visit to resource recycling site was arranged.

The contents of waste management and recycling broadened and deepened compared with its practices. In addition to garbage classification and recycling valuables, waste management and recycling expanded to include concepts of water reuse, energy conservation, toxic chemical recycling, climate change, and compost and food mileage. From the perspectives of meaning and significance, waste management and recycling education is related to the theories of matter cycles and the rationale and philosophy of sustainable development. As regards the pedagogy, waste management and recycling education has been transformed from simple daily routines to a systematic operation and a whole school approach, infusing into school curriculum and learning, and thinking about responsibility and sustainable development.

9.6.2 Strategies for Waste Management and Recycling Education in Schools

This study reviewed 40 years of waste management and recycling education in Taiwan. The review examined a successful story of waste management and recycling education implementation, and accordingly proposed a strategy for schools' recycling and waste management education. The first step of the strategy is to make waste management and recycling relevant to daily life and establish achievable goals; second, to raise students' and teachers' awareness of waste issues and conform to the global trend of environmental education; Third, to enhance waste management and recycling education in schools. The strategy applied in Taiwan consists of offering incentives, such as reducing costs of waste disposal, encouraging learning by doing through various activities, building networks to share and promote recycling education, infusing waste management and recycling education into the school curriculum, and being recognized with the National Environmental Education Award for systemic operations and a whole school approach of waste management and recycling education. In addition, experiences from Tainan City primary schools (Li et al., n.d.) suggested that more attention is necessary to educate parents, teachers, and students on waste management and to cultivate the habit of rinsing and cleaning materials for recycling. Some technical support and advice are also required to help school personnel troubleshoot the typical problem of slow-leave decomposition rate during composting. Examples of composting and waste prevention-related modules can be found in the California Department of Resources Recycling and Recovery's (CalRecycle) "Closing the Loop Curriculum" for Grades 4–6. Such modules could be integrated into the school curriculum to raise the awareness and understanding of teachers and students on composting and related concepts. A curriculum module includes lessons focusing on integrated waste management concepts, is "Composting," which pertains to concepts and activities related to nutrient cycling, scavengers and decomposers, and recycling (CalRecycle, 2000). In addition, more efforts should be devoted to share positive experiences of waste education among schools, provide funding support to purchase composting machines, and sponsor the operations of recycling rooms in schools.

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Tzu-Chau Chang is a Professor of the Graduate Institute of Environmental Education at National Taiwan Normal University. He has actively involved in promoting the infusion of EE into the national curriculum framework and education reform movement of Taiwan. He participated in developing the national curriculum framework in 2001 and 2016 and provided long-time consultation and supporting on teaching and learning of Environmental Education for schools of Taiwan. In addition, he has played a very important role to implement the projects of Taiwan Green School Program and Sustainable Campus Program, which have been still running and produced great impacts on the EE of Taiwan.

John Chi Kin Lee JP, Vice President (Academic) and Chair Professor of Curriculum and Instruction, joined The Education University of Hong Kong (EdUHK) [formerly known as The Hong Kong Institute of Education (HKIEd)] since 2010. He is also the Director of the Centre for Religious and Spirituality Education (CRSE), Co-Director (Research) of the Centre for Excellence in Learning and Teaching (CELT), and Co-Director of the Centre for Education in Environmental Sustainability (CEES). He was Dean of Education and Professor of Department of Curriculum and Instruction at The Chinese University of Hong Kong (CUHK).

Professor Lee has served as the Regional Editor (Asia-Pacific) of *Educational Research and Evaluation* and Executive Editor of *Teachers and Teaching* as well as editorial board members or advisory editors of many local, regional, and international journals. He is also a prolific writer, who has edited and written more than 25 books and published over 100 journal articles and book chapters.

Professor Lee served as the Team Leader of a World Bank consultancy project on teacher education and has also held many visiting/guest/adjunct professorships at universities overseas and in Mainland China. He is the Changjiang Chair Professor conferred by the Ministry of Education, the People's Republic of China.

Chapter 10
Enhancing Pupils' Pro-environmental Knowledge, Attitudes, and Behaviours Toward Plastic Recycling: A Quasi-experimental Study in Primary Schools

Chi Chiu Cheang, Tsz Yan Cheung, Winnie Wing Mui So, Irene Nga Yee Cheng, Lincoln Fok, Chi Ho Yeung and Cheuk Fai Chow

Abstract To tackle the serious problems caused by plastic wastes, it is critical to develop new plastic recycling beliefs and behavior, together with recycling skills (4 important steps of recycling: cleanliness, separation, compression, and sorting) of the plastic wastes in environmental education (EE). The study revealed the effectiveness of a plastic waste recycling program adopting an action competence approach with educational interventions using a new plastic waste recycling bin (PRB). The PRB allows further classification of plastic waste types. Seven primary schools in Hong Kong participated in the program. A total of 313 questionnaires which assessed pupils' classification knowledge, behaviours of plastic waste recycling, and their pro-environmental attitudes in terms of New Environmental Paradigm were received. Semi-structured interview with 27 pupils from the schools were also conducted. Recycling performance (actual behaviour) of using the brown bins (general plastic recycling bin) and the PRBs in the schools was assessed as the evidence of action competence in plastic waste recycling. Comparing the schools which adopted programmes with a combination of two types of recycling bins (brown bin vs. PRB) and interventions (Poster vs. half/full training courses to teach the recycling knowledge and skill), both quantitative and qualitative results showed that learners of the program enhanced their recycling knowledge (K), attitudes (A), and behaviour (B) concerning plastic waste recycling. The recycling performance proved that there is a statistically significant change in the recycling steps, separation and compression.

Authors Chi Chiu Cheang and Tsz Yan Cheung are equally contributed for this chapter.

C. C. Cheang · T. Y. Cheung · W. W. M. So (✉) · I. N. Y. Cheng · L. Fok · C. H. Yeung · C. F. Chow (✉)
Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, the Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: wiso@eduhk.hk

C. F. Chow
e-mail: cfchow@eduhk.hk

W. W. M. So et al. (eds.), *Environmental Sustainability and Education for Waste Management*, Education for Sustainability,
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The study provides insights for environmental educators to develop strategic solutions to ease environmental issues as well as putting these actions into practice in schools.

Keywords Plastic waste · Recycling · Actual behaviour · New environmental paradigm · Primary schools

10.1 Introduction

Plastic waste problem become more and more severe in the metropolitan cities owing to the rapid growth in both population and tourism. In 2011, the local government of Hong Kong attempted to tackle the problem by launching campaign to enhance the participation of plastic waste recycling in schools. Yet, the recycling bin used only contained a single compartment that could not avoid contaminations with other wastes and the plastic wastes collected. To promote proper plastic waste recycling practices, an innovative plastic waste recycling bin (PRB) has been launched. The PRB includes eight compartments that collect plastic wastes according to the plastic types. Together with educational interventions, the quality of recycling plastic wastes could be improved. The present study aims at assessing how effective different educational interventions associating with the PRB is to promote the pupils' action competence for plastic recycling and measure the quality of the recycling plastic wastes by using the PRB in the primary schools.

10.1.1 The Plastic Waste Problem in Hong Kong

The speedy growth of economic and urban development has led to a drastic increase in the consumption of plastic products, resulting in a tremendous amount of plastic waste all around the world. Plastics are commonly used in our daily life, such as dining ware, toys, and food packaging. Worse still, around 50% of the plastic products are used once and then discarded as waste (Hopewell, Dvorak, & Kosior, 2009).

Metropolitan Asian cities, such as Metro Tokyo, Taipei, Seoul, and Hong Kong, are experiencing rapid growth in both population and tourism. Population pressure and consumption patterns create stress on the local municipal solid waste (MSW) management systems (Table 10.1). Recent statistics indicate that 10,345 tons of MSW are generated every day in Hong Kong (Environmental Protection Department, 2016), of which plastic waste contributes around 2,131 tons and ranks the third among the different types of MSW. The huge amount of durable and voluminous plastic waste places a great burden on the landfills, the major waste management infrastructure in Hong Kong. It is estimated that these landfills will be saturated within the coming 10 years (Environmental Bureau, 2013).

Table 10.1 Current plastic waste problem in mega-cities

	Metro Tokyo	Taipei	Seoul	Hong Kong
MSW (tonnes) per day	7,546[a]	2,342[d]	9,189[i]	10,345[j]
Plastic waste (tonnes) per day	826[b]	389[d, e, f]	560.7[i]	2,132[j]
% contribution and ranking of plastic waste among all MSW	11.1%, ranking no. 4 among all MSW[b]	16.61%, ranking no. 4 among all MSW[d,e]	6.1%, ranking no. 4 among all MSW[i]	20.6%, ranking no. 3 among all MSW[j]
Plastic waste (kg) per person per day	0.08 kg[b]	0.14 kg[g]	0.05 kg[i]	0.29 kg[j]
Plastic waste management strategies	Recycling (83%)[c] Incineration (10%)[c] Landfilling (7%)[c]	Incineration (46%)[h] Recycling (52%)[h] Landfilling (2%)[h]	Incineration (54%)[i] Recycling (46%)[i]	Recycling (18%)[j] Landfilling (82%)[j]

[a]Clean Authority of Tokyo (2017a); [b]Clean Authority of Tokyo (2017b); [c]Plastic Waste Management Institute (2014); [d]Department of Environmental Protection, Taipei City Government, (2017); [e]Executive Yuan, R.O.C. (Taiwan), Environmental Protection Administration, Properties of Municipal Solid Waste (2017a); [f]Executive Yuan, R.O.C. (Taiwan), Environmental Protection Administration, Disposal of Municipal Solid Waste (2017b); [g]Taipei City Government, Demographic Overview, (2017); [h]Environmental Bureau. (2013); [i]Ministry of Environment, Environmental Statistics Yearbook 2014 (2014); [j]Environmental Protection Department (2016)

To avoid further aggravation of the waste management problem, a change in the plastic waste recycling behavior of Hong Kong citizens is urgently required. Up to 2013, 16,000 sets of waste separation bins (yellow for metals, blue for paper, and brown for plastics) were placed in public locations such as on curbs, in sport centers, schools, hospitals, etc. (HKSAR Gov't, 2013). Brown recycling bins (BB) are ubiquitous in the community, especially in the residential estates, for plastic waste collection. Despite the abundance of this recycle-supporting tool, the basic recycling steps such as cleaning, separating, compressing, and classifying the plastic parts before recycling are generally ignored by the public. This ignorance of the correct procedures is one of the major causes of the increase in the cost of post-processing, and the decrease in the quality and quantity of recyclables (Hopewell et al., 2009). This has created an additional burden on the local recycling industry, which had already been facing many difficulties such as limitation of land for recycling plants, the high cost of sustaining their operation, and the lack of invention of new supportive technologies (Tam & Tam, 2006). These problems all hinder the effective recycling of plastic waste in the city.

10.1.2 Introducing a Newly Designed Plastic Bin

Educators believe that education is the critical key to enhancing knowledge and encouraging positive alternate behavior (Hungerford & Volk, 1990; Kopnina, 2014). It is argued that educating the general public with proper pro-environmental behaviors in relation to plastic waste recycling could improve the quality of recyclables. This is especially true for primary school pupils whose conceptual mindsets regarding the world are developing (Evans et al., 2007). It is reported that young people possess a higher level of awareness of the environment than older individuals (Dunlap, Van Liere, Mertig, & Jones, 2000). Yet, their pro-environmental awareness and values tend to drop after age 13 (Pol & Castrechini, 2014). Encouragingly, a study from the United Kingdom found that knowledge from child-orientated EE could affect and transfer to adulthood with sustainable and intended pro-environmental changes (Damerell, Howe, & Milner-Gulland, 2013). Thus, it is necessary to educate primary pupils aged 6–12 in the hope of strengthening their pro-environmental beliefs and values for a sustainable future.

In 2011, the local government of Hong Kong launched a campaign called "Reduce Your Waste and Recycle Your Plastics" with a view to enhance plastic waste recycling in schools. Education kits including card games, CD-ROMs, leaflets, teacher guide books, and posters were provided to encourage better performance of plastic recycling (Environmental Protection Department, 2011). The kit also taught about sorting out the plastic wastes, and schools were given a new bottle-shaped recycling bin (BB) for plastic waste collection, the design of which was thought to be more attractive. However, with only a single compartment, the BBs do not allow users to pre-sort or pre-separate different types of plastic wastes. Users tend to put all the plastic wastes, including unclean articles containing residual food, directly into the BBs, potentially contaminating the other recyclables in place, thus reducing their quality and value.

In order to promote proper plastic waste recycling practices, an innovative plastic waste recycling bin (PRB) has been launched (Chow, So, & Cheung, 2016; So, Cheng, Chow, & Zhan, 2016, Chow et. al., 2017). The PRB includes eight compartments that collect eight types of plastic waste (Appendix 1). Bin users have to further separate and discard the plastic waste into the right compartment according to the plastic type. Prior to discarding the plastic waste, users are educated to clean, separate, and compress the recyclables, if applicable. These pre-disposal steps of recyclables can therefore promote the efficiency of plastic recycling.

10.1.3 Theoretical Framework

In the local primary school curriculum, schools can choose to implement EE either formally or informally within the curriculum (CDC, 1999). There are many benefits of EE programs in a school setting such as improving pupils' interpersonal skills, and developing their knowledge, environmental sensitivity, and sense of belonging to nature (Mobley, Vagias, & DeWard, 2009), which are responsible for shaping pro-environmental behaviors. Schools not only benefit from the recycling program by raising the pupils' awareness of sustainability, but EE goals can also be achieved.

However, there are various factors which hinder local EE development in schools due to the teachers' tight schedules and lack of specific environmental knowledge or support (Lee, 2000). Gottlieb, Vigoda-Gadot, and Haim (2013) mentioned that other "situational" constraints also prevent schools from carrying out EE such as the provision of recycling containers and facilities, the school's canteen and food packaging, or even the very short intervention period which means that pupils' internal values may not be supported enough to achieve a change in behavior. Thus, schools are encouraged to cooperate more with NGOs or other external organizations to carry out Green projects (Cheng & So, 2015), which may provide more resources and funding for environmental troubleshooting. In the present study, the seven local primary schools cooperated with the "I Act, U Act! Plastic Recycling" (IAUA) program to help tackle the plastic waste problem. This may have a greater impact and provide more innovative ideas for pupils to learn about environmental issues.

Transforming the theory of environmental sustainability into recycling behavior is not easy without the aid of systematic information and educational tools. The present study employed the "Action competence" approach (Cincera & Krajhanzl, 2013; Jensen & Schnack, 1997; Mogensen, 1997) in the program design by considering the determining factors, such as the promotion of behavior-related knowledge, skills, and awareness, and the perceived behavior of sustaining plastic waste recycling in schools.

10.1.3.1 Action Competence for Pro-environmental Actions

Action competence refers to the capability of a person to seek solutions to environmental problems and execute the solutions with actions. There are various components to develop competence through education such as transferring knowledge and skills, enhancing commitment, and developing a future vision of sustainable life style and actions (Jensen & Schnack, 1997). The person should develop reasoning and judgement of the environmental issues for action (Cincera & Krajhanzl, 2013; Mogensen, 1997). Jensen and Schnack (1997) further claimed that outcomes of EE designed to modify behaviors alone cannot be sustained. Thus, in addition to EE with behavioral modification, having EE designs involving critical thinking is essential to sustain the new behaviors and owe the capabilities to act in the long run (Seatter, 2011). A revised Bloom's Taxonomy also states that different dimensions of knowledge including factual, conceptual, procedural, and metacognitive knowledge enhance the learning process that contributes to applying the knowledge in novel situations (Anderson & Krathwohl, 2001). Deficiencies in knowledge obviously hinder environmental behavioral changes (De Young, 2000). Also, it has been found that people with higher pro-environmental knowledge would appreciate nature more (Roczen, Kaiser, Bogner, & Wilson, 2013).

10.1.3.2 School-Based Interventions for Developing Action Competence

A school-based intervention, in the form of an EE program, encourages the participation of whole schools and the development of an atmosphere conducive to positive behavioral change. It is reported that school-based EE programs may result in great enrichment of children's environmental knowledge and awareness (Rickinson, 2001; Zelezny, 1999) since schools and teachers are major providers of knowledge and information about environmental issues. Goodwin, Greasley, John, and Richardson (2010) also suggested that school-based EE programs allow children to act as green ambassadors to promote the green messages to their parents or siblings. As a result, messages of proper plastic recycling can be spread widely, from pupils to families and the whole community to bring about a positive recycling outcome through peer influence.

To implement an effective school-based EE program, Jensen (2002) suggested taking the approach of action competence into consideration. Action competence involves two major directions; firstly, it is a concept that pupils have to be able and willing to take action to recycle waste consciously, which is different from a random behavior or habit. Secondly, schools should carry out activities that address the solution of the environmental issues (Jensen & Schnack, 1997). The concept stresses that all actions should be carried out based on solving the problem with pupils' intention to understand the reason for their actions. This allows pupils to nurture the competence to act and to protect the environment from problems (Jensen, 2002).

10.1.4 Research Questions and Objectives

There are two kinds of environmental action: (i) direct action to contribute to problem solving and (ii) indirect action to influence others to participate and engage in the problem-solving process (Jensen & Schnack, 1997). Indirect actions usually relate to direct actions, and direct actions are the result of indirect actions. For example, direct action refers to practicing reduce, reuse, or recycle in daily life, while indirect action refers to the promotion of the pro-environmental idea to others such as holding a debate or course.

Hence, the present study applied school-based interventions to create capacity for action competence by installing PRBs in schools with training courses to endorse the actions of plastic waste recycling. The program design involved (i) indirect actions: creating an atmosphere for peer influence, (ii) direct action: installation of PRBs with a poster display to gain knowledge of the plastic waste problem and proper behavior, and the action tool to direct pupils to recycle plastic waste properly.

The program was evaluated by measuring pupils' pre- and post-knowledge (K), attitudes (A), and behaviour (B) regarding plastic waste recycling and the recycling quality after using the PRBs. A quasi-experimental setting was used to compare the effectiveness of the PRBs and BBs with or without interventions to promote the knowledge, attitudes, and behaviours of plastic waste recycling in primary schools. The schools were divided into different treatment groups and a baseline study was conducted. The research questions are listed as follows,

1. How does the plastic waste recycling program with different treatment groups (BB/PRB and with/without interventions) affect pupils' K, A, and B of plastic waste recycling?
2. How do the interventions promote the action competence in the schools?

10.2 Quasi-experimental Study in Seven Primary Schools in Hong Kong

10.2.1 Background

The research design involved intervention-based studies, evaluated by both quantitative and qualitative methods. A total of 330 pupils from seven primary schools, from grades 3 to 6, in Hong Kong were recruited to join the plastic waste recycling program called "I Act, U Act! Plastic Recycling" (IAUA).

10.2.2 Plastic Waste Recycling Program: IAUA

A factorial design with two factors, the bin types and the interventions, was adopted in the study (Table 10.2). Interventions involved poster displays (Fig. 10.1) and training courses. The participating schools were divided into four groups to use either PRBs or BBs for plastic waste collection, and received two types of intervention, respectively. There were two stages of intervention, each of which lasted for 3 weeks. The full training course involved all topics from the general waste to the plastic waste problem in Hong Kong, the 3Rs (reduce, reuse, and recycle) and plastic waste classification. During the full training course, pupils were asked to discuss the reasons for recycling and to do inquiry experiments to understand the reasons why it is valuable to classify plastics into different types to facilitate their recycling. Sharing time was allowed in the course to figure out the views, causes, and solutions to the problems of plastic wastes and recycling.

As the control group for the intervention, the "other teaching" training course (control group) was not provided with lessons about plastic waste classification and recycling, but other topics were taught such as creative thinking. Pupils were invited to join the course in each school. Since the course recruitment was open to all pupils for each school, not all the pupils who answered the pre-tests were included in the training course. Yet the spillover effect could be evaluated during interviews to see if the attending pupils shared the course content with non-attending pupils. This is

Table 10.2 Experimental groups of the plastic waste recycling education program

Group	School	Type of plastic waste recycling bin	Intervention	
			Stage 1	Stage 2
1.	A	PRB	No poster	Half training course
	B			
2.	C	PRB	Poster	Full training course
	D			
3.	E	Brown bin	Poster	Full training course
	F			
4.	G	Brown bin	No poster	Half training course

Fig. 10.1 Plastic waste recycling education poster set (with permissions from the Centre for Education in Environmental Sustainability)

important in promoting the environmental messages (Hiramatsu, Kurisu, Nakamura, Teraki, & Hanaki, 2014) of the training course.

10.2.3 The Program Flow

10.2.3.1 Baseline Study of Plastic Waste in the Schools

At the beginning of the program, a baseline study was conducted to assess the amount and recycling quality (cleanliness, separation, compression, and sorting) of the plastic waste from the currently used plastic waste recycling bins (brown bins) in the schools for two weeks. To assess the recycling quality and quantity, which were the actual plastic waste recycling outcomes, plastic wastes were collected each week from the participating schools and analyzed to serve as a proxy to assess direct action. Ten items were randomly selected from the brown bin for analysis.

10.2.3.2 Strategic Interventions for Education in Plastic Waste Recycling

First, the assigned schools were distributed a set of three educational posters about plastic waste recycling (Fig. 10.1). These poster sets were posted in each classroom and next to the recycling bin. The poster included the information of the four steps for plastic waste recycling and examples of the different types of plastic waste to facilitate the use of the bin. For schools that used brown bins, the figure showed the school's brown bin rather than the PRB. The poster set was posted at the assigned schools.

Afterwards, each school was given a full or "other teaching" training course about environmental protection. A total of 70 pupils were randomly selected from each school to join the 8-h training course, the content of which is similar to that described in the previous study (Chow, So, & Cheung, 2016).

10.3 Methods

This research adopted various methods including a questionnaire and interviews to assess the effect of the interventions on pupils' general and plastic classification knowledge, attitudes, and behaviours (KAB) regarding plastic waste recycling. Around 60–70 pupils, aged 9.5 on average, were randomly selected from each school to complete the questionnaire with their consent. For statistical analysis, paired t tests were conducted to compare the differences within each group before and after each intervention. Two-way ANOVA and paired t tests were conducted to compare the differences across and within intervention schools with different bin types. All the statistical tests were conducted using the computer software SPSS ver. 21 (IBM Corp., 2012).

10.3.1 Assessment of Pupils' Changes in Knowledge, Attitudes, and Behaviours

The assessment included a 30-min questionnaire classification knowledge, behaviours of plastic waste recycling, and their pro-environmental attitudes. The pre- and post-tests were taken by the same pupils. A pre-test was conducted before the intervention and there was a post-test after the courses to assess pupils' KAB changes. Knowledge included two categories. General knowledge referred to knowledge of the contexts of solid waste management in Hong Kong such as the situations of the local landfill sites, waste hierarchy, or waste management choices (for the questions please see Appendix 2). Specific knowledge involves the knowledge needed to classify different plastic wastes.

Attitude refers to the pro-environmental thoughts about the eco-crisis. The New Environmental Paradigm (NEP) scale was developed by Dunlap and Van Liere in the late 1970s for pro-environmental belief evaluation (Dunlap & Van Liere, 1978). The scale was revised for children and further developed into five constructs: limitation for growth, anti-anthropocentrism, the rights of nature, rejection of human exceptionalism, and eco-crisis (Dunlap et al., 2000; Manoli, Johnson, & Dunlap, 2007). The NEP was found to be able to reflect participants' ecological views, especially on waste recycling (Chung & Poon, 2001). If a person holds a higher NEP score, he/she values more highly natural assets (Lee & Paik, 2011). In other words, a person is more willing to recycle as this can protect the environment. The NEP scale consisted of 5 Likert-scale statements with selections ranging from strongly disagree (=1) to strongly agree (=5). The eco-crisis construct was selected to assess pupils' attitudes towards nature in the present study. The revised version of the NEP scale (Dunlap et al., 2000; Manoli et al., 2007) was adopted in the present study; this scale specializes in evaluating the pro-environmental beliefs of children aged from 8 to 10. The Cronbach's alpha reliability coefficient for attitudes towards plastic waste recycling revealed by the NEP scale is 0.772, which is within the accepted range of internal consistency.

Skills reflected what pupils would perform before recycling plastic wastes. As for the skill of plastic waste recycling, which refers to the 4-step recycling (cleanliness, separation, compression, and sorting) when disposing of plastic waste, the Cronbach's alpha reliability coefficient is 0.707.

10.3.2 Evaluation of Action Competence and Recycling Quality in the Schools

A total of 27 pupils from each primary school were selected randomly for a face-to-face interview to ask what they thought about plastic waste recycling after the program (Appendix 3). Their reflections were recorded in audio tracks with their prior consent. Some of their suggestions and ideas are summarized in the results.

To assess the recycling quality and quantity, which was the actual plastic waste recycling behavior, the same methodology as the baseline study was applied. Ten items were randomly selected from the brown bin and from each compartment of the PRB for analysis. The recycling quality of the collected plastic waste was quantified in terms of four aspects, cleanliness (CLE), separation (SEP), compression (COM), and sorting (SOR). These four aspects correspond to the four steps of plastic waste treatment proposed in the study. The plastic waste was defined as clean if all residue drink or food had been removed and/or no obvious dirt was observed on the recyclables. The waste was separated successfully when the non-plastic or other types of plastic parts were removed from the item. Items were counted as compressed if they were compressible and had been compressed to diminish the waste volume. If the items were correctly put into the right compartment according to their plastic type, they were regarded as correctly sorted. All four aspects of recycling quality were expressed as an accuracy percentage. The results of the recycling quality reflected how pupils applied their recycling concepts in dealing with the plastic waste.

10.4 Results

In the baseline study, statistically significant differences were not detected among the schools in terms of recycling quality (Kruskal-Wallis Test, CLE: $\chi^2(6) = 7.807$, $p = 0.253$; SEP: $X^2(6) = 8.281$, $p = 0.218$; COM: $X^2(6) = 8.119$, $p = 0.230$; SOR: $\chi^2(6) = 4.627$, $p = 0.586$) or weight ($X^2(6) = 6.560$, $p = 0.363$), indicating that there was no significant difference in the recycling practices among the different schools before the interventions. The quality data of the waste among schools were compared using the non-parametric Kruskal-Wallis test due to the violation of homogeneity assumption for parametric tests. No bias among the schools in handling plastic waste before joining the program was, thus, assumed. The combination of both factors (PRB and intervention) showed positive improvements in some of the post-test scores for all aspects. Further details of the KAB items along with pupils' reflections are described in the following sections.

10.4.1 General Knowledge of Waste Management

In general, pupils' post-scores of general knowledge of waste management increased after participating in this plastic waste recycling program, although there were no significant levels found among the bin types and the interventions shown in Table 10.3 On average, pupils could achieve 2.3 out of 5 marks for general knowledge. Yet, for question 2 shown in Table 10.4, pupils significantly improved the choice of priority in the waste hierarchy after the program with a 20% increase in accuracy ($p = 0.044$).

10.4.2 Specific Knowledge of Types of Plastic Waste After Strategic Interventions

Pupils' specific knowledge of sorting different types of plastic waste was enhanced after joining the program. In Table 10.3, there was a significant increase in the plastic waste knowledge in schools with intervention received ($p = 0.001$). Considering both

Table 10.3 Effectiveness of use of bins with and without intervention for K, A and B among schools

	Groupings for comparison	N	Pre ± S.D.	Post ± S.D.	Mean *Dif.*	Paired t-test		2-way ANOVA	
						t	Sig. (2-tail)	F	Sig.
General knowledge[a]	Intervention (I)							0.01	0.91
	Intervention	168	2.23 ± 0.98	2.30 ± 0.98	0.07	0.79	0.43		
	Null	126	2.40 ± 0.94	2.49 ± 1.07	0.09	0.73	0.47		
	Bin (II)							0.00	0.95
	PRB	160	2.21 ± 1.00	2.28 ± 1.02	0.07	0.80	0.42		
	Brown	134	2.43 ± 0.91	2.50 ± 0.97	0.07	0.71	0.48		
	I + II							0.16	0.69
	Intervention + PRB	92	1.96 ± 0.97	2.02 ± 0.93	0.06	0.31	0.76		
	Intervention + Brown	76	2.31 ± 0.85	2.36 ± 0.94	0.05	0.68	0.50		
	Null + PRB	66	2.54 ± 0.89	2.58 ± 1.13	0.04	0.80	0.43		
	Null + Brown	60	2.56 ± 0.94	2.63 ± 1.00	0.07	0.36	0.72		
Plastic knowledge[b]	Intervention (I)							10.41	0.001**
	Intervention	178	1.65 ± 1.47	2.23 ± 2.64	0.58	2.64	0.01#		

(continued)

Table 10.3 (continued)

	Groupings for comparison	N	Pre ± S.D.	Post ± S.D.	Mean *Dif.*	Paired t-test		2-way ANOVA	
						t	Sig. (2-tail)	F	Sig.
	Null	126	1.82 ± 1.75	1.83 ± 2.03	0.01	0.04	0.97		
	Bin (II)							0.19	0.66
	PRB	163	1.90 ± 1.73	2.19 ± 2.57	0.26	1.25	0.21		
	Brown	141	1.48 ± 1.36	1.86 ± 2.12	0.38	1.77	0.08		
	I + II							0.04	0.85
	Intervention + PRB	97	1.24 ± 1.33	1.78 ± 2.75	0.54	1.36	0.18		
	Intervention + Brown	81	0.89 ± 1.25	1.42 ± 2.33	0.53	2.66	0.01[#]		
	Null + PRB	66	1.27 ± 1.83	0.99 ± 1.73	**−0.28**	0.35	0.73		
	Null + Brown	60	1.20 ± 1.14	0.80 ± 1.27	**−0.40**	−0.51	0.61		
Attitude[c]	Intervention (I)							1.72	0.19
	Intervention	166	4.36 ± 0.65	4.41 ± 0.61	0.05	0.74	0.46		
	Null	129	4.31 ± 0.54	4.48 ± 0.60	0.17	2.66	0.01[#]		
	Bin (II)							2.23	0.14

(continued)

Table 10.3 (continued)

	Groupings for comparison	N	Pre ± S.D.	Post ± S.D.	Mean *Dif.*	Paired t-test		2-way ANOVA	
						t	Sig. (2-tail)	F	Sig.
	PRB	162	4.33 ± 0.57	4.48 ± 0.535	0.15	3.04	0.00##		
	Brown	133	4.35 ± 0.63	4.38 ± 0.677	0.03	0.40	0.69		
	I + II							0.51	0.48
	Intervention + PRB	90	4.32 ± 0.55	4.40 ± 0.56	0.08	1.01	0.32		
	Intervention + Brown	76	4.41 ± 0.62	4.43 ± 0.66	0.02	0.07	0.94		
	Null + PRB	72	4.34 ± 0.52	4.49 ± 0.54	0.15	3.95	0.00##		
	Null + BB	57	4.27 ± 0.58	4.33 ± 0.70	0.06	0.51	0.61		
Perceived behavior[d]	Intervention (I)							0.32	0.57
	Intervention	163	3.50 ± 0.93	3.56 ± 1.04	0.06	1.05	0.30		
	Null	131	3.37 ± 0.76	3.53 ± 1.11	0.16	1.83	0.07		
	Bin (II)							6.58	0.011*
	PRB	169	3.36 ± 0.82	3.63 ± 1.06	0.27	3.42	0.00##		
	Brown	125	3.56 ± 0.91	3.44 ± 1.06	**−0.12**	−0.52	0.61		

(continued)

Table 10.3 (continued)

	Groupings for comparison	N	Pre ± S.D.	Post ± S.D.	Mean *Dif.*	Paired t-test		2-way ANOVA	
						t	Sig. (2-tail)	F	Sig.
	I + II							0.77	0.38
	Intervention + PRB	91	3.43 ± 0.92	3.63 ± 0.98	0.20	−0.44	0.66		
	Intervention + Brown	72	3.60 ± 1.14	3.47 ± 1.12	**−0.13**	−0.29	0.78		
	Null + PRB	78	3.24 ± 1.05	3.62 ± 1.20	0.38	3.02	0.00##		
	Null + Brown	53	3.50 ± 0.71	3.40 ± 0.99	**−0.10**	1.80	0.08		

Note [a]The maximum score for general knowledge was 5. [b]The maximum score for plastic knowledge was 14. [c]The maximum score for attitude was 4. [d]The maximum score for intended behavior was 8. The scores shown in the pre- and post-tests are the average values of the scores of the questions in the respective parts. Negative mean differences are shown in bold, indicating a drop in the scores in the results of the post-test (i.e., Post-test mean minus pre-test mean). $^{*}p < 0.05$; $^{**}p < 0.005$ in ANOVA; $^{\#}p < 0.05$; $^{\#\#}p < 0.005$ in t-test). Missing values were excluded. Bonferroni correction was done

Table 10.4 Significant improvements of pupils' KAB

		Pre-test		Post-test 2		Pair-T test		
		Mean	SD	Mean	SD	N	t	Sig.
General knowledge[a]								
Q2	According to the waste hierarchy, which of the following should be the first priority?	0.365	0.482	0.436	0.497	312	2.018	0.044*
	Plastic knowledge[a]							
	Plastic wrap/Cling film (Type 4)	0.065	0.246	0.152	0.360	309	3.647	0.000**
	Nylon bag (Type 7)	0.061	0.240	0.116	0.321	310	2.557	0.011*
	Lactic acid bacteria drink bottle (Type 6)	0.048	0.215	0.114	0.317	311	3.099	0.002**
	Food storage bags (Type 4)	0.039	0.194	0.078	0.268	308	2.069	0.039*
	Attitude (Eco-crisis)[b]							
Q1	There are/will be too many people living on earth now/in the future	3.99	0.95	4.25	0.89	286	3.98	0.00**
Q3	Humans are destroying the natural environment	4.26	1.07	4.44	0.90	283	2.37	0.02**
	Perceived behavior[b]							
Q2	I will remove the residue drinks and wash the plastic bottle before discarding it into the recycling bin	4.19	1.18	4.01	1.18	306	−2.42	0.02*
Q3	I will compress the plastic waste (if compressible) before discarding it into the recycling bin	3.25	1.48	3.57	2.17	307	2.29	0.02*
Q4	I will remove the non-plastic parts of the plastic waste (e.g., price tags) before discarding it into the recycling bin	3.43	1.45	3.78	2.74	306	2.07	0.04*

$^{*}P < 0.05$, $^{**}P < 0.005$

Note [a]The full mark for each question is 1. [b]The full mark for each question is 5. For the full scope of each part's questions refer to Appendix 2–5 factors, schools receiving interventions and using the PRB improved in the specific knowledge in sorting plastics ($p = 0.015$). Yet, without interventions, no matter which types of bins (PRB or BB) were used, schools' mean difference of scores between the pre- and post-tests dropped (refer to the bold digits in Table 10.3). Table 10.4 shows that pupils could remember the plastic types of some items well such as plastic wrap, nylon bags, lactic acid bacteria drink bottles, and food storage bags, with a significant increase in the post-test scores. Pupils were capable of distinguishing the types of plastic waste which are commonly seen in our daily life (for other items, please see Appendix 4). However, there was a slight decrease in the accuracy of identifying the correct types for some of the plastic items such as cleaning bottles, water bottles, CDs, shower curtains, and soft drink bottles. Pupils may not have been familiar with these kinds of plastic waste, which are not so common in school settings.

10.4.3 Attitudes Towards Plastic Waste Recycling

In Table 10.3, pupils' belief in the eco-crisis was quite positive in general, as shown in the pre-test. However, two statements showed a significant increase in the post-scores as reported in Table 10.4. More pupils agreed that there are more people living on earth in the future ($p = 0.00$) and that humans are destroying the natural environment ($p = 0.02$), which may reflect how they felt towards the local waste problems.

10.4.4 Procedural Knowledge of Plastic Waste Recycling

The mean difference in scores between the pre- and post-tests decreased in schools using brown bins no matter if there was intervention or not (Table 10.3). This shows that the use of the PRB significantly improved the procedural knowledge of pupils' recycling of plastic waste ($p = 0.013$). In Table 10.4, some items, such as question 3 (compression: $p = 0.02$) and question 4 (separation: $p = 0.04$), showed a significant increase. Yet, pupils still thought that cleanliness and sorting were difficult to follow, as reflected by the significant decrease in the post-test score in question 2 (cleanliness).

10.4.5 Promoting Action Competence for Plastic Waste Recycling

Peer influence in promoting indirect action was evidenced. From the group interview, the pupils reflected that they had become more environmentally-friendly after the program. They understood more about how plastic waste is related to the eco-crisis, and the seriousness of the environmental problems urges them to do more. Some of them wished to protect the earth and environment more for their future generations such as by influencing others to become greener. Pupils from the "full training course" reflected that they shared information with their peers and even their families.

> After joining the program, I am eager to take part in plastic waste recycling by practicing the recycling 4 steps (cleanliness, separation, compression, and sorting) and I have kept doing it (the practice) till the present. [Pupil A from Group2]

> I do share the knowledge of plastic waste recycling with my classmates, friends, and family as they don't know and have never heard (such knowledge) and I want to teach them…[Pupil B from Group2]

The indications printed on the PRB surface showing the examples of the plastic wastes by type for each compartment are colorful and informative. In schools using the brown bin with intervention, pupils reflected that the poster set allowed them to be more familiar with the knowledge of plastic types. Asked to rank the attractiveness of the poster sets on a 5-point scale (5 = the best), they scored the posters from 4 to 5. However, they did not mention that the brown bin could facilitate the enrichment of knowledge of plastic types.

> I will look at the poster and then clean my bottle before recycling (into the brown bin). [Pupil D from Group 3]

Pupils from the PRB schools said that they felt curious about the PRB in their schools and approached it. In contrast, the brown bin only has a single compartment that mixed all plastic wastes together so the pupils thought that it was meaningless to clean, separate, compress, and classify the plastic waste in advance. Although some pupils thought that they had to spend more time discarding their waste when using the PRB by following the proper recycling steps, the posters motivated them to use the PRB more often.

> I go near the recycling bin (PRB) and observe the notice of the bin. It is interesting to put plastics into different compartments. [Pupil E from Group 2]

> I did not further classify the plastic wastes into types when using the brown bin. [Pupil F from Group 3]

10.4.6 Promotion of Pupils' Commitment and Actions for a Future Sustainable Life

In the interviews, pupils mentioned the future commitment and actions for a sustainable life. Positive commitments were found in groups 1 and 2 (PRB only and PRB with poster intervention respectively). Pupils could describe the details of their commitment and wanted to perform better so that they can protect the environment. They therefore sought solutions to collecting the plastic wastes from school and even home, and dropped them into the PRB provided.

> I will take the plastic wastes from home to school and discard them in the PRB. [Pupil F from Group 1]

> I want to protect the earth. [Pupil G from Group 1]

> After the lessons, I want to actively participate in plastic recycling. Before, I thought that it was difficult so I did not do it. Now I think that it is quite easy and convenient, and I can do it whenever I can, so I will do it when I have time (to approach the PRB). [Pupil H from Group 2]

> I want to participate more and perform the 4-steps properly as I don't want to see the end of the world approaching. [Pupil I from Group 2]

Interestingly, pupils from groups 3 and 4, who were using the BB with or without posters respectively, showed a rather passive response towards future commitment to a sustainable life. Thus, together with the data shown in the previous paragraphs, recycling competence requires proper education, promotion, and a suitable tool to evoke the pro-environmental outcomes.

> I will spend more time noticing the type of plastic wastes that belongs to…[Pupil J from Group 3]

> I did not use the brown bin because I am lazy. …[Pupil K from Group 4]

> I did not know the location of the brown bin so I did not use it. [Pupil L from Group 4]

10.4.7 Improved Recycling Qualities Using PRB

The status of plastic waste served as the evidence of action competence in plastic waste recycling, indicating a better performance of pupils from schools using the PRBs in terms of the recycling parameters. SEP and COM were significantly improved in schools using the PRB ($p < 0.005$). Although there were no significant differences in CLE, a higher percentage of plastic waste from those schools using the PRBs was cleaner (62.85% > 56.94% for brown bin schools, excluding the baseline data) (Table 10.5).

As for plastic waste sorting accuracy, the plastic waste was checked for the correct type in each plastic compartment of the PRBs each week. The polyethylene terephthalate (PET) compartment's sorting accuracy was similar for the two groups with or without intervention (Fig. 10.2). The total amount of plastic waste collected from group 2 (PRB with poster invention) was higher than that from the group 1 (PRB only) schools, at 1.66 kg/week versus 1 kg/week, respectively with $p = 0.066$ (One-way ANOVA). Although the result was not yet significant, the PRB with intervention could attain a higher usage rate.

Table 10.5 Recycling performance of using the brown bins and the PRBs in the schools

Step[a] type of bin		N^b	Mean%	SD%	F	Sig.
CLE	Brown bin	35	56.94	32.83	0.66	0.42
	PRB	32	62.85	25.84		
SEP	Brown bin	35	37.17	26.90	14.22	0.00**
	PRB	32	60.78	24.08		
COM	Brown bin	35	28.00	29.85	12.76	0.00**
	PRB	32	52.91	26.95		

[a] *CLE* Cleanliness; *SEP* Separation; *COM* Compression
[b] *N* is the number of weeks
** $P < 0.005$, One-way ANOVA test

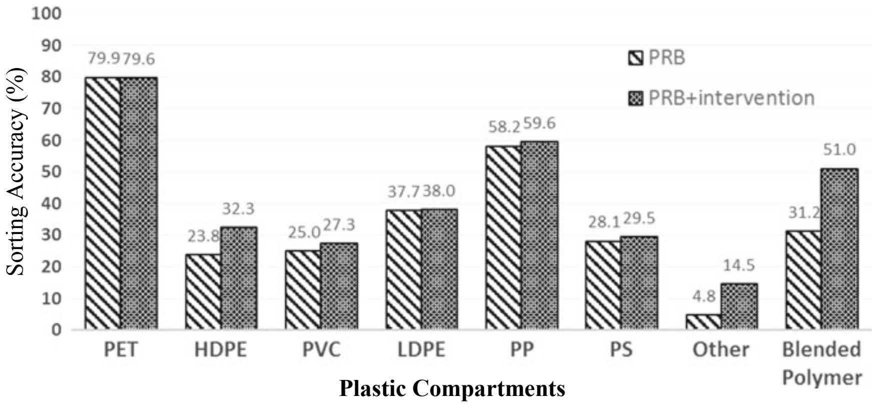

Fig. 10.2 Plastic waste sorting accuracy (%) when using the PRB with and without intervention

10.5 Discussion

10.5.1 Effective Recycling Program Using the PRB in Combination with Intervention

Through incorporating the school-based action competence approach into the program design for plastic waste recycling in schools, the program successfully enhanced pupils' learning of plastic waste recycling, especially with the use of the PRB and the interventions to sustain pupils' intention and behavior to use the bin properly. As reflected in the improved plastic waste data, the PRB with interventions strengthened the pupils' sorting accuracy of plastic waste, which is attributable to the additional sources of information provided by the posters. Plastic knowledge of classifying plastic types was significantly enhanced, which may facilitate their waste handling process. The PRB also enhanced the behaviours among pupils, such as recycling the plastic waste by type and performing the recycling steps in advance, as they found that putting the plastic waste into the corresponding compartment was interesting. Besides, a higher proportion of plastic waste was found to be separated and compressed after using the PRB. More importantly, this provided an opportunity for pupils to practise the recycling action. On the other hand, use of the BBs may have discouraged the pupils from performing 4-step recycling, especially the classification, even though they understood the recycling principles and knowledge better after the interventions, as the BBs only contain one compartment which makes it meaningless to further process the plastic waste before discarding it. In comparison, the PRB contains eight compartments that allow pupils to discard their plastic waste according to type, providing practical meaning for classifying the waste in advance.

Interestingly, it is observed that there were very mild increases in the pupils' KAB after joining the program as a whole compared with the starting survey. Similar results were also reported by Goodwin et al. (2010) that school pupils tend to raise their pro-environmental attitudes a little after knowing their school has participated in green programs (a Hawthorne-type effect). The face-to-face interviews allowed the research team to understand the pupils' pro-environmental attitudes in more detail. The interviews reflected that pupils from the treatment groups were quite positive about the use of the PRB. The PRB further encouraged the pupils' recycling methods, and gave them opportunities to practice the actions.

10.5.2 Importance of a Strategic Intervention in Plastic Recycling

10.5.2.1 Promotion of Direct Environmental Actions

Application of the PRB in primary schools is practical and meaningful for improving plastic recycling as a direct activator. Pupils could experience new ways of recycling by understanding the types of plastics and performing the 4-step recycling procedure. The present study reveals that the initial step to change the behavior of plastic recycling requires a tailor-made recycling bin (PRB) as an education tool, and interventions. The PRB can be an education tool to fill the gap in the teacher's guide book published by the Environmental Protection Department (2011). Thus, installing recycling bins and adopting appropriate strategies can positively direct environmental action. In a college campus recycling intervention designed by Largo-Wight et al. (2013), it was found that an increase in recycling bins largely and significantly encouraged the recycling outcome. With the PRB, pupils can now sort the plastic types and discard them into their corresponding compartment for storage. This is an environmental action for solving the poor condition of plastic waste in recycling bins and maintaining its recyclable value.

To guide pupils to use the PRB, poster displays are treated as a low cost and technical intervention but with positive effects in many recycling campaigns (Cole & Fieselman, 2013; Delprato, 1977; Kalsher, Rodocker, Racicot, & Wogalter, 1993). Information provided by the posters can be declarative, such as the plastic types and examples of plastic waste, or can be procedural-oriented such as showing the recycling steps based on the classification of Gagne, Yekovich, and Yekovich (1993). Iyer and Kashyap (2007) supported that both information types are effective in terms of influencing recycling performance, which is more practical than using incentive strategies. Yet, the location of the posters should be installed in eye-catching and easy-to-reach locations for positive outcomes (Geller, Chaffee, & Ingram, 1975). Therefore, the posters were posted in every classroom of the assigned schools as prompts and a source of information to remind pupils of the four proper steps of plastic waste recycling. Posters were also posted next to the PRBs, which made them convenient for the bin users to perform the recycling steps immediately before discarding their recyclables. Since a single intervention with a poster may not be effective for the ultimate goal of the program, as pupils had to approach the poster to read the information, a thorough knowledge base of plastic waste management will help sustain the proper recycling behaviors in the longer term (Iyer & Kashyap, 2007).

10.5.2.2 Creating Educational Contexts for Indirect Environmental Actions

Green training courses were conducted in the treatment schools in addition to the poster intervention to further strengthen the pupils' KAB of plastic recycling. They could then help spread the green messages to others. In the interviews, the pupils reflected that they shared what they had learnt from the training course with others, but the spillover effect still has room for improvement in the primary school setting. However, combining the interventions with the use of the PRB, both strategies could enhance the recycling outcome observed in the present study.

10.5.3 Limitations of the Present Study

It was shown that pupils from the schools using the PRBs with or without intervention were already very good in terms of their pro-environmental attitudes. A more significant level of enhancement in attitudes may require greater efforts for their attainment. Smeesters, Warlop, and Abeele (2001) considered that attitudes are stable characteristic features of every person and may not be easily changed. Thus, a 3-week intervention and the presence of the PRBs may not be sufficient for promoting attitude changes among pupils, as reflected in the NEP. Besides, due to the limitation of time and space, the training course was only open to a certain quota of pupils (70 pupils/school) in the hope of providing intensive training for the pupils as green ambassadors.

To further promote proper plastic recycling, PRBs can be installed in different locations such as secondary schools, university or college dormitories, offices, shopping malls, or housing estates. However, effective promotion schemes have to be studied as different locations target different users. To engage more people of different backgrounds in using the PRBs, interventions and the action competence approach are worth investigating to promote recycling. Education does exert a great influence on improving the environment and nurturing a sustainable future by promoting action competence for a green lifestyle. The present study encourages environmental educators to develop and justify the strategies of the surrounding environmental issues and put them into practical educational use, with positive action as feedback.

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Appendix 1: Detail of the Plastic Classification of the PRB (EPD, 2011)

	Plastic types	Examples
1.	PET	Soft drink, water bottles
2.	HDPE	Detergent or juice bottles
3.	PVC	Disinfectant container, pipes, shower curtains or plastic labels
4.	LDPE	Packaging or plastic bags
5.	PP	Liquid containers, folders or cups
6.	PS	CD cover, live lactobacillus drink bottles or foam container
7.	Others	Toys, nylon, pump dispensers
8.	Blended polymer	Plastics with other materials blended

Appendix 2: Pupils' General Knowledge of Waste Management

	Pre-test		Post-test 2		Pair-T test		
General knowledge	Mean	SD	Mean	SD	N	*t*	Sig.
How many current operating landfill sites are there in Hong Kong?	0.850	0.358	0.853	0.355	313	0.132	0.895
Which of the following is/are the source(s) of municipal solid waste in Hong Kong?	0.586	0.493	0.589	0.493	309	0.093	0.926
In which of the following time periods is the SENT Landfill site in Tseung Kwan O expected to reach saturation?	0.324	0.469	0.295	0.457	312	−0.943	0.346
According to the waste hierarchy, which of the following should be the first priority?	0.365	0.482	0.436	0.497	312	2.018	0.044*
According to the government plan of SENT Landfill site expansion, which of the following types of land is planned to be used?	0.180	0.385	0.213	0.410	300	1.179	0.239

*$P < 0.05$

Note The full mark for each question in Table 10.1 is 1

Appendix 3: Interview Questions

(a) Compulsory questions

1. How do you know about different types of plastic?
2. After joining this program, did you spend extra time understanding more about plastic recycling, classification and the 4 steps of recycling?
3. In your opinion, what threats would plastic waste pose to the environment?
4. Do you want to participate more in plastic classification and the 4 steps of recycling?

(b) For schools with posters

5. Is the poster design appealing to you? (1–5 marks, 5 marks = very appealing)
6. Did the poster help you to know more about plastic classification?

7. Can you comment on our poster? Any improvements needed? (can show the poster)

(c) For schools with PRB

8. Have you ever used the PRB recycling bins on campus? (if yes) Did you read the recycling hints on the boxes (i.e., the 4 Recycling Steps) before recycling?
9. Have you faced any difficulties when using the PRB recycling bins?

(d) For schools with Brown bins

10. Have you ever used the brown plastic recycling bin? (if yes) Did you do the 4 recycling steps before recycling rubbish? Why or why not?
11. Have you faced any difficulties when using the Brown bins?

Appendix 4: Pupils' Knowledge of Types of Plastic Waste

Correct type	Plastic items	Pre-test		Post-test 2		Pair-T test		
		Mean	SD	Mean	SD	*N*	*t*	Sig.
4	Plastic bag	0.094	0.292	0.100	0.300	310	0.308	0.758
2	Cleaning product bottle	0.162	0.369	0.152	0.360	309	−0.366	0.715
1	Disposable water bottle	0.160	0.367	0.127	0.334	307	−1.251	0.212
4	Plastic wrap/cling film	0.065	0.246	0.152	0.360	309	3.647	0.000**
6	Styrofoam takeaway box	0.035	0.185	0.061	0.240	311	1.515	0.131
7	CD	0.103	0.304	0.100	0.300	311	−0.135	0.893
5	Disposable straws	0.049	0.215	0.065	0.246	309	0.845	0.399
5	Disposable water bottle cap	0.074	0.263	0.078	0.268	309	0.156	0.876
3	Credit card	0.049	0.216	0.078	0.269	307	1.621	0.106
3	Shower curtain	0.081	0.273	0.065	0.246	309	−0.780	0.436
1	Soft drink bottle	0.126	0.333	0.113	0.317	309	−0.516	0.606
7	Nylon bag	0.061	0.240	0.116	0.321	310	2.557	0.011*
6	Lactic acid bacteria drink bottle	0.048	0.215	0.114	0.317	311	3.099	0.002**
4	Food storage bags	0.039	0.194	0.078	0.268	308	2.069	0.039*

$^{*}P < 0.05$, $^{**}P < 0.005$

Note The full mark for each question in Table 10.2 is 1

Appendix 5: Scope of Attitude and Perceived Behavior Measurement

Attitude (Eco-crisis) (1 = totally disagree to 5 = totally agree)
Q1 There are/will be too many people living on earth now/in the future.
Q2 Plants and humans have the same right of survival
Q3 Humans are destroying the natural environment
Q4 Humans have sufficient wisdom to prevent the decay of the earth
Q5 Humans have to follow the rules of nature
Q6 Humans destroy the nature will bring up bad consequences
Q7 The natural environment have the sufficient power to reverse the problems created by the humans in morden daily life
Q8 Humans are the master of all things
Q9 Humans will understand the principles of the nature and be capable to control the natural environment
Q10 There will be great natural disasters if the situation is not improved
Perceived behavior (1 = never to 5 = always)
Q1 I will remove the cap and package of the plastic bottle before discarding it into the recycling bin
Q2 I will remove the residue drinks and wash the plastic bottle before discarding it into the recycling bin
Q3 I will compress the plastic waste (if compressible) before discarding it into the recycling bin
Q4 I will remove the non-plastic parts of the plastic waste (e.g., price tags) before discarding it into the recycling bin
Q5 I aware of different texture of plastic wastes
Q6 I will tie a lot or compress the plastic bag before discarding it into the recycling bin
Q7 Most of my rubbish/wastes are made from plastics
Q8 When processing rubbish/wastes, I will sort the plastic waste out for recycling

The full mark for each question is 5

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Chi Chiu Cheang is an Associate Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong (EdUHK). Dr. Cheang received his doctoral degrees from the Chinese University of Hong Kong. He was trained to be an environmental ecologist. His research expertise includes the ecology, taxonomy, phylogenetic inference and phylogeographic studies of marine organisms. Dr. Cheang extended his research interest to the education for sustainability and environmental education, particularly on the experiential learning in the field-based, place-based and service-based pedagogies, after joining EdUHK.

Tsz Yan Cheung received her Ph.D. degree in reproductive biology from the University of Hong Kong (HKU). She then further completed the professional teacher training, postgraduate diploma in education at the Chinese University of Hong Kong (CUHK) with major in biology and minor in music teaching. She is currently a Post-doctoral Fellow at the CUHK and has attained rich interdisciplinary experiences in both scientific and social science research. Her major research interests include environmental education, science education, toxicology, public health, aging and gerontology.

Winnie Wing Mui So is a Professor of Department of Science and Environmental Studies at the Education University of Hong Kong, and the Director of the Centre for Education in Environmen-

tal Sustainability. Her main research areas are STEM education, science and environmental education. She has been active with professional contribution, being the past president of the Asia-Pacific Education Research Association and executive member of the World Education Research Association, Hong Kong Educational Research Association and East Asian Association for Science Education.

Irene Nga Yee Cheng is an Assistant Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong. Research interests of Dr. Irene Cheng include geographical education, interdisciplinary curriculum and teacher knowledge and development. As an experienced teacher educator, her teaching foci relate to the development of interdisciplinary subjects, including General Studies, Environmental Studies, Geography, as well as integrating pedagogical content knowledge and curriculum and methods of the subjects outlined above. Dr. Cheng is also the Chair of the Geography Curriculum Development Committee under the Education Bureau, Hong Kong since 2014; and the Hong Kong Geographical Association in 2017 to 2019.

Lincoln Fok is an Associate Professor of the Department of Science and Environmental Studies at the Education University of Hong Kong. He is a believer of, and practices experiential learning. By training, his research focuses on hydrology and geomorphology with a particular concern on the impacts of water and sediment quantity and quality along with their implications on the environment. More recently, his research has also been extended to marine debris, eco-tourism, protected area management, environmental consciousness and education for sustainability.

Chi Ho Yeung received a B.Sc., an M.Phil., and a Ph.D. degree in Physics from the Hong Kong University of Science and Technology (HKUST). He then worked as a postdoctoral research fellow in University of Fribourg in Switzerland and Aston University in the United Kingdom for 4 years. He is currently an Associate Professor at The Education University of Hong Kong. His major research interests include statistical physics, disordered systems, optimization, transportation networks, recommendation systems, complex and social networks, and the application of information technology in education.

Cheuk Fai Chow is an Associate Professor of Department of Science and Environmental Studies and the Director of Knowledge Transfer at the Education University of Hong Kong. He received his B.Sc. (Applied Chemistry) and Ph.D. from the City University of Hong Kong. He obtained a Croucher fellowship and did his post-doctoral training with Nobel laureate Jean Marie Lehn (The University of Strasbourg, France). His research interest lies in applying his environmental studies for energy, water resource and plastic waste studies.

Chapter 11
Solid Waste Management in Tourist Destinations in Developing Nations: Case Studies in Hoi An, Vietnam, and Puncak, Indonesia

Jane Singer, Kinh Thi Kieu and Andrea Emma Pravitasari

Abstract Waste management presents special challenges for tourism destinations in the developing world. Although large tourist inflows and accompanying development can greatly increase the volume of municipal waste, affluent travelers expect high aesthetic and sanitary standards to be met. Local governments often lack sufficient capacity to handle waste sustainably and local awareness of the need for waste segregation, recycling, or other practices may be low. In this chapter, the authors discuss two projects—in urban Hoi An, Vietnam, and rural Puncak, Indonesia—that are attempting to raise awareness and community capacity for waste management by involving local university students, researchers, government, and community groups in innovative waste education initiatives. The issues involved in solid waste management in rural and urban destinations may vary, as urban sites may find it easier to attract ODA or other external funding and expertise for implementing waste collection and treatment. In both case studies, however, students and researchers accrue diverse benefits from participation in collaborative projects, while residents and local governments benefit from large reserves of volunteer labor, expertise, and exchanges. The challenges for both sites include funding, overcommitted university faculty, conflicts between project and academic schedules, and the difficulty of changing long-ingrained household waste practices. The chapter concludes with recommendations for improved university and community engagement for CBSWM initiatives.

Keywords Waste education · Solid waste management · Ecotourism · Community resilience · Stakeholder collaboration

J. Singer (✉)
Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan
e-mail: singer.jane.6e@kyoto-u.ac.jp

K. T. Kieu
The University of Science and Education, The University of Danang, Da Nang, Vietnam

A. E. Pravitasari
Bogor Agricultural University (IPB University), Bogor, Indonesia

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11.1 Introduction

International tourism is among the greatest source of export earnings in many emerging economies, with tourist arrivals in developing countries accounting for 46% of total international arrivals in 2011 (United Nations World Tourism Organization, n.d.). Tourism can serve as a catalyst for infrastructure development, rapid and dynamic economic growth and burgeoning employment throughout the developing world (Glasson, Godfrey, & Goodey, 1995), but overly rapid tourism growth may eventually trigger its own decline (Wong, 1998), imperiling long-term sustainability as it threatens the natural resources—wildlife, coastal reefs, forests, water bodies—and aesthetic beauty that initially attracted tourists. In this context, it is clear that sustainable tourism is contingent upon managing growth-induced stressors such as the increasing generation of solid waste (SW). However, for tourism sites in many developing nations, low institutional capacity, scarce funds, and low levels of local awareness may complicate the challenge of managing increased solid waste. Localities in developing countries often suffer from low rates of waste collection, irregular collection, open dumping and burning, weak legislation and waste regulations, a lack of leaching and other pollution controls, and infestation by vermin and insects (Manaf, Samah, & Zukki, 2009).

A hotel guest can produce an average of 1 kg of solid waste per day, according to Zorpas, Voukkali, and Loizia (2015). International travelers, with greater consumption and larger per capita hotel floor space, account for greater waste than domestic visitors, as suggested by a survey of beach resorts in the Maldives that found that visitors at larger resort hotels accounted for 1.5 times more waste than those at small hotels (Brown, Turner, Hameed, & Bateman, 1997). In many municipalities and resort areas in emerging nations, solid waste continues to be burned in open fires or buried nearby, producing dioxins and leaching into groundwater. Local governments in tourist sites must also deal with what has been labeled the "tourism effect," namely differences in waste composition from that of other areas, with higher than locally prevailing ratios of nonbiodegradable waste such as PET bottles, plastic packaging, aluminum cans, increased roadside litter and marked seasonal variation in waste volume (Gidarakos, Havas, & Ntzamilis, 2006).

For tourism to contribute to sustainable development, it must be "economically viable, ecologically sensitive and culturally appropriate" (Mbaiwa, 2003). Resources must be managed to benefit those not directly employed in tourism, and solutions to problems such as increased waste must be inclusive and participatory, based on increased awareness of the 3Rs (reduce, reuse, and recycle) and predicated on replacement of informal sector livelihoods like waste scavenging for the economically marginalized with other sources of income such as recycling or composting (Mbaiwa, 2003). Raising public awareness of the need for reducing litter, source segregation of waste and the benefits of recycling and composting is critical to achieve effective solid waste management (Moghadam, Mokhtarani, & Mokhtarani, 2009; Babayemi & Dauda, 2009), but public awareness is generally low in developing countries, directly impacting waste volume and collection efficiency as well as environmental health.

Community participation in waste separation has been found to be the key to success in efforts to recycle organic waste (Boonrod, Towprayoon, Bonnet, & Tripetchkul, 2015). According to a study of waste separation in Hanoi (Nguyen, Zhu, & Le, 2015), positive behavior change is promoted when the desired activity is not overly demanding or inconvenient, when residents express trust in the effectiveness of local rules and regulations and information exchange, and when residents are assured of reciprocity, that is, that others are also cooperating with waste separation initiatives. Awareness can be raised through formal, school-based education as part of Education for Sustainable Development curricula and through nonformal approaches targeting the public via mass media, public awareness campaigns, and utilization of social networks. School-based education can combine both formal curriculum and nonformal place-based activities such as roadside and river litter campaigns or composting for school gardens. Complementary formal and informal education often occurs, as when children share learning about waste management with their parents, influencing household practices (Maddox, Doran, Williams, & Kus, 2011; Grodzinska-Jurczak, Bartosiewicz, Twardowska, & Ballantyne, 2003). This chapter will explore efforts implemented in two popular tourist destinations—Hoi An in central Vietnam and Puncak adjoining Bogor, Indonesia—to educate students and local residents and promote improved community-based solid waste management. The two sites were selected since both are burdened by increasing demand and limited capacity for managing waste resulting from domestic and international tourist inflows, yet since Hoi An is urban and Puncak is in a remote upland area the approaches adopted in the two sites for improving community awareness and institutional responses have greatly varied.

11.2 Community-Based Waste Management and Education in Hoi An, Vietnam

Hoi An is a provincial city in Quang Nam province, central Vietnam, located on the northern bank of the Thu Bon River on the south-central coast. The city consists of nine urban wards and four communes, including the Cham Islands (Fig. 11.1), with a total population of 92,000 and a total area of 61.71 km^2 (Quang Nam People's Committee, 2014) (Fig. 11.2).

Hoi An was recognized as a UNESCO World Heritage Site in 1999, due to its ancient Chinese and Japanese architecture, temples, and other historical monuments and its cultural and artistic heritage. A well-preserved port city active in trade and shipping throughout Southeast Asia, 2,000-year-old Hoi An is known for its tangible and intangible heritage, including streetscapes, festivals, cuisine, and performing arts (Marks, 2008). Local economic stagnation during most of the twentieth century helped account for preservation of the city's ancient architecture, but the

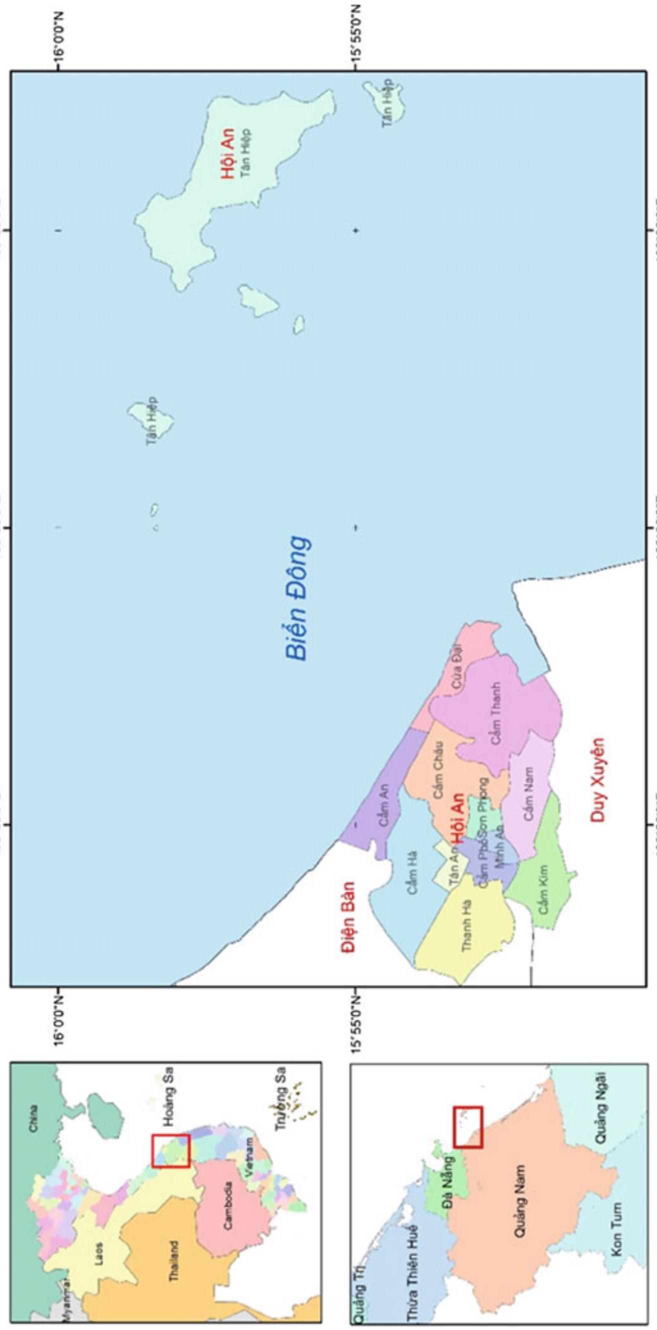

Fig. 11.1 Administrative map of Hoi An. *Source* Based on GIS data from the Hoi An People's Committee

Fig. 11.2 Hoi An's historic district. Photo with permission from Tran Dinh Dung

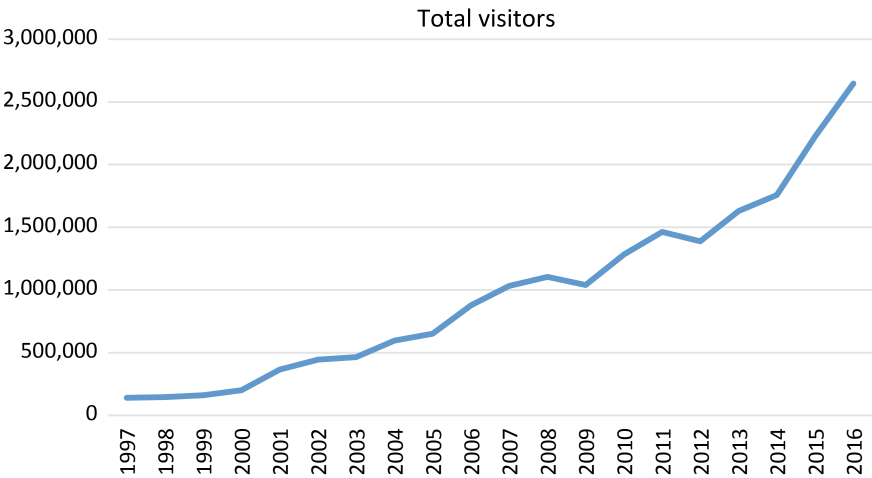

Fig. 11.3 Total visitors to Hoi An by year. *Source* Hoi An Department of Commerce and Tourism (2016)

1980s brought the onset of local tourism (Di Giovine, 2009). Tourism dramatically expanded during the 1990s, increasing by a magnitude of nearly 50 times, from 3,400 tourists in 1991 to 160,314 tourists in 1999 (UNESCO, 2000, 2008). The trend continued, as shown in Fig. 11.3. Hoi An received its millionth visitor in 2007, the eighth million visitor in 2015 and the tenth million in May 2017 (Hoi An Department of Commerce and Tourism, 2016).

Hoi An is considered one of the most sustainable tourist destinations in Vietnam, with broad collaborative efforts to conserve both the local heritage and the environment undertaken by governmental organizations, enterprises, and local residents. The Lantern Festival, for instance, is held on the 15th day of every lunar month by Hoi An residents to allow tourists to experience pre-modern life in Hoi An. Tourism has benefited Hoi An by promoting economic development, job opportunities, and rapid urbanization. Tourism and related commerce is now the biggest economic sector in Hoi An, accounting for 68% of total municipal revenues (Hoi An Department of Commerce and Tourism, 2016). However, it has also brought adverse environmental impacts. The growing number of visitors results in increased traffic, noise and air pollution, as well as a growing volume of waste requiring collection and disposal (Marks, 2008).

11.3 Solid Waste Management in Hoi An

Municipal solid waste collection commenced in Hoi An in 2003 and has been upgraded in recent years due to international development assistance from Japan and multilateral funds like the Global Environment Facility (GEF) that have enabled the hiring of staff, and the introduction of modern sanitation trucks and waste treatment. The city's total volume of solid waste (SW) keeps increasing along with the number of tourists and rising living standards, and it is expected that the main municipal landfill located in Cam Ha will exceed its capacity in the near future. The total volume of solid waste (SW) in Hoi An is presented in Fig. 11.4.

Solid waste in Hoi An (see Fig. 11.4) is managed by Hoi An Public Works Joint Stock Company (Hoi An PWJSC), a private company with a monopoly on waste

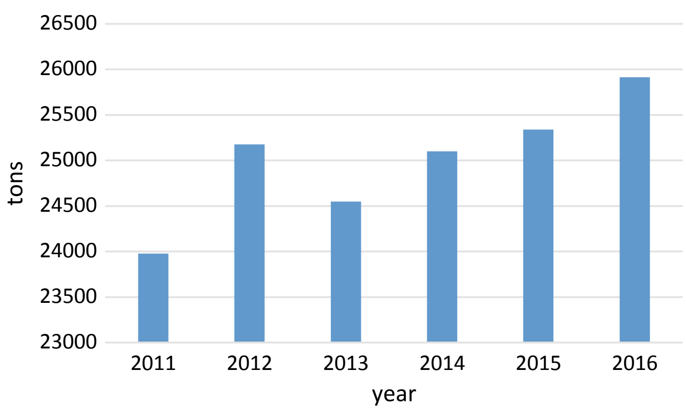

Fig. 11.4 Solid waste in Hoi An by year. *Source* Hoi An Department of Natural Resources and Environment (Hoi An DoNRE) (2017)

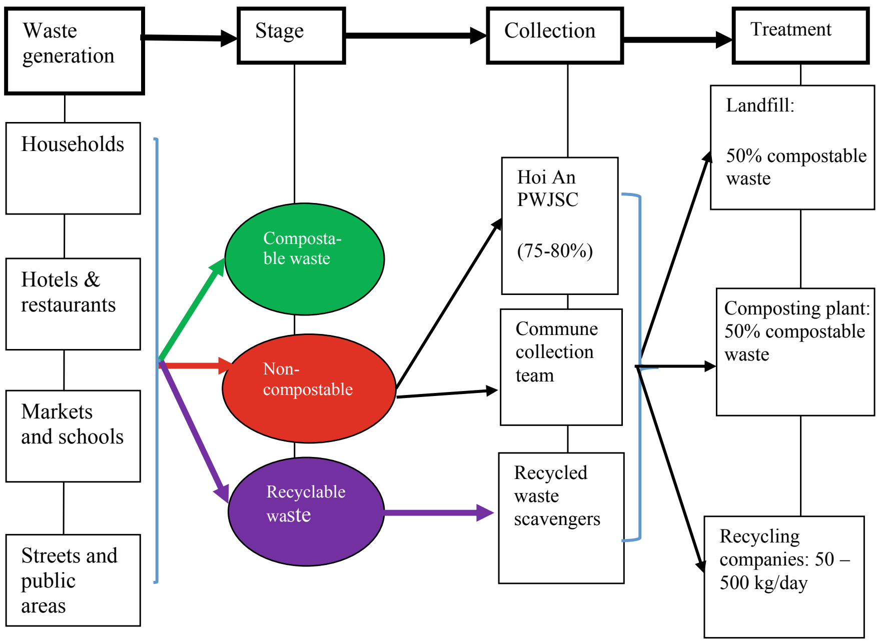

Fig. 11.5 Solid waste management system in Hoi An. *Source* Adapted from Chu (2014), with permission from Chu Manh Trinh

collection. The total amount of SW collected in Hoi An is approximately 75 tons per day, of which 60% is organic waste (accounting for 400–500 kg/m) (Hoi An DoNRE, 2017). The collection rate is 85%, commensurate with the average rate for urban areas in Vietnam (Hoi An DoNRE, 2017). The collection rate in urban areas is relatively high (95–100%) and lower in suburban and rural areas (60%) (Hoi An DoNRE, 2017). The solid waste management (SWM) system is presented in Fig. 11.5.

Solid waste is segregated at the source before collection, primarily by Hoi An PWJSC. In some rural areas, a commune collection team helps to collect waste from households and transfer it to landfill. Most recyclable waste is collected by scavengers and sold to recycling companies. In September 2012, a composting plant was installed in Hoi An. Currently, the plant composts around 55 tons of SW daily, producing 1,600 tons of composted fertilizer per day of which 1,230 tons are locally utilized (Hoi An DoNRE, 2017). Subsequently, in 2016, a garbage incineration plant was installed to reduce landfill overload. Solid waste management (SWM) in Hoi An has developed with the assistance of various funding organizations including the United Nations Industrial Development Organization (UNIDO), UNESCO, and particularly JICA (Japan International Cooperation Agency), Japan's overseas development agency, a very active donor that provides Hoi An not only with funds but also consultation to achieve eco-city status. JICA has conducted a project on solid waste management in Hoi An city in cooperation with Naha city, Okinawa prefecture, with a grant of US$11.2 million.

It is worth noting that Hoi An is one of the first cities in Vietnam to successfully segregate solid waste for composting. The segregation rate of 75% is quite high (Hoi An DoNRE, 2016). This rate has been attributed to the city's establishment of an incineration plant and composting plant, pro-sustainability civic leaders who have actively solicited ODA and other funding for improving waste management, and enactment of local fines for littering and environmental pollution (Decree 155/2014/ND-CT). However, without doubt a principal reason for this success is the pairing of community-based solid waste management (CBSWM) activities with diverse SWM awareness campaigns run by international organizations, local authorities, schools, researchers, civil society, and local residents, including programs entitled "Say No to Plastic," "Home Composting," "Women and Solid Waste Segregation," "Schools with Environmental Education," "Farmers Manage Agricultural Wastes", and "Business Sectors with Environmental Protection."

JICA has sent at least four volunteers who could communicate in Vietnamese to Hoi An's Department of Natural Resources (DoNRE) to train the staff in conducting environmental education (EE) activities such as games, school activities, mobile EE classes, solid waste segregation, 3R education, and a campaign entitled "Clean Home, Clean Town, Clean City." Instruction by the JICA volunteers helped to build the capacity of the local DoNRE staff for EE, enabling them to conduct EE and solid waste education via training workshops at wards and communes. The local heads of important mass organizations, especially the Women's Union and Farmers' Union, two nationwide government-linked groups with a membership of over 10 million each, have actively encouraged their communities to carry out solid waste segregation from an early stage.

11.4 History and Description of Waste Education Activities

Environmental education plays an important role in promoting SWM in Hoi An. As a World Heritage city, Hoi An has received various types of project grants for improving environmental quality, including many focusing on education. A 2010 project by JICA, for example, sought to embed EE across the education system in Hoi An. After the project term ended, JICA continued to sponsor Japanese volunteers who have led environmental education initiatives in Hoi An schools with such themes as refusing to use plastic, litter campaigns, solid waste segregation, and the 3Rs.

Hoi An has been selected to host many sustainability-related training courses because of its vision of environmentally friendly development. The course "Sustainability Field School", for example, has been sponsored annually since 2014 by Action Center for City Development (ACCD), a local NGO, teaching Vietnamese students to compost waste for organic farms, among other topics. In August 2017, Vietnamese Youth and Sustainable Development Summit (VYS), a forum for young

Vietnamese interested in sustainability, decided to hold their training activities in Hoi An.

The tertiary education sector has also benefited from EE initiatives. The University of Education-The University of Danang (DUEd) established a partnership with the Management Board of the Cham Islands Marine Protected Area (MPA), a governmental organization founded by UNESCO and the Hoi An government when the Cham Islands became a World Biosphere Reserve in 2009. To improve student understanding of SWM and CBSWM, since 2014 DUEd has collaborated on a training course with an MPA expert who successfully mainstreamed the 3Rs in Cam Ha Ward and Cam Pho Commune and initiated a complete ban on plastic in the Cham Islands.

Solid waste education at many universities in Vietnam concentrates on technology and theory but offers few hands-on activities for students, even though in many rural or suburban areas of Vietnam application of such technologies remains limited. Information about more feasible 3R and small-scale applications for managing SW is rarely provided. For the training course, a DUEd lecturer worked with the MPA expert to revise the syllabus with hands-on activities and practical knowledge that would improve student competencies and awareness. For instance, student volunteers joined MPA-hosted group discussions with local communities to learn about the challenges of solid waste segregation. Subsequently, the DUEd lecturer and the MPA expert co-taught classes and led students on field visits to Cham Islands and Hoi An's ancient town.

11.5 Achievements and Challenges of the Projects

Three students who were involved in the training course were interviewed to evaluate the course effectiveness as a model for collaborative waste education between universities and local organizations. The students identified the following outcomes of the course:

- Connected classroom learning with real-life examples.
- Learned more practical knowledge.
- Strengthened their relationship with local communities in Hoi An and Cham Islands as volunteers.
- Inspired thesis research.
- Enhanced personal skills.
- Assisted with job recruiting.

This co-teaching model also promoted the university's community outreach, which enables university professors to establish long-term partnerships with local organizations and communities for further research. The local communities and organizations, in turn, can benefit from the human resources of the university. In fact, according to the MPA expert, although the 3R project in Cam Ha Ward and Cam Pho Commune ended in 2014, the involvement of students and university lecturers has encouraged local residents to continue segregating SW and practicing home composting. Today, with the assistance of DUEd and MPA staff, the 3R model is scaling up in other districts of Quang Nam province like Dien Ban and Nui Thanh.

The success of this co-teaching model can be attributed to the strong support of the current dean, a positive relationship between DUEd and MPA, and the enthusiasm of several faculty lecturers and MPA staff who helped to guide students during their fieldwork. Yet the program has some challenges. Much time and energy are required to not only revise the syllabus but also to lead students to work with communities, adding to the administrative burden. In addition, continuity and the transfer of the model to other staff at both DUEd and MPA after core members leave may be difficult.

11.6 Waste Management and Environmental Education in Rural Puncak—Bogor, Indonesia

Puncak is the most popular tourist destination for residents of Jakarta—the capital city of Indonesia—and its satellite cities. It is located on the upstream Ciliwung river watershed in the southern part of Bogor Regency in West Java. The region has an area of 14,587.06 ha covering 27 villages (Desa) in the four districts of Megamendung, Cisarua, Sukaraja, and Ciawi (see Fig. 11.6). Puncak plays multifunctional roles in both conservation and tourism (Rustiadi, Iman, Pravitasari, & Mulya, 2014) due to its location in the most populated urban cluster in Indonesia and upstream of the Ciliwung watershed, the main river flowing through Jakarta. The management of the upstream watershed ecosystem affects the sustainability of watershed ecosystems downstream. Flooding occurs virtually every year in downstream urban areas, especially during the rainy season in January and February; an estimated 80 people died during the worst recorded flooding in 2007. The severity of the floods has increased in recent years, exacerbated by the volume of solid waste carried downstream by the Ciliwung River. The significance of the Puncak area was recognized by a Presidential Decree (54/2008) directing the area to maintain an ecological balance as a water catchment area and for flood control (Pravitasari, Rustiadi, Mulya, Iman, & Fuadina, 2017).

Puncak is known for its natural beauty, cool air, and wealth of biological resources, offering visitors a mountainous landscape of tea plantations located at an altitude of 1,000 m above sea level. The increasing number of villas and tourism resorts in this area has spurred local economic development, as the population and built-up areas have expanded rapidly. According to Alihar (2002), the total population of Puncak increased from 5.7 million in 1980 to 11.7 million in 2000. Rapid development has transformed forests, agricultural areas, and water catchment areas into residential, industrial, and commercial areas, resulting in various adverse environmental impacts, including floods, erosion, and landslides in Puncak and surrounding areas. It has also been accompanied by the increasing accrual of unmanaged inorganic waste. Refuse piles are increasingly prevalent along the banks of the Ciliwung River. The most

Fig. 11.6 Location of Puncak Area. *Source* Map prepared by Andrea Emma Pravitasari

abundant SW is on roadsides, produced by small stalls along the road and littering by tourists. Waste collection trucks transport both wet and dry waste, while some of what remains is burned by local residents.

High demand for land in the Puncak area has resulted in an investment boom, and expanded transportation networks linking Jakarta to outlying areas like Bogor and Bandung have spurred virtually uncontrollable growth. Large amounts of prime agricultural land have been converted into housing developments (Firman & Dharmapatani, 1994), resulting in reduced water absorption capacity in the upstream Ciliwung watershed that contributes to floods in the downstream area. Steep slopes, high annual rainfall, and intensive land cultivation have substantially intensified soil erosion and surface run-off and exacerbated the risk of landslides. Water and air pollution and frequent traffic jams are also causing concern. The continuing development of tourism in Puncak is threatening further environmental degradation so countermeasures are greatly needed.

Table 11.1 Waste in Tugu Utara Village, Puncak

Land use	Weight (kg/ha/year)	Area of buildings (ha)	Total weight (kg/year)
Settlements	262.46	74.36	19,515.82
Villas/hotels	217.94	20.73	451.72
Other structures	3.87	5.05	19.55
Total	484.27	100.14	24,054.09

Source Dewanti (2017)

11.7 Statistics on Tourism and Waste

Bogor Regency Regulation No. 35 (2014) identified three districts in Puncak as tourism-affected: Cisarua, Megamendung, and part of Ciawi. Based on research conducted by Dwikorawati (2012), the total number of tourists in the Puncak area increased by 21.11% in five years, from 1,102,680 tourists in 2004 to 1,335,443 in 2009. The number includes up to 100,000 travelers per year from Saudi Arabia and other Middle Eastern nations (Suhada & Florentin, 2017). Tourist visits to Puncak especially increase during weekends. Traffic density is highest at such popular destinations in Puncak as the Gunung Mas tea plantation, Taman Wisata Matahari amusement park, and the Curug Cilember forest area.

Increasing tourism is driving continuing growth of solid waste, especially from roadside stalls and settlements. Bogor Regency produces 1.2 million tons of waste in one year, but the regency government, which bears responsibility for waste management, only collects and disposes of 25% of the waste due to an insufficient number of sanitation trucks. Research conducted by a local university student in Tugu Utara Village, Cisarua District, showed that the highest volume of waste was produced by local settlements (see Table 11.1). The district government has encouraged communities to create their own waste management systems and to foster a sustainable natural environment by cleaning up garbage on the road and transporting waste to landfill sites.

11.8 History and Description of Waste Education Activities

According to Damanhari (2008), some of the factors contributing to poor SWM in Indonesia include inadequate funding, low prioritization by local governments for waste management, and limited human resources, but the problems are compounded by poorly implemented waste education. In Indonesia, waste management education is taught in primary schools as part of mandated environmental education. Such learning mainly consists of knowledge of the difference between organic and inorganic waste for the elementary school student. With the aim of improving environmental awareness and conserving the environment, environmental education and population

Fig. 11.7 Waste separation instruction for elementary school students (with permission from Aya Hanzawa)

studies have been incorporated into formal education in primary school since 1986 under the rubric of studies in population and environment (PKLH). National Law No. 32/2009 on Environmental Protection and Management, which included compulsory provision of environmental education, was enacted in 2009, but the nation continues to lag in ESD implementation and public awareness (Parker, 2017) and at least in Puncak, students' waste education curriculum often cannot be applied in daily life due to the lack of waste sorting, transport and disposal facilities.

In the Puncak area, activities have been conducted by Bogor-area university students and other volunteers to increase awareness of the 3Rs and the need to sort waste (Fig. 11.7). Students have also carried out action research in local villages to raise community awareness of the need to improve Puncak's physical environment by implementing participatory environmental planning. This includes technical studies on local land use, spatial inconsistencies, and land use/land cover changes as well as participatory studies on socioeconomic aspects, including local culture, demolition of vacation homes, and community development in Puncak.

The *Konsorsium Penyelamatan Puncak* (Save Puncak Consortium) was established in 2014 as an open consortium that invites government institutions, communities, business entities, academia, media, and other parties to jointly improve the environmental quality of the Puncak water catchment area. The consortium was initiated by a research institute, The Center for Regional Systems, Analysis, Planning and Development (CRESTPENT/P4W), Bogor Agricultural University, some

Fig. 11.8 Activity of PRA (with permission from Lutfia Nursetya Fuadina)

NGOs (Forest Watch Indonesia, Ciliwung Care Community), and some local community representatives in recognition of the need for a multi-stakeholder approach to tackle the complex issues faced by Puncak. The consortium implements tested participatory development approaches like PRA (participatory rural appraisal) and RRA (rapid rural appraisal) to promote village-level discussion of the importance of environmental preservation for reducing the impact of disaster risk (Fig. 11.8). The consortium began collaborative environmental activities with residents in Tugu Utara and Tugu Selatan villages in 2014. They first identified 44 unsightly solid waste dumps in both villages, most located inside a tea plantation and on a riverbank. After the sites were identified, the community agreed to eradicate the garbage piles, and clean-up campaigns have been conducted on a monthly basis since that time, in collaboration with villagers of all ages and volunteers from outside the area (Fig. 11.9). After the waste is collected, it is moved to more accessible locations for transporting to disposal sites by truck.

11.9 Achievements and Challenges

Campaign and consortium activities in Puncak Area are generating greater grassroots participation by local communities, NGOs, academicians, and local government officers, and this has led to the emergence of local advocates for changes in policies, relationships, and resource allocation to promote sustainable SWM. The consortium has striven to establish strong ties with village leaders to promote participation. However, many challenges remain in reducing waste. Communities have found it difficult to dispose of already accumulated waste in overwhelmed, often inaccessible local landfill sites. In addition, municipal sanitation trucks come only once a week and do not reach all areas. Outside of irregular volunteer activities, there is

Fig. 11.9 Consortium-sponsored litter campaign in Puncak Area. *Source* http://savepuncak.org/gallery/, with permission from Save Puncak Consortium

little attempt to educate residents about waste management; many regard waste as solely the responsibility of the government.

Funding for management of final disposal sites has become a major constraint for municipalities (MacMillan, 2007). However, the overall costs of SWM educational activities are low if considering the benefits of a cleaner and better environment (Zurbrugg, 2002), including mitigation of disaster hazards such as landslides at garbage piles.

There has been some conflict with communities living near dumpsites or with other cities that refuse the disposal of waste from outside. It is clear that local government is not yet cognizant of the need to commit time and resources for solid waste management. In addition, there is a need to investigate new pathways for managing solid waste through the innovative collection, separation, and disposal mechanisms.

11.10 Summary and Recommendations

Although increased tourism brings increases in SW generation at all travel destinations, the challenges and capacity for waste management in developing nations can greatly vary. For urban sites, especially those with UNESCO World Heritage Site designation, tourist inflows can serve as a double-edged sword for effective waste management. Tourists from developed nations generate more waste than local residents yet often have high expectations for sanitation and public cleanliness. Nevertheless, their presence may spur greater municipal and household prioritization of waste management, leading to improved waste segregation, composting and recycling behavior. Local actors may be able to solicit increased ODA and other funding for waste education and awareness campaigns, development assistance and technology transfer to improve waste management. Since many of the tourists originate in developed countries there may be greater recognition of an ethical burden for these countries to contribute to improving the environment at these key tourism sites.

For urban areas like Hoi An, a collaboration between local universities, NGOs, local government, and other actors can bring long-term benefits, but sustaining short-term courses, programs, and funding as students and other stakeholders cycle in and out can pose a challenge. Funding should be secured for teaching collaborative courses, and research grant proposals should be a priority. Regular discussions or meetings can help faculty members transfer knowledge of course administration, and active partnerships with local organizations can be strengthened with joint research and by sponsoring student internships and/or volunteering.

Rural areas may face greater challenges, as poor funding and capacity result in poor or nonexistent SW collection, and levels of education and awareness of waste management are low. This is especially true for areas not directly impacted by tourism. Some recommendations for supporting the implementation of successful waste management in rural areas like Puncak include: (1) Educate and encourage people to carry out 3R practices; (2) Foster an SW approach that can generate jobs for informal economy scavengers and other local residents in composting, recycling and similar practices; (3) Encourage local involvement in SWM by residents, senior citizens, NGOs, neighborhood associations, volunteers, students, researchers, and local government staff; (4) Build local government capacity and promote technology transfer for waste management and (5) Implement community-based nonformal environmental education. Since the schools are among the best venues for promoting SWM education, the following activities are advised: (a) work with local teachers in setting up educational programs/activities; (b) establish a pilot project in a few schools, then expand to the entire school system; and (c) reward students who participate in SWM projects to increase involvement.

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Jane Singer is Associate Professor at the Graduate School of Global Environmental Studies (GSGES), Kyoto University, Japan. She has a Master's degree from Columbia University and a Ph.D. from Kyoto University. Her principal research focus is displacement due to development and climate change in Asia Pacific. She also researches tertiary ESD and community resilience issues. Recent co-edited monographs include Global Implications of Development, Disasters and Climate Change (with Susanna Price, 2016); Education for Sustainability in Japan (with Tracey Gannon, Fumiko Noguchi and Yoko Mochizuki, 2017); and Country Frameworks for Development Displacement and Resettlement (with Susanna Price, 2019), all from Routledge.

Kinh Thi Kieu obtained her Bachelor and Master's Degrees in Environmental Engineering at The University of Technology, The University of Danang in Vietnam and her Ph.D. in Environmental Management at the Graduate School of Global Environmental Studies, Kyoto University. Currently, she is a lecturer and head of the Department of Environment and Biological Resources, The University of Science and Education, The University of Danang.

Andrea Emma Pravitasari obtained a Bachelor's Degree in the Soil Science Study Program at the Department of Soil Science and Land Resources at Bogor Agricultural University (IPB University) and a Master's Degree in Regional Planning Study Program at the Graduate School of Bogor Agricultural University (IPB University). She received a Ph.D. in Environmental Management from the Graduate School of Global Environmental Studies (GSGES), Kyoto University. Currently, she is a Lecturer at Division of Regional Planning, Department of Soil Science and Land Resources, Bogor Agricultural University (IPB University) and she also a researcher at Center for Regional Systems Analysis, Planning and Development (CRESTPENT/P4W), IPB.

Chapter 12
A Critical Cartography of Waste Education in Australia: Turning to a Posthumanist Framing

Amy Cutter-Mackenzie-Knowles and Lisa Siegel

Abstract There is no doubt that the current Anthropocene geologic era is directly a result of human malconsumption. Australian schools have readily engaged in a wide variety of environmental education programmes to tackle the results of one form of this malconsumption: waste. Waste has indeed become a central concept of environmental education in Australia for the past four decades. In this Chapter, waste education is critically examined in an Australian context, followed by an in-depth cartography of waste education programmes. What this cartography reveals is that while there is a reasonably strong culture of waste education and recycling in particular in Australian schools and communities, research also shows that waste per capita increased in the same period. Thus, contemporary waste education programmes and pedagogies are acting on the margins of malconsumption. This chapter, therefore, troubles the stewardship model of environmental education that lies at the heart of these Australian waste education programmes, contending that these programmes need to move beyond a focus on one aspect of the waste cycle (recycling) to a new model of waste education that is rooted in post-humanist educational theory. A posthumanist waste education offers a new kind of imaginary through disrupting and diverting malconsumption at its core/s; humans and their relationships with the more-than-human or nonhuman.

Keywords Waste · Waste Wise Schools · Waste education · Malconsumption · Posthumanism

A. Cutter-Mackenzie-Knowles (✉) · L. Siegel
Sustainability, Environment & Education (SEE) Research Cluster, School of Education, Southern Cross University, Lismore, Australia
e-mail: Amy.Cutter-Mackenzie@scu.edu.au

L. Siegel
e-mail: l.siegel.10@student.scu.edu.au

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12.1 Australian Malconsumption…. and the 'War on Waste'

Earth has reached a tipping point where it has now entered into a new geologic era, the Anthropocene (Crutzen, 2006). The Anthropocene has been propelled by excessive human activity; in essence, overpopulation and overconsumption. Human beings are perhaps the only species incapable of existing within their own carrying capacity. It is projected that the uppermost capability of the Earth to sustain human life is 10 billion in population. With a population of 7.2 billion, it is forecast that the population will reach 10 billion by 2050 (United Nations, 2015). Environmentalists and environmental educators though are optimistic that humans will make a U-turn, plateauing the population at 9–10 billion and thus remaining within the limits of human carrying capacity. However, current predictions place the human population at 11.6 billion by 2100 (United Nations, 2015) placing serious doubts on any prospect of it plateauing. With this in mind, the issue of overconsumption has never been more critical.

In 2017, the Australian Broadcasting Commission (ABC) released a TV series called 'War on Waste'. The intent of the programme is to act as an exposé uncovering Australia's waste problem. The programme prompted the question '*What has changed in the Australian psyche, and in our consumer culture, that has led us to become among the most wasteful nations in the developed [minority] world?*' Among minority Western cultures, Australia is one of the highest consumers of municipal waste per person. Each person produces on average 565 kg of municipal waste per year (Pickin & Randell, 2016). The United States of America has one of the highest municipal waste rates, with an average of 740.95 kg of waste produced per person per year (United States Environmental Protection Agency, 2018).

The most recent national report on waste in Australia reported:

- In 2014–15 Australia produced about 64 million tonnes of waste, which is equivalent to 2.7 tonnes of waste per capita. Almost 60% of this was recycled;
- The trend is towards more recycling and more recovery of energy from waste;
- In 2014–15 Australia produced the equivalent of 565 kg per capita of municipal waste, 831 kg of construction and demolition waste, 459 kg of fly ash and 849 kg of other commercial and industrial waste; and
- Trend analysis in the report shows the composition of waste is changing. Some significant material streams—paper and cardboard, glass and fly ash—are declining. Waste metals, organics and plastics also appear to be reducing, at least on a per capita basis. Masonry materials from demolition, on the other hand, are increasing (Pickin & Randell, 2016, pp. vi–viii).

What is clear from the above-mentioned trends is that Australia has an intractable waste problem. At the heart of this problem though is overconsumption, which is the act of consuming to excess. In 1998, Hillcoat and Rensburg argued that the concept of consumption was largely absent in environmental education and its research. They claimed that 'current consumption patterns are linked to historical trends in the psychological configuration of the self' (p. 8). The crucial argument here is that consumption is fundamental to a person's meaning-making and overall happiness. These arguments are further supported by Bentley, Fien, and Neil's (2004) research which revealed that:

> Young people establish their own identities through what they buy. They seek social inclusion by purchasing the newest and 'coolest' products on the market. The desire to obtain the latest consumer gadgets helps fuel a competitive race (p. 1).

Turning to the concept of malconsumption, according to Hillcoat and Rensburg (1998), 'malconsumption is indicative of a way of life that does not recognise or pay heed to the ecological and social significance of the act of consumption' (p. 89). Hillcoat and Rensburg directly link malconsumption with the empty self which they maintain began in the middle of the 19th century where a 'therapeutic ethos' in conjunction with capitalism took hold of Western minority societies. Concepts such as 'shopping therapy' or 'retail therapy' epitomise the 'empty self' in this regard.

Of critical importance, to what extent do educators engage with the issue of malconsumption? Some 20 years ago, Hillcoat and Rensburg conjectured that 'environmental education curricula and programmes either support malconsumption, ignore it, treat it in insufficient depth, romanticise the more-than-human in a disempowering way or fail to address the deeply entrenching mean-making role of consumption' (p. 94). This Chapter presents a cartography of Australian waste education progams in an attempt to address our opening question in addition to reconsidering Hillcoat and Rensburg's (1998) chief argument that environmental education (as a field) is failing to confront the challenge of malconsumption.

12.2 A Cartography of Australian Waste Education Programmes

12.2.1 At the National Level…

The cartography of Australian waste education programmes begins from a wide-angle lens view, by considering the offerings of the Australian National Curriculum in regards to waste education. The National Curriculum, which was introduced in 2014, comprises eight key learning areas English, Mathematics, Science, Humanities and Social Sciences, the Arts, Technologies, Health and Physical Education and Languages. 'Content Descriptions' state specifically what students ought to learn in each discipline. Throughout the entire National Curriculum from Foundation (Kindergarten) through Senior Secondary (Year 12), the topic of Waste appears as a mandatory Content Description in only two units of work: in Year 4 HASS (Human and Social Sciences) with a unit entitled 'How people, places and environments interact, past and present'; and in Senior Secondary Earth and Environmental Science, in the unit 'Living on Earth - extracting, using and managing Earth resources' (ACARA, n.d.).

The curriculum also includes ‘Content Elaborations’ which are optional teaching ideas, included to give teachers ‘ideas about how they might teach the content’ (ACARA, n.d.a). The topic of Waste appears in only 29 of the hundreds of ‘Content Elaborations’ throughout the eight key learning areas. Furthermore, these optional teaching suggestions are included in only four out of the eight core disciplines: Science (only in Years 2, 4, 7 and 8); Human and Social Sciences, including Geography (HASS in Years 1, 2, 4, and 5, and Geography in Year 9); Technologies, including Design and Technology (Years Foundation—Year 8) and Digital Technology (only Years 7–8); and, strangely enough, in three Languages (Greek, Turkish for Years 9–10, and Aboriginal/Torres Strait Islander Languages in Years 7–10). Examples of these suggested Content Elaborations range from

> Identifying which resources they can recycle, reduce, re-use or none of these, and what local spaces and systems (for example, rules, signs, waste collection truck routes) support these activities (Year 1 HASS)
>
> to
>
> Investigating everyday applications of physical separation techniques such as filtering, sorting waste materials, reducing pollution, extracting products from plants, separating blood products and cleaning up oil spills (Year 7 Science)
>
> to
>
> Creating persuasive texts, such as brochures or video clips, for example, to encourage people from the wider community to attend a cultural event or to recycle waste containers and materials (Year 9–10 Modern Greek)

While the word ‘reduce’ is utilised, it is not contextualised within consumption more broadly nor does it consider the explicit relationship between identity and consumption. It is further important to note that the Australian National Curriculum includes a ‘Cross-Curriculum Priority’ entitled ‘Sustainability’—one of three such priorities. Key concepts of the Sustainability strand include exploring ‘the interdependent and dynamic nature of systems that support all life on Earth and our collective wellbeing’ and ‘building capacities for thinking and acting in ways that are necessary to create a more sustainable future’ (ACARA, n.d.). These concepts are clearly based on the basic premise of the interconnection of living systems, and the necessity of helping students to develop this understanding through interdisciplinary learning and to learn the capacity building skills necessary to act on this understanding. It is unanticipated then to note that the topic of Waste, which is a crucial aspect of human living systems and would arguably be an important component of Sustainability, is only included as optional activities for half of the subjects in the Curriculum, and when included, is focused on the physical properties of resources, recycling, and good citizenship.

12.2.2 At the States and Territories Level…

Although the Australian Curriculum ‘sets the expectations for what all young Australians should be taught, regardless of where they live in Australia or their background' (ACARA, n.d.), not all of the Australian states and territories have adopted the full Australian Curriculum. New South Wales, Victoria, and Western Australia all have state curricula that are based in the Australian Curriculum but still maintain their own localised contextualisation, for instance, in the case of Western Australia, to make the curriculum 'more suitable for Western Australian students and teachers' (SCSA, 2014). In the case of New South Wales and Western Australia, waste education and sustainability, in general, have even less of a presence in their adaptations of the Australian Curriculum. Only Victoria has expanded on the idea of a Cross-Curriculum priority by creating an expansive 9-page document that details the importance and interdisciplinary nature of sustainability education, including waste education (VCAA, n.d.).

As we narrow our lens to look at the cartography of programmes in the Australian states and territories, it is thus not unexpected that Victoria has hosted what is possibly the most successful Australian waste education programme to date, the 'Waste Wise Schools' programme, which ran from 1997 to 2007 in over 1,000 Victorian schools, with a significant number of NSW schools also participating (Cutter-Mackenzie, 2010). The stated goals of the programme were:

1. *to bring about lasting change in school culture towards waste/litter minimisation (and ultimately sustainability) through whole school engagement in learning and action for waste/litter minimisation and sustainability, integration of school curriculum and operations and the building of links with local communities; and*
2. *to bring about lasting cultural change towards waste/litter minimisation and sustainability in families and the wider community through learning and action (Kinns, 2006).*

In 2008, the programme was integrated into the ResourceSmart Schools programme and now appears as the 'Waste' module in that programme. Run by Sustainability Victoria, the ResourceSmart Schools programme is 'an award-winning Victorian Government programme that assists schools to embed sustainability in everything they do' (Sustainability Victoria, 2017a). According to their website, over 1,300 schools have participated in the programme. It is an accreditation programme made up of five modules that include a core module and four topical modules (waste, water, biodiversity, and energy). The modules are carried out by the schools themselves, with the support of 'sustainability experts' (Sustainability Victoria, 2017a). The Waste module is made up of teaching resources and 63 actions, of which at least 47 items need to be completed in order for the school to be accredited. The items include actions connected to Research, Planning, Reporting, and Community Engagement as well as actions around reducing food waste and litter, and encouraging recycling and reuse. In particular, the Waste module is described as helping to 'minimise waste sent to landfill through the operational practices of 'reduce, reuse, recycle', and save on bills'. It then goes on to say that 'Building waste reduction into every aspect of school life not only benefits our environment, it also helps schools reduce costs and improves quality of life for the community. This is increasingly important for the reputation of schools as students, teachers and parents become aware of climate change and other environmental issues facing our communities' (Sustainability Victoria, 2017b).

The Western Australia Waste Authority also touts a school accreditation program called Waste Wise Schools, which includes units for Primary Schools on Compost, Plastic Free July, What is Waste?, Worms, and the 3Rs, and one High School unit on plastic water bottles. The programme offers an introductory workshop, with steps towards accreditation to be facilitated by the school itself. The programme description states that 'waste is a topic that fits easily into every learning area. As such, waste should be integrated into current curriculum rather than used as an "add on"', and that 'underlying the Waste Wise Schools Programme is the core value of environmental responsibility.… Ultimately, the hope is that students feel empowered with their new knowledge and develop environmentally sound values and behaviours' (Waste Authority, 2018, n.p.). However, their website was last updated in 2015 and they have no upcoming workshops listed.

The South Australia government runs a programme called the 'WOW (Wipe Out Waste) Schools Program', which states its goal as simply 'learning about and reducing waste in a whole of community approach', and provides training and resources for schools, including an assisted Bin Materials Audit (WOW, n.d.). The WOW programme is a partnership between the South Australian government and a not-for-profit organisation called KESAB (Keep South Australia Beautiful). The Actsmart Schools programme is the Australian Capital Territory's version of a similar waste education programme: it too provides curricula, resources, and accreditation to participating schools. Some of the 'Big Understandings' that the Actsmart programme offer are that 'Waste is a resource…..most can be avoided, reduced, reused and recycled'; 'Products and materials have a life cycle'; and 'Effective waste management supports a healthy environment' (ACT Government, 2015).

12.2.3 At a Local Level…

As can be seen from the above programme descriptions, waste education programmes that are run at a state/territory government agency level are heavily inclined towards resource recovery education, with programme rationales focusing on cost-cutting and good citizenship. Will zooming into focus on the cartography of waste education programmes in local communities show us anything different? In an online review of the waste education offered to local schools by ten local government areas in four states and one territory (see Table 12.1), it is interesting to note that while resource recovery education (i.e. the 3Rs—Reduce Reuse Recycle) is the only type of programme that is consistently offered across all ten communities, composting and worm farming programmes (which do not necessarily fall only into the categories of cost-cutting and good citizenship) feature in the programming of seven of the communities. In the end, the programmes that local governments are offering to the schools in their communities seem to go beyond what is mandated in the National Curriculum.

Table 12.1 Waste education programmes offered to schools by LGAs

	Recycling education (the 3Rs)	Composting	Worm farms	Litter in the environment (incl. Marine Debris)	Education about waste/landfill services	Waste-free shopping	Rubbish-free lunchboxes	History of waste
LGA 1 (NT)	✓				✓			
LGA 2 (QLD)	✓	✓	✓		✓			
LGA 3 (VIC)	✓	✓	✓	✓		✓	✓	
LGA 4 (NSW)	✓	✓	✓	✓	✓			
LGA 5 (VIC)	✓				✓			✓
LGA 6 (VIC)	✓	✓	✓	✓		✓	✓	
LGA 7 (NSW)	✓			✓				
LGA 8 (SA)	✓	✓	✓		✓		✓	
LGA 9 (QLD)	✓	✓	✓	✓	✓	✓		✓
LGA 10 (VIC)	✓	✓	✓	✓		✓	✓	
Total	10	7	7	6	6	4	4	2

However, the real concern is that even these local programmes do not seem to be enough to curb the tide of malconsumption in Australia. As noted in the introduction, while recycling behaviours have improved, arguably in part due to the focus on this topic in most waste education programmes, waste per capita rose in the decade between 2006–2007 and 2014–2015. As a nation, Australia is generating more commercial/industrial waste and construction/demolition waste, which are related to the tide of malconsumption. This Chapter now turns to a theorising of why the current praxis is not succeeding, and what type of waste education programme could combat this rising tide of waste.

12.3 Moving Towards a 'Zero-Waste' Waste Pedagogy

> 'We' are not outside observers of the world. Nor are we simply located at particular places in the world; rather, we are part of the world in its ongoing intra-activity (Barad, 2003, p. 828).

12.3.1 The Limited Potential of Stewardship

The current emphasis on recycling in Australian waste education is hardly unforeseen. It is a natural progression from the popular and successful environmental campaign to 'Keep Australia Beautiful' that began in the early 1970s, and which encourages Australians to practice stewardship of the beaches and waterways (Keep Australia Beautiful, 1975). Recycling education encourages stewardship of our waste. As Australian early childhood educator Taylor (2017) describes, 'in practice, most environmental pedagogies still pivot around resolutely humanist understandings of agency and position learners as potential environmental stewards' (p. 1449). While the stewardship model has had an important role in environmental education, it is proposed that its potential is limited in redressing malconsumption. These limitations will be considered before moving on to an alternative model.

12.3.1.1 Stewardship = Human Exceptionalism = Same Old Problems

A particular concern with the stewardship model of environmental education is that it is rooted in a firmly entrenched notion of two distinct entities: 'human' and 'nature'. Taylor describes the dilemma created by the belief that 'nature exists 'out there' in a pure space that is somehow separate' (p. 1452), leading to the further assumption that nature needs tending and regulating by humans. She contends that 'this is particularly problematic, as it is the mistaken belief in human exceptionalism that has led many in the 'developed' [minority] world to think that we can 'improve' upon nature and exploit the earth's resources with impunity' (p. 1453).

12.3.1.2 Stewardship = Results from Reconnection with Nature = Not Possible Because We Already Are Nature

An increasingly prevalent theory of environmental education is the ‘nature connection’ theory, popularised after the release of Richard Louv’s 2008 book ‘*Last Child in the Woods: Saving our Children from Nature-Deficit Disorder*’. Based in the field of ecopsychology, nature connection theory posits that developing a strong connection to the natural world helps arouse feelings of empathetic care. The contention is that if humans ‘reconnect’ to nature, they will learn to love it and take care of it: ‘healing the broken bond between our young and nature’, is important not only ‘because our mental, physical, and spiritual health depends on it…the health of the earth is at stake as well’ (Louv, 2008, p. 3). However, developing a connection to something implies that there are two separate entities that can then be connected. This is problematic, for as Fletcher (2017) posits: ‘the idea that one could be disconnected from ‘nature’…is fundamentally grounded in a culturally specific nature-culture dichotomy’ (p. 228). In other words, humans already are nature. The goal of ‘reconnecting’ actually enforces the idea of the very separation it argues against (see discussion in Dickinson, 2013 and Malone, 2016).

12.3.1.3 Stewardship = Continuation of the Mess We Are Already in Now

Since the beginning of this century, it has become more and more evident that ‘human extractive and consumptive activities over the last 50 years has fundamentally changed the earth’s geo-biospheric systems, causing the relatively stable Holocene era to tip into the Anthropocene’ (Taylor, 2017, p. 1448). In spite of the increasing evidence of the negative effects human ‘stewardship’ has had on this planet, the model continues as the accepted path of environmental education, as we have seen evidence in our cartography of Waste Education in Australia. It is imperative we try something new. Jorgenson, Madsen, and Læssøe (2018) contend that waste education has been, and still is in most cases, based either in behaviour change modelling or an action competence approach, both of which are missing the ‘interwoven material, social, sensuous, practical, and intellectual aspects of waste management in everyday life’ (p. 808). What does the interwoven nature of waste offer us as educators? First, it questions the idea of waste itself. Second, it supports the idea of a transdisciplinary pedagogical approach. Both of these factors will be considered in the final section of this chapter.

12.3.2 A Waste Education Pedagogy Without the ‘Waste’

First, the word ‘waste’, based on the Latin ‘vastus’ meaning empty or desolate, should be troubled. Arguably, this is a word based firmly in a humanist outlook. Humans

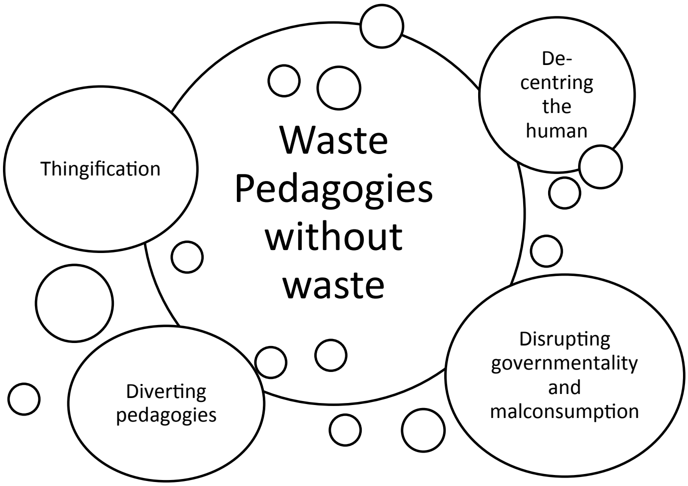

Fig. 12.1 Posthumanist waste pedagogies without waste

have invented the idea of empty, whereas in the other-than-human world (or more-than-human world) true emptiness is hard to find. By way of a simple example, an ‘empty’ bowl is actually full of air. Humans have also invented the idea of waste, and have now taken it to the extreme, as per the research cited in the first part of this chapter. In the natural world, there is no such thing as waste. Fallen leaves, bird droppings, dead insects are not ‘waste’; they are end products of natural phenomena that eventually become part of the humus of the forest floor that then nourishes new plant life.

How can there be waste education pedagogies without ‘waste’? There are modes of thinking about the environment that do not put human activity necessarily at the centre, and it is suggested that waste education should move towards embracing what can be termed a ‘posthumanist’ framing. According to Barad (2003), looking through a posthumanist lens ‘calls into question the givenness of the differential categories of “human” and “nonhuman”, examining the practices through which these differential boundaries are stabilized and destabilized’ (p. 808). Fisch (2017), theorising about the field of biomimetic praxis (a framework of design which ‘emerges through inspirational technics of interaction with material nature’ (p. 806)), suggests embracing ‘the idea of a nonnormative yet coherent ethical framework that is not the product of human design [which] derives instead from a relational ecology of human and nonhuman actors’ (p. 807). While he is referring to biomimetic praxis, this can be applied to waste education, which can thus be explored through a framework that recognises that waste is a purely human-induced concept that is having a shockingly deleterious effect on the other-than-human portion of the planet (Fig. 12.1).

In presenting posthumanist waste education pedagogies without ‘waste’, four key concepts are proposed.

The first concept of waste education challenges the bifurcation of nature (Whitehead, 1920) where nature is apportioned into parts. Learning how everything in nature is interconnected and entangled requires one to decentre the human where humans are one of many species. Early childhood educator Hodgins (2015) muses about these connections as she handles the recycled craft materials at her school: 'Where and how were these materials produced? Whose/which bodies enacted, and suffer(ed) from, their production? Why and how will I care about these multiple past-present-futures of production that our inquiries touch?' (p. 94) Such questions necessitate a more-than-human ethic, which contemporary waste education programmes currently fail to embrace.

The second concept focuses on the deep investigation of the 'waste' materials themselves. What are their fundamental characteristics? What happens to them under different conditions? Jorgensen et al. (2018) note that seeing the 'processes of decay and temporal differences in the decay of different materials appear[s] to provide an entry point for thinking about the future in more concrete terms among both younger and older children' (p. 811). In essence, this is a scrutinisation of things or what Hodgins (2015) calls *Thingification*—the turning of relations into 'things', 'entities', 'relata'—which infects much of the way we understand the world and our relationship to it.

The third concept considers what reducing consumption (and in turn production and trade) actually looks like and does in a society where consuming [indeed malconsuming] is often portrayed as an act of good citizenship (Tsai, 2010). The capitalist drive to consume is rarely disrupted by dominant waste 'management' solutions (e.g. recycling). Hird and colleagues (2014) argue that 'privatization and individual responsibilization' (p. 443) of waste management operates 'within a capitalist rationale to manage waste in ways that do not disturb circuits of mass production and mass consumption (and industry profit)' (p. 444). How do we begin to interfere with this governmentality?

And the final concept troubles the recycling agenda. While the least effective, recycling is the most promoted waste management strategy, one that significantly generates its own waste (Hird, Lougheed, Rowe, & Kuyvenhoven, 2014), and one into which we have thoroughly integrated children and schools, as a quick Google search of 'children recycling activities' will demonstrate, reaching 107,000,000 hits in 0.46 s. Hird et al. (2014) raise questions as to whether we are actually burdening children, our little recycling champions, rather than involving them in the mundaneness (and mendacity), muck, and movement of waste(ing), and whether this focus is the most valuable expenditure of our (precious) resources. Focusing solely on individual consumer usage and responsibility also diverts needed attention and questions regarding industrial and governmental accountability as to what (and how) things get stored, recycled, burned and buried, and about that which we are simply bequeathing to future generations for them to deal with (Hird, 2012; Hird et al., 2014). Individual responsibility and 'the presumption that the world can be contained and controlled by human forces' (p. 120) drive a stewardship approach to environmental issues where humans are positioned as the heroic saviours of the earth.

These four concepts represent a new mode of waste education that radically shifts existing humanist waste education practices. This requires a fundamental turn in Western minority culture where consumption is focused on basic need rather than want or desire. Greenpeace's (2015) 'The 9 'R's (*i.e. reduce, reuse, recycle, repair, remake, refuse, remember, respect and restore*) of a sustainable life' shift traditional waste education programmes (such as the 3Rs) and may act as a transition to posthumanist waste education.

12.4 Conclusion

Two decades ago Hillcoat and Rensburg (1998) argued that environmental education is failing to respond to malconsumption and its grip on minority Western cultures. Reviewing the cartography of waste education in Australia, this Chapter maintains that such failings endure with little progress being made in redressing malconsumption. Contemporary waste education programmes and pedagogies are acting on the margins of malconsumption primarily through 'reducing' mantras. However, the dominant discourse squarely centres on recycling which fails to confront, disrupt or divert malconsumption. Redressing malconsumption requires fundamental shifts where humans are not at the centre. A posthumanist waste education offers a new kind of imaginary through disrupting and diverting malconsumption at its core/s; humans and their relationships with the more-than-human or nonhuman. As Morris (2015, p. 53) eloquently states: 'a posthumanist education builds upon and goes beyond a humanist education…. We must move out of an anthropocentric mind frame and begin to understand that we are in the middle of nature's web'.

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Amy Cutter-Mackenzie-Knowles is a Professor of Sustainability, Environment and Education at Southern Cross University, School of Education, Australia. She is the Deputy Head of School Research & HDR Training for the School of Education, as well as the Research Leader of the Sustainability, Environment, and Arts Education (SEAE) Research Cluster. She has led over 30 research projects in environmental education and published over 150 publications largely centred on ontologies in/as nature through socioecological and more recently post-humanist theoretical orientations. She has a particular interest in child-framed arts-based research methodologies. Amy has also been recognised for both her teaching and research excellence in environmental education, including the Australian Association for Environmental Education Fellowship (Life Achievement Award) for her outstanding contribution to environmental education research.

Lisa Siegel is currently undertaking Ph.D. research in the School of Education at Southern Cross University, where she is a member of the Sustainability, Environment, and Arts Education (SEAE) Research Cluster. Her research is focused on the individual and collective life experiences of female environmental activists in Australia. Lisa tutors in the SCU School of Education, and is currently the convenor of the Mid North Coast Sustainability Education Network.

Part III
New Science and Technologies for Waste Treatment

Chapter 13
A Study on Fenton Technology for Polypropylene Waste Degradation and Recovery of High-Value Chemicals

Cheuk Fai Chow and Chung Sum Chan

Abstract Plastic waste management and handling are critical issues, and the development of breakthrough technology for these purposes is a challenging task. In this chapter, it will explore the feasibility of waste degradation and hopefully provide some insights and fundamental information for scientists and chemical engineers to address the issues of degradation and mineralization of inert plastic wastes, with polypropylene (PP) as an example, through effective chemical processes including surface activation and Fenton and photo-Fenton technology. To achieve a greener reaction process for practical use, commercially available hydrogen peroxide (H_2O_2) has been widely used as an oxidant. The Fenton reaction under ambient dark conditions was successful in converting the activated PP materials into water-soluble organic matter and carbon dioxide (CO_2) within 40 min, while the photo-Fenton reaction under UV-vis illumination was able to achieve complete mineralization within 80 min as determined by the analysis of the reaction solutions. In addition, the dissolved organic matter generated from the Fenton reaction was identified as belonging to three main classes: monocarboxylic acids, dicarboxylic acids, and diols. The study revealed that the concentration of H_2O_2 used in the Fenton reaction significantly affects the amount of diols and carboxylic acids recovered from the PP degradation, where the ratio could be tuned from 37.2 to 2.1% for diols and from 55.9 to 93.1% for carboxylic acids, under dark conditions. Moreover, under photo-Fenton degradation conditions, due to rapid decomposition, a positive pressure was observed (CO_2 gas: 550 kPa/g of material) from complete degradation of the activated PP. The gas pressure could potentially be converted into mechanical energy for further applications.

C. F. Chow (✉)
Department of Science and Environmental Studies and Centre for Education in Environmental Sustainability, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: cfchow@eduhk.hk

C. S. Chan
Centre for Education in Environmental Sustainability, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China

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13.1 Introduction

The wide range of applications of synthetic plastics in our daily life leads to extremely high consumption rates and significant waste handling problems. The ineffective treatment of plastic wastes adds to the threat of the limited supply of fossil fuel. According to the United States Environmental Protection Agency, 75.5% of the plastic material in the U.S. Municipal Solid Waste Stream was sent to landfills in 2014, with the remaining plastic material recycled (9.5%) or incinerated for energy generation (15%) (United States Environmental Protection Agency, 2016). The high cost of recycling (Wong, Ngadi, Abdullah, & Inuwa, 2015) and the problems associated with incineration such as generation of dioxins, polycyclic aromatic hydrocarbons (PAHs), and toxic ash (Siddique, Khatib, & Kaur, 2008) has resulted in landfills becoming increasingly stressed. Polypropylene (PP) constitutes 24.3% of the total plastic waste and is ranked second in worldwide plastic wastes. Its annual production currently exceeds 275 million metric tons (Jambeck et al., 2015). PP, a saturated and nonfunctional polymer that is "paraffinic" and extremely inert, was first discovered in 1951 by Hogan and Banks while attempting to convert propylene into gasoline (Sailors & Hogan, 1981) and is now widely produced using Ziegler-Natta catalysts for various applications (Sinn & Kaminsky, 1980). Current practices handle large amounts of inert PP wastes by disposal in landfills, which results in the loss of the high carbon content of these materials and their associated energy. However, effective technology for plastic waste treatment is limited. Several methods, such as photolysis, ozonolysis, ultrasound, biodegradation, pyrolysis, and catalytic degradation can be found in the literature for the mineralization of PP wastes or for their conversion into high-value chemicals/energy, to recover these energy-rich resources.

Photolysis involves the use of light to degrade materials. UV radiation can cleave the C–C and C–H bonds of PP at a wavelength of approximately 370 nm (Andrady, 1997). When PP film is exposed to the UV radiation, the polymer and oxygen react to form polymer peroxy radicals that can then cleave the C–C and C–H bonds of the tertiary carbon atoms of PP (Andrady, 1997). Photolysis of PP usually results in the loss of its mechanical properties, such as extensibility and strength, while decreasing its average molecular weight. The polymer breaks down into organic fragments such as CO_2, alcohols, ketones, and carboxylic acids (Fernando, Christensen, Egerton, & White, 2007). Ozonolysis is an oxidative process for the degradation of carbonaceous material by ozone. Saturated polymers such as PP react with ozone, resulting in the formation of polymer peroxy radicals that can oxidize PP into oxygen-containing materials such as carbonyls and unsaturated carbonyl polymers (Walzak et al., 1995). A study by MacManus et al. suggested that when PP film is exposed to UV radiation and ozone, insertion of oxygen atoms occurs on the surface of PP, resulting in ether linkage crosslinking as well as carbonyl and carboxyl acid containing polymeric materials (MacManus, Walzak, & McIntyre, 1999). Ultrasound can also be used to degrade plastic polymer when coupled with strong mechanical stress. Vibrational waves pass through the solution, resulting in a high shear gradient that leads to cavitation on the surface of the polymer chain and breakdown of the chemical bonds in the polymers (Chakraborty, Sarkar, Kumar, & Madras, 2004). The degradation of PP with ultrasound under different conditions has been studied (Chakraborty et al., 2004; Desai, Shenoy, & Gogate, 2008; Lin & Isayev, 2006). Chakraborty et al. reported that the degradation rate of PP in o-dichlorobenzene decreased with increase in the temperature (Chakraborty et al., 2004). Lin and Isayev monitored the degradation of PP and the associated changes in its mechanical properties under high-intensity ultrasound (Lin & Isayev, 2006). Desai et al. reported that using a low viscosity solvent in the ultrasound degradation of PP resulted in a higher extent of degradation (Desai et al., 2008). Biodegradation is a biochemical degradation process that results in the cracking of materials by microorganisms. The biodegradation of PP normally involves attaching microorganisms to the surface of the polymer, which acts as the carbon source that facilitates growth by the action of the enzymes in the microorganisms. The polymer is eventually degraded in this process (Arutchelvi et al., 2008). With careful selection of efficient microbial strains such as *Brevibacillus borstelensis* (Hadad, Geresh, & Sivan, 2005) and *Stenotrophomonas panacihumi* PA3-2 (Jeon & Kim, 2016), even the saturated PP polymer with strong and inert C–C and C–H bonds can be metabolized. Pyrolysis is the thermal degradation process of material by heat and pressure. Under reaction conditions involving intense heat and in the absence of oxygen, high-value materials for industrial applications like oil, gas, and char can be produced (Sharuddin, Abnisa, Daud, & Daud, 2016). The yield of oil, gas, and char by the pyrolysis of PP usually depends on the temperature. Ahmad et al. reported that the pyrolysis of PP at 300 °C using a micro-steel reactor yielded 69.82 wt% liquid oil, 28.84 wt% gaseous components, and 1.34 wt% solid residue (Ahmad et al., 2015). Fakhrhoseini and Dastanian obtained 82.12 wt% liquid oil, 17.76 wt% gaseous components, and 0.12 wt% solid residue at 500 °C from the pyrolysis of PP (FakhrHoseini & Dastanian, 2013). Catalytic degradation uses a catalyst to degrade synthetic polymers into hydrocarbons with higher commercial value. The advantages of using catalytic degradation include the relatively narrow distribution of hydrocarbon products and the lower operation temperatures when compared with pyrolysis (Hwang, Choi, Kim, Park, & Woo, 1998). Zeolites have been used for the catalytic degradation of PP, with the degradation temperature and the degraded hydrocarbon products being strongly governed by the nature and amount of the zeolite used (Zhao et al., 1996). The catalytic activity of zeolites also depends on their pore size and acidity, which affect the activation energy of C–C and C–H bond breakage (Durmuş, Naci Koç, Selda Pozan, & Kaşgöz, 2005). Other than zeolites, kaoline (Panda & Singh, 2014), silica, alumina (Ishihara et al., 1993; Lin & Yen, 2005), and activated carbon catalysts containing Pt and Fe (Uemichi, Makino, & Kanazuka, 1989) have also been reported for the catalytic degradation of PP.

Considering the aforementioned methods for degrading PP, most reported technologies require demanding operating conditions with high consumption of energy, uncontaminated single-type plastic waste, expensive catalysts, or dangerous ionizing radiation. Biodegradation methods are attractive and environmentally friendly, but require long periods of time for the microorganisms to completely degrade the plastics. These factors combine to hinder the development of plastic waste conversion. Therefore, it is necessary to develop a method to achieve rapid and low-cost degradation of PP with controllable mineralization and breakdown products under mild conditions. Fenton and photo-Fenton reactions are promising alternatives and the chemical reactions involved are advanced oxidation processes (AOPs), commonly employed in rapid degradation and mineralization techniques for chemical substances resistant to conventional technologies (Fenton, 1894; Litter, 2005). Both processes involve oxidative reactions that generate highly oxidizing species, such as hydroxyl radicals (·OH, E = 2.73 V) from H_2O_2 in the presence of Fe(III) catalysts, for the destruction and ultimate mineralization of the targeted contaminants (Umar, Aziz, & Yusoff, 2010). Due to their high efficiency, simplicity, and ability to treat a wide range of organic pollutants, both reactions are powerful methods that are capable of destroying a wide range of hazardous organic pollutants (Barb, Baxendal, George, & Hargrave, 1949; Haber & Weiss, 1934; Umar et al., 2010). Although both processes can generate hydroxyl radicals, the photo-Fenton reaction can facilitate the reduction of Fe(III) to Fe(II) to produce more hydroxyl radicals via photolysis (Deng & Englehardt, 2006; Hermosilla, Cortijo, & Huang, 2009; Kavitha & Palanivelu, 2004), and the photo-decarboxylation of Fe(III)-carboxylates (Ollis, Pelizzetti, & Serpone, 1989; Pignatello, Oliveros, & MacKay, 2006). Depending on the operating parameters (pH, Fenton reagents, time, irradiation, etc.), the Fenton or photo-Fenton reactions may lead to either complete mineralization of the organic contaminants to CO_2, H_2O, and inorganic salts, or partial degradation of the contaminants to low molecular weight organic fragments (Umar et al., 2010). Despite the fact that the Fenton and photo-Fenton reactions have been widely used to degrade pollutants (Ollis et al., 1989; Pignatello et al. 2006), there have only been a few reports of plastic waste degradation, especially for saturated and nonfunctional inert polymers. In this work, the feasibility of applying Fenton and photo-Fenton reactions for the mineralization of PP wastes or for converting them into high-value chemicals are investigated. Our results showed that conversion and mineralization of PP into water-soluble organic matter and/or carbon dioxide can be achieved by grafting Fe(III)-sulfonated functionalities onto the polymer substrates, which undergo oxidation in the presence of H_2O_2 with suitable concentration, initial pH, and levels of irradiation. The degradation method described herein is applicable for most PP wastes, such as drinking bottles and microwave boxes.

13.2 Experimental

Materials and Methods Polypropylene (average Mw ~ 12,000) was purchased from Sigma-Aldrich. Chlorosulfonic acid (98%) was obtained from International Laboratory. Chloroform (ACS), Ferric chloride (Acros), hydrochloric acid (Sigma-

Aldrich), dichloromethane (ACS), and 30 wt% hydrogen peroxide (BDH) were obtained and used without further purification.

The dissolved organic carbon content of the degradation mixtures was determined by filtering through 1.0 μm pore size membrane filters (Pall Corporation) followed by the determination of their total organic carbon content using a Shimadzu TOC-L CSH high-sensitivity total organic analyzer. Infrared spectra in the range of 500–4000 cm^{-1} were recorded on a Perkin Elmer Model Frontier Fourier-transform infrared spectroscopy (FTIR) spectrometer. The elemental analyses were performed on a Vario EL CHNS analyzer. Analyses of the iron contents of the activated polymers were performed using an Agilent 7900 inductively coupled plasma mass spectrometer (ICP-MS). The surface morphologies of the polymer particles were characterized using scanning electron microscopy (SEM) with a Philips XL30 ESEM-FEG coupled with energy dispersed spectroscopy (EDS). Characterization and quantification of the dissolved organic matter in the degradation studies were performed using an Agilent 1100 High-performance liquid chromatography (HPLC) coupled to a diode-array detector (DAD, G1315A system) and an electrospray ionization mass spectrometer (ESI-MS, PE SCIEX API 2000 LC/MS/MS system) with an Alltech Allsphere ODS-2 column (5 μm, 250 mm × 4.6 mm i.d.). The samples were injected using an autosampler with an injection volume of 5 μL. Eluents required for the liquid chromatography were prepared by dissolution of appropriate amounts of sulfuric acid (1 mM) and sodium sulfate (8 mM) in Milli-Q water. The solutions were then filtered through disposable 1 μm glass fiber membrane filters (Pall Corporation) and degassed in an ultrasonic bath prior to use. The mobile phase flow rate was 0.5 mL/min and the separation temperature was 25 °C. Peaks were recorded at 210 nm. Gas chromatograph–mass spectrometric (GC-MS) analyses were performed on a HP (Hewlett Packard) 6890 series gas chromatograph coupled with an HP 5973 mass selective detector. Injections were carried out with an HP 7683 autosampler. The capillary column used was an Agilent HP-5MS (30 m × 0.25 mm, 0.25 μm). Helium was used as the carrier gas at a flow rate of 1.0 mL/min. The temperature program was: initial temperature, 60 °C for 2 min; ramp at 10 °C/min to 280 °C and held for 2 min; injection temperature, 280 °C; and transfer line, 280 °C. The sample injection volume was 2 μL. Split injection mode with a split ratio of 2:1 was used. The ionizing voltage was 70 eV. The source temperature was set at 250 °C. UV-visible spectroscopic analyses were performed on a Cary 50 UV-visible spectrophotometer.

Preparation of the Activated PP Materials ($PPSO_3$–Fe) PP beads were obtained from Sigma-Aldrich. PP beads and commercially available PP soymilk bottles and lunch bowls were ground to the size range of 125–250 μm prior to use. The PP material (1.00 g) was dissolved in 25 mL of 1,1,2,2-tetrachloroethane with stirring (200 rpm) under reflux at 65 °C (Chow et al., 2016, 2017; Dimov & Islam, 1991; Fischer & Eysel, 1994; Ihata, 1988; Kaneko et al., 2004). A mixture of concentrated chlorosulfuric acid and dichloromethane (15 mL, 1:2 v/v) was added dropwise over 30 min. The resulting mixture was allowed to react for an additional 2 h. The organic solvents were removed by distillation. $FeCl_3$ solution (0.75 M, 100 mL) was added to the mixture, which was then stirred overnight. A black precipitate was obtained by centrifugation and was washed with deionized water until the supernatant became almost colorless. The solids were then oven-dried at 80 °C for a total yield of 1.63 g. IR (KBr): $\nu_{O\text{–}H} = 3354\ cm^{-1}$; $\nu_{C\text{–}H} = 2954$, 2918, 2870, and 2839 cm^{-1}; $\nu_{C=C} = 1636\ cm^{-1}$; $\nu_{S=O} = 1151$ and 1033 cm^{-1}; $\nu_{Fe\text{–}O} = 528\ cm^{-1}$. The elemental analysis showed: C, 39.14; H, 5.21; N, 0.00; S, 7.87%.

Degradation of $PPSO_3$–Fe by Fenton Reaction In a typical degradation reaction, 0.15 g of **$PPSO_3$–Fe** powder (particle size in the range of 125–250 μm) was suspended in deionized water (85 mL) with ultrasonication for 10 min. Hydrochloric acid or NaOH was added to the reaction mixture to adjust the initial pH to 2.6. Hydrogen peroxide (30 wt%, 10.00 mL, i.e., 650.0 mmol/g of polymer used) was then added to the reaction mixture. The final volume of the reaction mixture was maintained at 100 mL, and hence the initial concentration of hydrogen peroxide was 3.0 wt%. The reaction was initiated by placing the reaction mixture in the dark under ambient conditions for 120 min. The dissolved organic carbon (DOC) in the reaction mixtures and the weight of the remaining suspended polymer were then recorded. The reaction was also studied using various initial hydrogen peroxide concentrations (81.25, 162.5, 325, and 650 mmol per gram of activated material).

Determination of Diols The crude products were extracted from the filtered reaction mixture (10.0 mL) by ethanol (4 mL) assisted by salting out with excess ammonium sulfate (5 g). The extract was further reacted with sodium periodate and acetylacetone. The diol content was then quantified by UV-visible spectroscopy.

Determination of Carboxylic Acids and Alkylsulfonic Acids The filtered reaction mixture was alkalized by NaOH to pH 11. The aqueous solution was then dried under vacuum and the crude product was extracted twice by methanol (3:4 v/v based on the aqueous content). The extracted organic matter was characterized and quantified by HPLC-DAD and GC-MS.

Mineralization of $PPSO_3$–Fe by Photo-Fenton Reaction

$PPSO_3$–Fe (125–250 μm) was suspended in deionized water (85 mL) using ultrasonication for 10 min. The initial pH of the mixture was adjusted to 2.5. Then, 30% H_2O_2 (10 mL, 650 mmol/g of activated plastic) was added to the suspension, and the final volume was adjusted to 100 mL with deionized water. The reaction was initiated by placing the reaction mixture 30 cm from a UV-vis lamp. The mixture was stirred under ambient conditions for 2 h. The light-triggered reaction was studied by varying the input light power ranging from 0 to 500 W. The reaction mixtures were filtered through 1.0 μm pore-size membrane filters (Pall Corporation). The carbon content of the reaction mixtures was determined using a Shimadzu TOC-L CSH high-sensitivity total organic analyzer. The amount of remaining solid plastic materials was recorded.

Three working conditions, (i) pH, (ii) amount of H_2O_2, and (iii) reaction time were studied. The effect of pH on the light-triggered reaction was studied by varying the pH from 1 to 7 by adding HCl or NaOH to the reaction mixture. While the effect of H_2O_2 on the light-triggered reaction was studied by adding 0–10 mL of H_2O_2

solution (0–650 mmol/g of activated plastic) to the reaction mixture. The effect of reaction time was studied by monitoring the light-triggered reaction over a period of 9 h. The final volume of each reaction mixture was adjusted to 100 mL with deionized water. All reactions were initiated by placing the reaction mixture 30 cm from the 500 W UV-vis lamp. The carbon content of the reaction mixture and the amount of remaining solid plastic materials were recorded.

Amount of CO_2 produced by the light–dark cycles in the light-triggered reaction of $PPSO_3$–Fe

$PPSO_3$–Fe, PP and activated commercial PP samples (0.005 g) were separately suspended in deionized water (1.4 mL) in 2 mL GC-vials, where they were ultrasonicated for 10 min and then placed in a 28.1 °C water bath for another 10 min. A solution of 30% H_2O_2 (0.008 mL, 100 mmol/g of activated plastic) was then added to the suspension and the final volume was adjusted to 1.5 mL with deionized water. The pressure of gas released was measured by manometer (density as 0.938 kg/m^3). The reaction was initiated by placing the reaction mixture 30 cm under light (400 W UV-vis lamp) and dark conditions with respect of reaction time. The pressure of gas recorded was calculated according to the equation $P = h \cdot g \cdot d$ where P is the calculated pressure (kPa), h is the height of the oil increased, g is the force of gravity (9.81 m/s^2) and d is the density of the oil (0.915 kg/m^3).

13.3 Results and Discussion

Activation of PP PP was activated by chlorosulfuric acid-mediated sulfonation of the carbon-hydrogen bonds followed by grafting Fe(III) onto the polymer chains. Recent studies demonstrated that the Fenton degradation of polyethylene (PE) and polyvinyl chloride (PVC) waste is feasible (Chow et al., 2017; Chow, Wong, Ho, Chan, & Gong, 2016), but the reaction with the more inert PP has not yet been explored. By applying similar activation conditions, the active PP material (**$PPSO_3$–Fe**) was prepared by reacting the virgin PP powder with 12.5 vol.% chlorosulfuric acid in chloroform in an open atmosphere under reflux at 65 °C, followed by grafting Fe(III) (Chow et al., 2016). **$PPSO_3$–Fe** was isolated as an air-stable black precipitate that was insoluble in water and common organic solvents. The sulfonation and grafting of Fe(III) onto the polymer chains was confirmed by IR spectroscopy, where two sets of new peaks at 1151 and 1033 cm^{-1} ($\nu_{S=O}$) and 528 cm^{-1} (ν_{Fe-O}) were observed for **$PPSO_3$–Fe** (Fig. 13.1). Figure 13.2a shows the SEM image and EDS of the **$PPSO_3$–Fe** particles. The average size of the **$PPSO_3$–Fe** particles was found to be ~118 μm. It's chemical composition was determined using EDS where the peaks arising from C, O, S, and Fe were recorded (Fig. 13.2b). Elemental and ICP-MS analysis indicated that the material contained ~8.0 wt% sulfur and ~12.3 wt% iron. The S/Fe mole ratio in the **$PPSO_3$–Fe** was ~1, suggesting that every sulfonate group in the activated polymer chelated to one Fe(III) ion, while the carbon to sulfur (C/S) mole ratio in the **$PPSO_3$–Fe** was found to be 13 on average, indicating

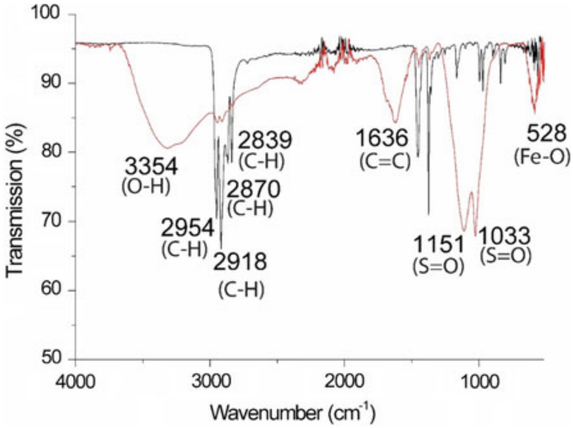


Fig. 13.1 FTIR characterization of the chemical nature of PP before (—) and after (—) treatment with chlorosulfonic acid, indicating the presence of sulfonate functional groups in the polymer material

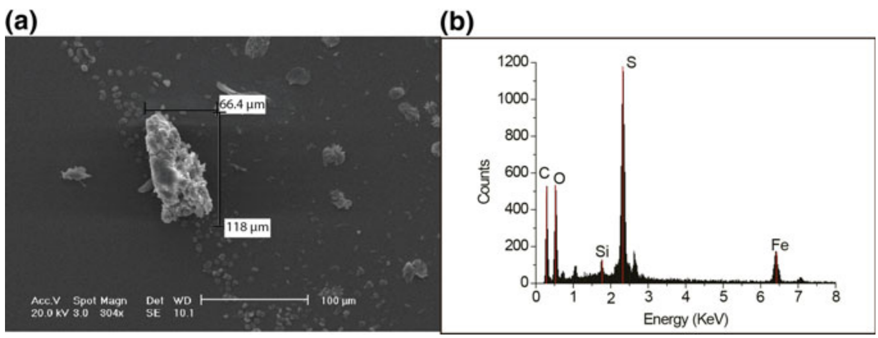


Fig. 13.2 **a** SEM images and **b** EDS of the **$PPSO_3$–Fe**

that every four propylene units in the activated polymer had one sulfonate group. It is also found that the generated **$PPSO_3$–Fe** contained alkene functionality by FTIR (Fig. 13.1).

Degradation of $PPSO_3$–Fe by the Fenton and Photo-Fenton Reactions Fenton and photo-Fenton reactions were conducted by suspending 150 mg of the polymer materials (PP and **$PPSO_3$–Fe**) in water with 650.0 mmol/g H_2O_2 at pH 2.5 under dark and ambient UV-vis conditions, respectively. Figure 13.3 shows the change in the organic and dry weight content during the course of the two treatments of **$PPSO_3$–Fe** and PP. Under the Fenton treatment, the DOC content of **$PPSO_3$–Fe** increased rapidly at the beginning and reached its maximum of ~390.0 mg/L at 50 min, while the content plateaued during the later stage of the degradation process (Fig. 13.3a). On the other hand, under the photo-Fenton treatment of **$PPSO_3$–Fe**, a different degradation pattern emerged with the DOC content of **$PPSO_3$–Fe** increasing rapidly at the beginning of the degradation and reaching its maximum of ~350.0 mg/L at 20 min, then decreasing to a minimum after 80 min (Fig. 13.3a). The increasing DOC content of the reaction mixtures of **$PPSO_3$–Fe** at the onset of both the Fenton and photo-Fenton processes can be explained by the oxidative breakage of the carbon-carbon polymer chains to produce water-soluble and lower molecular weight organic fragments in the reaction mixture. Under the Fenton treatment, the hydrophilic organic fragments remained intact without further degradation, while under the so-called strong photo-Fenton oxidative treatment, the small hydrophilic organic molecules are further oxidized to CO_2 (Fig. 13.3a). No evidence of any degradation or mineralization of the virgin PP polymer was observed after 9 h for either the Fenton or photo-Fenton treatments. With respect to the DOC changes, the degradation of **$PPSO_3$–Fe** in terms of dry weight loss was found to increase rapidly and leveled off at 95% degradation (i.e., 95% dry weight loss) in the first 50 and 20 min for the Fenton and photo-Fenton reaction treatments, respectively (Fig. 13.3b).

Degradation Products from the Fenton and Photo-Fenton Reactions Scheme 13.1 shows the production of organic products and/or carbon dioxide from PP polymers under the Fenton and photo-Fenton treatments with the 650.0 mmol/g H_2O_2. Through the photo-Fenton treatments, **$PPSO_3$–Fe** was completely mineralized into carbon dioxide and water. It is found that with 30 min of UV-Vis illumination (400 W) of **$PPSO_3$–Fe** (0.15 g) in neutral deionized water (15 mL) and H_2O_2 (100.0 mmol/g sample), 400 kPa/g of activated polymer of gas pressure (CO_2) was generated. On the other hand, through the Fenton treatment of **$PPSO_3$–Fe** under dark conditions, 64% of its carbon content was degraded into dissolved organic matter, while only 36% of its carbon content was mineralized in the form of carbon dioxide. The organic matter could be isolated from the reaction mixture through solvent extraction with alcohols. The extracts were then characterized and quantified by HPLC-DAD, GS-MS, and UV-visible spectroscopy. Through the Fenton treatment of **$PPSO_3$–Fe** under dark conditions with 650.0 mmol/g H_2O_2 at pH 2.5, carboxylic acid was the major component (93.0%) of the extract, while diols (2.7%) were a considerably smaller proportion. Approximately 4.3% of the organic molecules in the extracts could not be identified. Supplementary Information (SI) Fig. 13.1 shows the HPLC chromatograph of the extract of the dissolved organic matter of the degraded **$PPSO_3$–Fe**. Through HPLC analysis, it is found that the carboxylic acid component was mainly comprised of monocarboxylic acids (formic and acetic acid), dicarboxylic acids (oxalic, propanedioic, and butanedioic acid), and other carboxylic acids which constituted 32.2%, 13.7%, and 47.1%, respectively, of the total (Table 13.1, entry 4). 1,2-Diols were identified to contribute to 2.7% of total carbon content by UV-visible analysis (SI Fig. 13.2). It is envisioned that through the Fenton and photo-Fenton treatment of **$PPSO_3$–Fe**, there is potential to utilize their degradation products, i.e., pressure generated by CO_2 and the dissolved organic matter for mechanical and chemical energy, respectively.

Control of the Degradation Products of the Fenton and Photo-Fenton Reactions The composition of the organic products obtained from the Fenton degradation can be effectively controlled by varying the concentration of hydrogen peroxide. Table 13.1

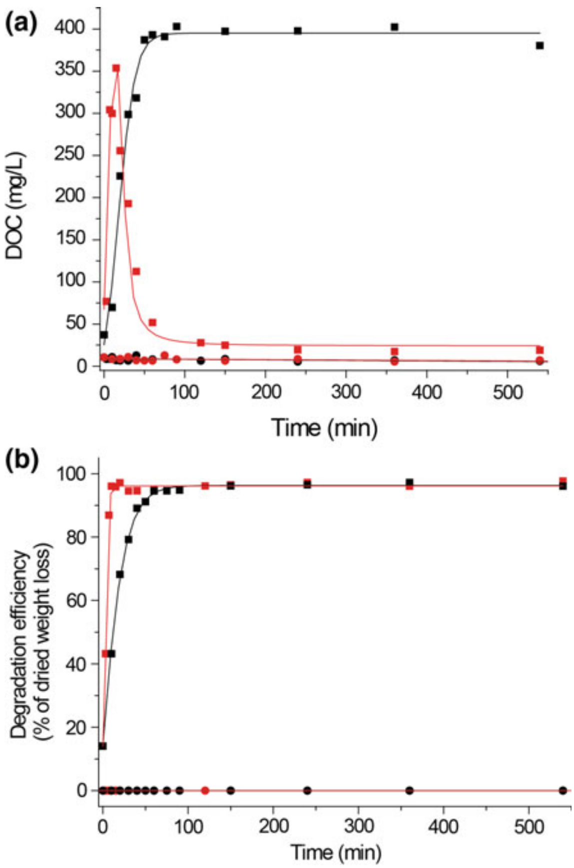
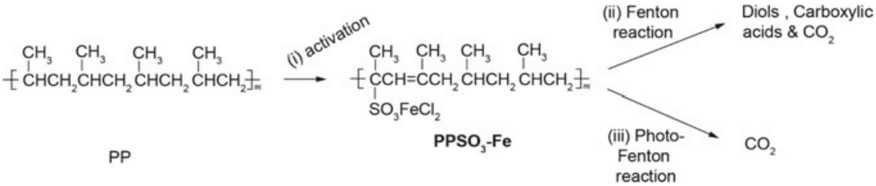


Fig. 13.3 Fenton treatment of **PPSO$_3$–Fe** (–■–) and PP (– ● –)and Photo-Fenton treatment of **PPSO$_3$–Fe** (–■–) and PP (– ● –) beads. The degradation efficiency was expressed as **a** the percentage of dry weight loss, and **b** the change in dissolved organic carbon (DOC) content over the course of the treatment. The initial polymer loading, pH, and H_2O_2 loading were 100 mg, 2.5, and 650 mmol/g, respectively. The photo-Fenton reactions were performed under 500 W UV-vis irradiation, while the Fenton reactions were performed under dark ambient conditions. Each data point is the mean value of three independent degradation runs



Scheme 13.1 Polymer activation, Fenton treatment, and photo-Fenton treatment of PP and the resulting degradation products. Reaction conditions: (i) chlorosulfuric acid and $FeCl_3$ in 1,1,2,2-tetrachloroethane; (ii) acidic conditions, dark, 650.0 mmol H_2O_2 per gram of **PPSO$_3$–Fe**; and (iii) acidic conditions, UV-Vis illumination, H_2O_2

Table 13.1 Degradation of the activated PP (**$PPSO_3$–Fe**) with Fenton treatment

H_2O_2 used (wt%)	Degradation efficiency (DOC (mg/L))	Yield of the degradation products (%)								
		Monocarboxylic acid		Dicarboxylic acid			Other carboxylic acids (%)	Diols (%)	Other organic matter (%)	Total (%)
		C1[a] (%)	C2[b] (%)	C2′[c] (%)	C3[d] (%)	C4[e] (%)				
0.5	89.1% (485.3)	6.7	15.7	0.7	0.7	4.4	27.7	31.2	12.8	100
0.75	99.6% (473.3)	8.1	21.4	1.2	1.7	5.3	28.6	15.2	18.5	100
1.5	99.7% (478.5)	9.6	22.6	2.1	2.0	7.1	37.0	11.6	8.0	100
3.0	98.4% (438.8)	8.9	23.3	3.2	2.4	8.2	47.1	2.7	4.3	100

[a]Formic acid. [b]Acetic acid. [c]Oxalic acid. [d]Propanedoic acid. [e]Butanedoic acid

shows the effect of the concentration of H_2O_2 on the distribution of degradation products recovered from the Fenton degradation of **$PPSO_3$–Fe**. In the system with low H_2O_2 concentration, for example, 108 mmol per gram of **$PPSO_3$–Fe**, 56.0% of the degradation products was found to be carboxylic acids (including mono-, di-, and other carboxylic acids), while 31.2% were diols. The diols were potentially oxidized to carbonyl compounds or carboxylic acids with excess oxidants. With increasing concentration of H_2O_2 from 108 to 650 mmol per gram of **$PPSO_3$–Fe**, the degradation efficiency in terms of dry weight loss was maximized to nearly 100% and the DOC decreased slightly from 485.3 to 438.8 mg/L. The decrease in DOC with nearly 100% complete degradation of the activated polymer suggested the degradation of the dissolved organic matter to carbon dioxide at higher concentrations of H_2O_2. Moreover, the proportion of diols was found to decrease significantly from 31.2 to 2.7% of the total carbon content in the dissolved organic matter, whereas carboxylic acids increased from 56.0 to 93.0%. Acetic acid became the major product and increased from 15.7 to 23.3% of the total carbon, while all other carboxylic acids increased dramatically from 27.7 to 47.1%. This suggested that the majority of degradation products, either diols or carboxylic acids, could be controlled by manipulating the concentration of H_2O_2 in the Fenton degradation.

Through the photo-Fenton treatment of **$PPSO_3$–Fe**, the mechanical energy, through the buildup of gas pressure, produced from the oxidation of the plastic material can be effectively controlled under several light-and-dark cycles. The crushed activated and nonactivated powder (0.005 g) were separately suspended in deionized water (1.5 mL) and H_2O_2 (100.0 mmol/g sample) in vials and irradiated with a UV-Vis lamp at 400 W. The reaction mixtures were cycled between illumination for 3 min and dark conditions for 5 min for four consecutive cycles. Figure 13.4 shows the light-controlled CO_2 gas release from the decomposition of the activated polymers. In each light/dark cycle, pressure was only generated during the illumination period indicating the mineralization of active PP to CO_2. Through 4 consecutive light-on/off cycles, the CO_2 gas generated built up a pressure (mechanical energy) of 550 kPa/g from the degradation of the activated polymer. It should be noted that there was no change in volume during the dark phases. The control experiment with nonactivated polymer only generated a small amount of pressure, which was due to the temperature increase caused by the UV-lamp.

Fenton and Photo-Fenton Reactions of Real PP Waste To test the application potential of this degradation protocol to treat PP waste from commercial and industrial sources, two of the most abundant PP wastes, soymilk bottles, and microwave lunch bowls, were selected for degradation investigation. The highest yield of organic products was achieved using 3 wt% of H_2O_2 in the Fenton degradation. Table 13.2 summarizes the degradation efficiencies of the collected plastic waste samples. In a 2 h reaction, 98.4 and 93.7% degradation was achieved for the soymilk bottles and microwave lunch bowls, respectively. The DOC content was found to be 432.2 mg/L for the soymilk bottles and 438.6 mg/L for the bowls. Greater than 90% degradation was achieved for both commercial PP samples, which suggests that the Fenton process could be applicable for the degradation of PP polymer matrix containing dyes

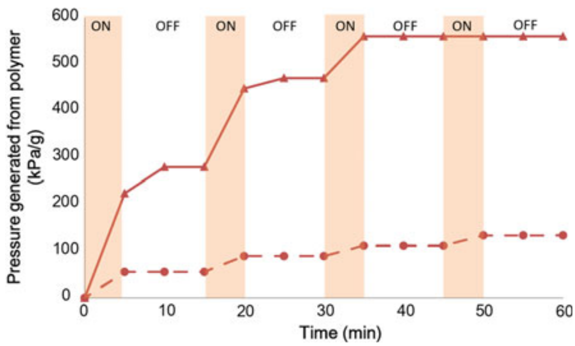


Fig. 13.4 The gas volume change generated by the degradation of (solid line) **$PPSO_3$–Fe**, (dashed line) PP + Fe under conditions of deionized water, 400 W UV-vis lamp, and 100.0 mmol/g H_2O_2 under 5 min light—10 min dark cycles

and plasticizers. The organic products recovered from the real samples were similar to that recovered from the virgin PP material. Over 95% of the carbon content in the dissolved organic matter extracted from the degraded solution of the real samples was determined to be carboxylic acids. The distribution of the monocarboxylic acids (formic and acetic acid) and the dicarboxylic acids (oxalic, propanedioic, and butanedioic acid) obtained from the degradation of the real samples were similar to that of the virgin PP. Acetic acid was found to be the most abundant single product (23.3–27.5%) from the recovery of both the virgin PP and real samples. Through the photo-Fenton degradation, CO_2 pressure of 350 and 430 kPa/g from the degradation of soymilk bottles and microwave lunch bowls were generated, respectively, with H_2O_2 (100.0 mmol/g sample) under a UV-vis lamp at 400 W.

13.4 Conclusion

In conclusion, this study successfully demonstrated the utility of Fenton technology with and without photo-assistance for the degradation of PP plastic waste into useful and recoverable resources under mild conditions. The Fenton process was found to be an efficient method for the breakdown of solid PP wastes after chemical activation into a number of water-soluble organic products such as carboxylic acids and diols, which are high-value industrial chemicals. In addition, for the degradation process under illumination, all the solid waste decomposed to CO_2 gas could build up a pressure that could be used as a mechanical energy source. The effectiveness of this method to degrade inert solid PP waste into small molecules and gas in a short period of time may be an alternative for the handling of the massive amount of domestic plastic waste currently disposed of in landfills.

Acknowledgements This study was funded by a grant from the Research Grants Council of Hong Kong SAR, China (GRF 18303716) and the grants from The Education University of Hong Kong (Project No. R04231, 04262 and 04300). Special thanks to the City University of Hong Kong for assistance with the SEM and EDS studies.

Table 13.2 Characteristics of the organic products recovered from the real PP plastic samples (soymilk bottles and lunch bowls) via the Fenton treatment

PP waste sample	Degradation efficiency (DOC (mg/L))	Yield of the degradation products (%)								
		Monocarboxylic acid		Dicarboxylic acid			Other carboxylic acids	Diols	Other organic matters	Total
		C1[a] (%)	C2[b] (%)	C2′[c] (%)	C3[d] (%)	C4[e] (%)				
Soymilk bottles	98.4% (432.2)	8.4	27.5	3.2	2.7	8.7	45.8	–[f]	3.7	100
Microwave Lunch bowls	93.7% (438.6)	8.4	27.3	2.9	2.4	8.4	46.0	–[f]	4.7	100

[a]Formic acid. [b]Acetic acid. [c]Oxalic acid. [d]Propanedoic acid. [e]Butanedoic acid. [f]Not determined

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Cheuk Fai Chow is an Associate Professor of Department of Science and Environmental Studies and the Director of Knowledge Transfer at the Education University of Hong Kong. He received his B.Sc. (Applied Chemistry) and Ph.D. from the City University of Hong Kong. He obtained a Croucher fellowship and did his postdoctoral training with Nobel laureate Jean Marie Lehn (The University of Strasbourg, France). His research interest lies in applying his environmental studies for energy, water resource, and plastic waste studies.

Chung Sum Chan is a Project Officer in the Centre for Education in Environmental Sustainability at The Education University of Hong Kong. He received his B.Sc. and M.Phil. degrees in Chemistry from The Chinese University of Hong Kong. He focuses his efforts on the study of plastic degradation, and the promotion of plastic resources education.

Chapter 14
Carbon Dioxide Biosequestration and Wastewater Treatment Using Microalgae

Simona Francesca Consoletti and Pepijn Prinsen

Abstract Algae have been studied for many years and recently microalgae have become a hot topic thanks to their multiple uses. This chapter studies the application of microalgae in biosequestration for carbon dioxide (CO_2) capture. CO_2 biosequestration is an important approach to tackle climate change. The use of algae to assimilate CO_2 has multiple advantages: mitigation of emission risks at point sources (e.g., power plants) and no fertile soil requirements. Still, the application of microalgae cultivation techniques for CO_2 biosequestration in situ on industrial sites faces some challenges, such as temperature management, CO_2 storage and scalability. The second part of this chapter explores the application of microalgae strains in wastewater treatment technologies for the production of biofuels. The development of cost-effective and environmentally friendly wastewater treatment technologies is an important research area on the road toward sustainable production processes. Algae can be used to control the chemical oxygen demand and the content of ammonia and total phosphorus. A high diversity exists among natural microalgae; therefore, strain screening techniques and the adoption of biotechnological tools for the development of commercial strains are an important research area. Not only the strain type is important, the development of stable microbial ecologies with other algae strain types and with bacteria or fungi is also essential to develop stable growth consortia.

Keywords Microalgae · Carbon dioxide biosequestration · Biofuels · Wastewater treatment · Nutrient recycling

S. F. Consoletti
Department of Agriculture, Food and Environmental Science, University of Foggia, Via Napoli 25, 71121 Foggia, Italy
e-mail: simonaconsoletti@gmail.com

P. Prinsen (✉)
Department of. Organic Chemistry, University of Cordoba (UCO), Campus de Rabanales, Edificio Marie Curie (C-3) Ctra Nnal IV, Km. 396, 14014 Cordoba, Spain
e-mail: qo2prprp@uco.es

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14.1 Introduction to Microalgae

Microalgae are eukaryotic cellular organisms with a cell wall, plasma membrane, cytoplasm, nucleus, organelles and plastids. They contain chlorophyllic active centers where photosynthesis takes place. Altogether, they produce close to 50% of all the photosynthetically produced O_2 on Earth (Lü, Sheahan, & Fu, 2011). Microalgae cell dimensions range from a few μm to *ca.* 200 μm. It has been estimated that only $4–5 \times 10^4$ species out of the available $2–8 \times 10^5$ are described in the literature (Suganya, Varman, Masjuki, & Renganathan, 2016), belonging to *Chlorophyceae* (green algae), *Cyanophyceae* (blue-green algae), *Chrysophyceae* (golden algae) and *Bacillariophyceae* (diatoms). Microalgae have been studied for many decades, mostly in application fields related to environmental management, for example, in wastewater treatment. More recently, numerous works on microalgae cultivation, harvesting, extraction, and conversion methods have been published, including various reviews (Barry, Wolfe, English, Ruddick, & Lambert, 2016; Brennan & Owende, 2010; Elliot, 2016; Klinthong, Yang, Huang, & Tan, 2015; Kröger & Müller-Langer, 2012; Mata, Martins, & Caetano, 2010; Naghdi, González González, Chan, & Schenk, 2016; Ruiz et al., 2016; Singh & Sharma, 2012; Singh & Singh, 2015; Skjånes, Rebours, & Lindblad, 2013; Toor, Rosendahl, & Rudolf, 2011; Vuppaladadiyam, Prinsen, Raheem, Luque, & Zhao, 2018; Williams & Laurens, 2010; Zhao & Su, 2014). The use of algae biomass feedstocks for the production of bioenergy, biochemicals, and biofuels has now become a hot topic in the scientific community. Algae have some inherent differences from terrestrial plants: (1) whereas most terrestrial plants tolerate freshwater only, some algae strains tolerate saline water and wastewater; (2) algae do not require fertile soil in contrast to most terrestrial plants; (3) algae can be grown throughout the whole year (only seasonal fluctuations); (4) algae present highly varying chemical compositions (as a general rule they contain much lower levels of lignin and polyphenols and more ashes compared to most terrestrial plants); (5) crop and wood production sites are more decentralized (need for transport), while in many cases algae cultivars can be built in the vicinity of industrial sites; and (6) their harvesting techniques.

14.1.1 Cultivation Techniques and Growth Parameters

Phototrophic microalgae absorb sunlight and can assimilate both organic and inorganic nutrients from their environment, including CO_2 from the air or dissolved in water. Photoautotrophic algae use light as their energy source and mainly inorganic substrates as their carbon source. Heterotrophic species use organic substrates both as energy and carbon sources, while the mixotrophic species use light, CO_2, and organic substrates. Considering the costs of nutrients and artificial light, photoautotrophic production is the most viable option for the production of algae biomass on a large scale.

Microalgae can be grown in open and closed cultivation systems. Open systems include natural waters and constructed aquaculture systems, such as unstirred circular and raceway ponds. Closed system designs include flat-plate, tubular, and column photobioreactors. Closed systems permit the cultivation of specific species for an extended duration with minimal risk of contamination, whereas (microbial) contamination and weather conditions limit the stability of open cultivation systems. Moreover, in closed systems, growth parameters can be better controlled. Hybrid cultivation systems have also been demonstrated. The growth parameters of microalgae include: (1) light intensity and perception (wavelength), (2) temperature, (3) pH, (4) salinity, and (5) nutrient feed. These affect not only their biomass growth rate, but also their biomass composition.

14.1.2 Chemical Composition

14.1.2.1 Primary Metabolites

Microalgae primary metabolites are carbohydrates, proteins, and lipids. Their relative and absolute amounts can vary, sometimes very drastically, depending on the species and the growth conditions. The carbohydrate composition and structural characteristics were reviewed by Popper et al. (2011). Many green algae have rigid structured plant-like cell walls, constituted of cellulose and/or other biopolymers. Microalgae also accumulate considerable amounts of energy storage carbohydrates, for example, starch and glycogen. Microalgae carbohydrates exhibit widely varying structures and biological activities. Some find commercial applications in cosmetics and skin-care products, emulsifiers, the food industry, and medicine. Algae lipids are classified as polar amphipathic phospho- and glycolipids (membrane lipids) and neutral lipids composed mainly of triacylglycerides (TAG), which are the high-energy density fraction of microalgae, and which can be converted into biodiesel and green diesel (hydrotreated algal oil). It still remains unclear how to tune the final lipid composition in the biomass, as not everything is known about the biosynthesis of fatty acids in microalgae (lipid precursors). Proteins and peptides are the least defined fraction of microalgae. Nevertheless, they constitute a promising sustainable alternative for nitrogen-rich feeds in animal production systems and food (supplements) for human consumption. Recently, proteins were projected as the most viable commercial product derived from microalgae for the near future (Bravo-Fritz, Sáez-Navarrete, Herrera-Zeppelin, & Varas-Concha, 2016; Ruiz et al., 2016), whereas the commercialization of algae-derived biofuels was projected to become commercially viable on a longer time scale, depending on the progress in the development of large-scale cost-effective cultivation, harvesting, and extraction technologies.

14.1.2.2 Secondary Metabolites

Secondary metabolites include pigments (carotenoids, chlorophylls, and phycobilins), lutein, vitamins, polyketides, polyhydroxyalkanoates, and phenolic compounds. Carotenoids include carotenes (β-carotene, astaxanthin, etc.) and xanthophylls. Some are high-added value compounds; they easily counter the high costs related to their production and isolation, even at small production scales. As a general rule, secondary metabolite production occurs more toward the end or even after the growth stage, often induced by stress conditions. This makes their production, extraction and commercialization, almost incompatible with the large-scale production of biofuels derived from lipids and carbohydrates. Recently, Skjånes et al. (2013) reviewed which secondary metabolites can be produced compatibly with the production of H_2, a biofuel produced under anaerobic stress conditions, especially under sulfur deprivation.

14.2 Carbon Dioxide Biosequestration Using Microalgae

In 2015, the Environmental Protection Agency (EPA, USA) included algal carbon capture and utilization in its Clean Power Plan to meet regulatory requirements for point source pollutants. Algae can recycle carbon from CO_2-rich flue gases emitted from stationary sources, including power plants and other industrial emitters, such as bioethanol and ammonia plants. These CO_2 sources are a cheaper feedstock than pure commercial CO_2. However, treating flue gases leads to important practical constraints for facilities of that size, related to the dilution of the CO_2 gas in the feed and the presence of SO_x and NO_x. Therefore, the distance and the degree of integration of the algae cultivars with the industrial site is a crucial factor, which is not always straightforward.

14.2.1 Mitigation of CO_2 Emissions Through Photosynthetic Carbon Fixation: Concept

Carbon dioxide (CO_2) is the major contributor among all greenhouse gases present in the Earth´s atmosphere. The combustion of fossil fuels represents the major part of anthropogenic emissions. According to International Energy Agency (2016), the emission of CO_2 from the combustion of fuels increased continuously and more than doubled from 1973 (15,458 Mt) to 2014 (32,381 Mt), as illustrated in Fig. 14.1. In this period, the share of coal and natural gas combustion increased from 36 to 46% and from 14 to 20%, respectively. The share of the combustion of oil-derived products, in contrast, decreased from 50 to 34%. The global electricity produced rose from 6,131 (1973) to 23,816 TWh (2014), in which the use of coal and natural

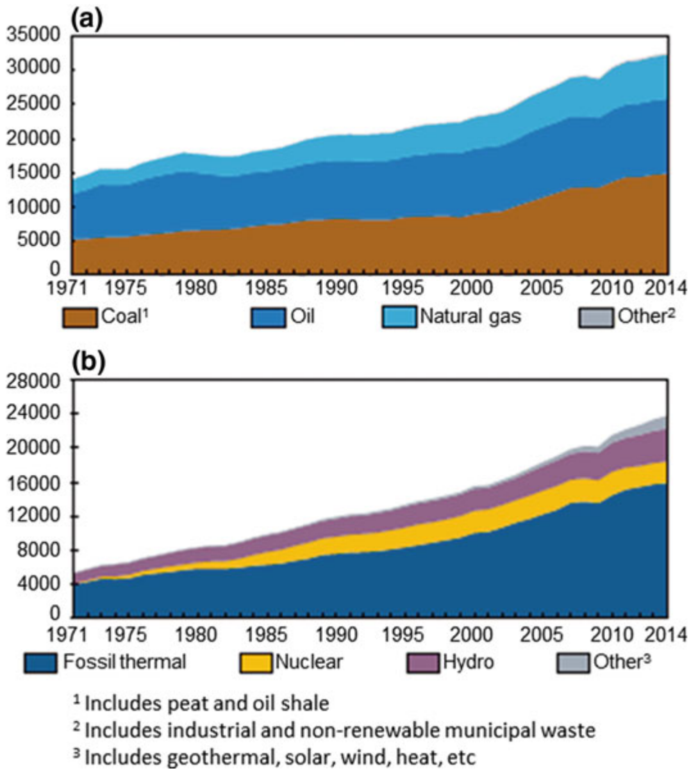


Fig. 14.1 **a** World CO_2 emissions (Mt) from fuel combustion; and **b** World electricity generation by fuel (TWh) from 1971 to 2014. Based on IEA data from Key World Statistics (2016), © OECD/IEA 2015, www.iea.org/statistics. Licence: www.iea.org/t&c

gas rose from 38 to 41% and from 12 to 22%, respectively. These facts clearly show that there is an imminent need for the development and adoption of CO_2 emission mitigation strategies, particularly in fossil-based electricity power plants.

Strategies for the sequestration of CO_2 from flue gas streams have become an important research area (Chelf, Brown, & Wyman, 1993). On one hand, geological sequestration strategies based on chemical reaction (e.g., washing with alkaline solutions) have been proposed. Although feasible in terms of scalability, this strategy may be costly and unsafe in the long-term (Farrelly, Everard, Fagan, & McDonnell, 2013; Lam, Lee, & Mohamed, 2012). Another mitigation route is biological sequestration, a novel approach that aims to capture CO_2 from point sources with photosynthetic autotrophic organisms such as microalgae (Fig. 14.2).

The general concept of CO_2 biosequestration is based on the closure of the carbon cycle through the sustainable use of renewable feedstocks to limit the net enrichment of CO_2 gas in the Earth´s atmosphere. Lignocellulosic and other types of plant-derived biomass have been widely studied for the production of bioenergy, chem-

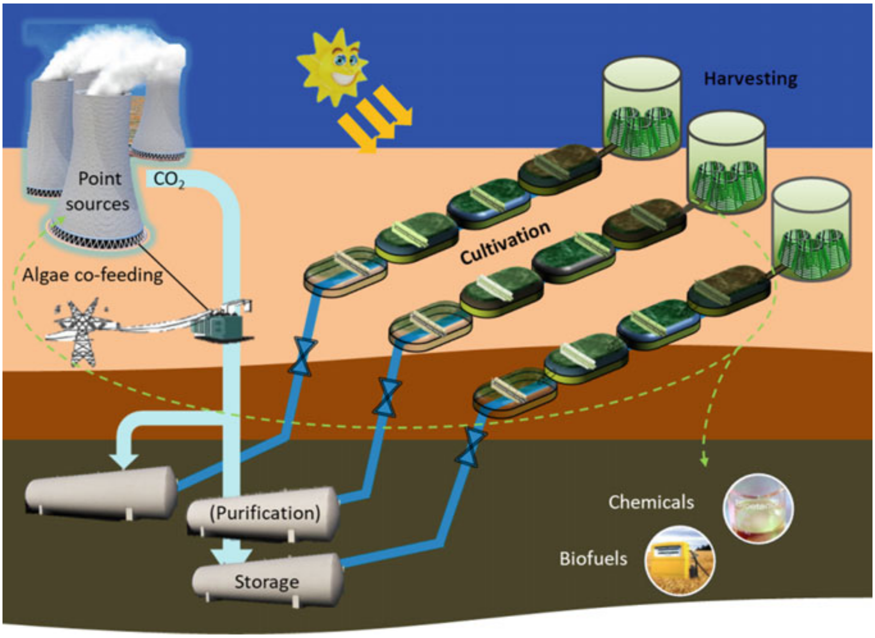


Fig. 14.2 CO_2 emission point source mitigation strategy through biosequestration using microalgae. Reprinted from Journal of Cleaner Production, 181, Raheem et al., (2018). A review on sustainable microalgae-based biofuel and bioenergy production: recent developments, 42–59, 2018, with permission from Elsevier

icals, biofuels, and biomaterials. While fossil feedstocks are considered as limited resources, lignocellulosic feedstocks are renewable on a human-life time scale (typically 1 year for annual plants, 1–10 years for perennial plants, and 10–100 years for woody plants). The extent to which the utilization of renewable resources contributes to the reduction in the net CO_2 emissions depends on the amount of carbon fluxed from the air into the renewable feedstock all the way to the final product until it is finally released again as CO_2 upon combustion (cycle), and on the frequency at which this carbon recycle event occurs. From this point of view, microalgae are very attractive, because they offer considerable biomass productivities in relatively short periods of time (high carbon cycle turnover frequency).

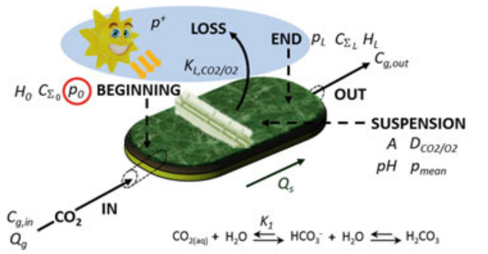
14.2.2 Toward Sustainable Algae Cultivation in the Vicinity of Power Plants

Most challenges that exist in the field of algae cultivation for CO_2 capture from power plants are related to technical constraints. Proper gas feeding techniques are required. Gas blowers can take away flue gas from a chimney via Venturi gas coolers and scrubbers to deliver gas to the saturation system. Introducing CO_2-rich gas to the cultivation system is energy intensive, often requiring gas compression and bubbling (Doucha, Straka, & Lívanský, 2005; Langley, Harrison, & van Hille, 2012; Wilson et al., 2014). A liquid-driven vacuum pump (venturi or eductor) is employed to minimize costs while maximizing mass transfer to the liquid phase, based on the Bernoulli principle of entraining gas in a liquid flow.

14.2.2.1 CO_2 Absorption from Flue Gases: Modeling

Most of the studies on biosequestration of CO_2 from flue gas streams using microalgae (Doucha et al., 2005; Farrelly et al., 2013; Ho, Chen, Lee, & Chang, 2011; Klinthong et al., 2015; Kumar, Dasgupta, Nayak, Lindblad, & Das, 2011; Langley et al., 2012; Ono & Cuello, 2007; Wilson et al., 2014;) have focused on maximizing the algae productivity (g m^{-2} d^{-1}), and have paid little attention to CO_2 recovery (ϕ, %), which is important at an industrial level when carbon credits are involved. Doucha et al. (2005) conducted studies on the photosynthetic sequestration of CO_2 with Chlorella sp. in an open thin-layer photobioreactor. The CO_2 rich flue gas was generated by combustion of natural gas. The authors introduced a model (Fig. 14.3) to describe the CO_2 recovery, to determine the optimal partial pressure (p_0) of CO_2 in the suspension, and to determine the optimal flue gas flow rate and composition at ϕ. To minimize losses of dissolved CO_2 in the algal suspension into the atmosphere, the partial CO_2 pressure at the end of the culture area (p_L) was maintained at a minimum of 0.1–0.2 kPa, required for non-limited algal growth (Lívanský & Doucha, 1998; Weissman, Goebel, & Benemann, 1988). Another technical constraint is the fact that algae assimilation and growth vary continuously on a daily basis. On average, depending mainly on the geographical location and the season (which determine the photosynthetically active radiation and temperature profiles), a growth period of *ca.* 11 h is used for algae growth modeling. The optimum daily course of the flue gas supply rate into a culture unit can be calculated from Eq. (1) and (2) (Fig. 14.3). The course of the CO_2 utilization (φ) in function of the flow rate of the flue gas feed is shown in Fig. 14.4. From the fraction of CO_2 absorbed in the algal suspension (φ), only a part is finally assimilated in the algal biomass, typically *ca.* 80% (Doucha et al., 2005). Theoretically, based on the mean carbon content in the harvested algal dry biomass (47 wt%), *ca.* 1.72 kg of CO_2 per kg biomass is required. Thus, with a CO_2 utilization of 49%, it can be calculated that 4.4 kg CO_2 in the flue gas is required for the production of 1 kg algal biomass.

When using this result in modeling a 40 kW cogeneration unit which uses *ca.* 21.6 m^3 biogas (22.2 MJ m^{-3} heating value, depending on the CH_4 content) from a 500 m^3 digester (fed with agricultural residues) which produces *ca.* 1,025 kg CO_2 day^{-1}, it can be calculated that 470 kg CO_2 is utilized to produce 106 kg dry algal biomass per day. At a mean net algae productivity of 20 g m^{-2} day^{-1}, the algae culture area size required would be *ca.* 5300 m^2. Over a 150-day operational stability period (of the anaerobic biodigester), about 16 tons of dry algal biomass can be produced in a culture season under mid-European climatic conditions (Doucha et al., 2005). If



$$CO_{2(aq)} + H_2O \overset{K_1}{\rightleftarrows} HCO_3^- + H_2O \rightleftarrows H_2CO_3$$

$$M = \frac{(Qg \times \rho_{CO2} \times Cg_{,in})}{100} \quad \text{(1) } CO_2 \text{ supply}$$

$$\frac{M}{A} = \frac{[R_{CO2} + KL_{,CO2} \times KH \times (p_{mean} - p^+)]}{[\frac{DEC}{100}]} \quad \text{(2) areal } CO_2 \text{ supply}$$

$$K_{L,CO2} = K_{L,O2} \times \sqrt{\frac{D_{CO2}}{D_{O2}}} \quad R_{CO2} = Y_{CO2/O2} \times R_{O2} \quad \text{(3a,3b) mass transfer}$$

$$p_{mean} = \frac{(p_0 - pL)}{ln\frac{p_0}{p_L}} \quad \text{(4) partial } CO_2 \text{ pressure in algae suspension}$$

$$log\, p_{mean} = a - b \times pH \quad \text{(5) pH in } CO_2 \text{ saturated algae suspension}$$

$$DEC = 100 \times (1 - \frac{C_{g,out}}{C_{g,in}}) = 100 \times (1 - a \times Q_g{}^b) \quad \text{(6) Degree of decarbonization by algae suspension}$$

$$Q_s(C_{\Sigma_0} - C_{\Sigma_L}) = (R_{CO2} \times A) + [K_{L,CO2} \times A \times K_H (p_{mean} - p^+)] \quad \text{(7) mass balance for dissolved carbon}$$

$$C_{\Sigma_0} = K_H \times p_0 \times (1 + \frac{K_1}{H_0}) \quad C_{\Sigma_L} = K_H \times p_L \times (1 + a_1 \times \frac{K_1}{H_L}) \quad \text{(8a,8b) Dissolved } CO_2 \text{ concentration}$$

$$p_0 = \frac{[(\frac{M}{Q_s \times KH}) + pL \times (1 + a_1 \times \frac{K_1}{H_L})]}{[1 + \frac{K_1}{H_0}]} \quad \text{(9) } CO_2 \text{ pressure} \qquad \phi = \frac{(R_{CO2} \times A)}{M} \quad \text{(10) } CO_2 \text{ recovery}$$

Symbol	Variable	Units
M	CO_2 supply rate	$g\ h^{-1}$
Q_g	Volumetric flow rate (flue gas)	$m^3\ h^{-1}$
ρ_{CO2}	CO_2 density	$g\ m^{-3}$
$C_{g,in/out}$	CO_2 content gas stream IN/OUT	vol%
A	Culture area	m^2
R_{CO2}	CO_2 consumption rate	$g\ m^{-2}\ h^{-1}$
$K_{L,CO2/O2}$	Liquid phase mass transfer coefficient from the suspension to the atmosphere	$m\ h^{-1}$
K_H	Henry's constant for CO_2	$g\ m^{-3}\ kPa^{-1}$
p_{mean}	Mean partial pressure of CO_2 in algal suspension	kPa
p^+	Partial pressure of CO_2 in ambient atmosphere	kPa
DEC	Degree of flue gas decarbonization after passing through the suspension	%
$Y_{CO2/O2}$	Amount (g) of CO_2 consumed by algal cells to evolve 1 g of O_2 by photosynthesis	
R_{O2}	O_2 evolution rate	$g\ m^{-2}\ h^{-1}$
$D_{CO2/O2}$	CO_2/O_2 diffusion coefficients in suspension	$m^2\ h^{-1}$
p_0	Partial pressure of dissolved carbon at the BEGINNING	kPa
p_L	Partial pressure of dissolved carbon at the BEGINNING	kPa
Q_s	Volumetric flow of suspension	$m^3\ h^{-1}$
$C_{\Sigma 0/L}$	Total CO_2 concentration (free + chemically bound) at BEGINNING/END of cultivars	$g\ m^{-3}$
$H_{0,L}$	Proton concentration at BEGINNING/END of cultivars	$mol\ m^{-3}$
a_1	Empirical coefficient (correction on equilibrium of CO_2 with HCO_3^-)	-
K_1	First apparent dissociation constant of HCO_3^-	-
ϕ	Utilization of CO_2 by the algae in relation to CO_2 supplied in flue gas	%

Fig. 14.3 Model description and definition of variables of photosynthetic biosequestration of CO_2 from a flue gas stream in a raceway pond. Adapted by permission from Springer ©, Journal of Applied Phycology, Utilization of flue gas for cultivation of microalgae (*Chlorella* sp.) in an outdoor open thin-layer photobioreactor, Doucha et al. (2005)

Parameter	Value
A (m^2)	55
$K_{L,O2}$ ($m\ h^{-1}$)	0.24
$K_{L,CO2}$ ($m\ h_{-1}$)	0.21
p_L (kPa)	0.2
p^+ (kPa)	0.04
Q^s ($m^3\ h^{-1}$)	13.6
$Y_{CO2/O2}$ (g CO_2 g^{-1} O_2)	1.115

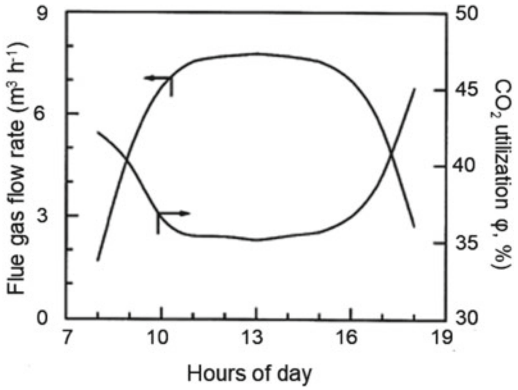


Fig. 14.4 CO_2 utilization φ in the function of the flue gas flow rate from a natural gas boiler, based on the model described in Fig. 14.3 and the data input shown in the table. Adapted by permission from Springer ©, Journal of Applied Phycology, Utilization of flue gas for cultivation of microalgae (*Chlorella* sp.) in an outdoor open thin-layer photobioreactor, Doucha et al. (2005)

Fig. 14.5 Design template and image and image of vertical photobioreactors placed in series at 18 m^3 scale

one aims to capture CO_2 24 h a day from the biogas plant, a gas holder unit needs to be installed to store the CO_2 emitted at night to supply it to the algae cultivars during daylight hours. Based on 11 h daylight, this would require a 11,650 m^2 cultivation area. For a 300 MW installation, this would require a 40 km^2 *photobioreactor* culture area, which is significantly less than the 100 km^2 of *open pond* reported by Grobbelaar, Mohn, and Soeder (2000) for a 300 MW thermoelectric coal-fired power plant (based on a 37 g m^{-2} day^{-1} CO_2 fixation rate during 12 h day^{-1} and 200-day $year^{-1}$). This demonstrates that vertical tubular photobioreactors (Fig. 14.5) would be more feasible to maintain the cultivation area in reasonable dimensions. State-of-the-art results were claimed by the USA-based company Algenol Biotech LLC (Barry et al., 2016; www.algenol.com), which links sugar production to algal photosynthesis using CO_2 feedstock from a power plant. Their process may utilize more than 90% of the CO_2 feed, wherein a portion of the carbon captured in these sugars is converted into ethanol. The ethanol is secreted into the culture media and is collected in the headspace of the reactor, where it is purified and stored. This process is essentially different from the classic bioethanol production method (through chemical/enzymatic hydrolysis followed by subsequent fermentation). This direct-secretion process produces *ca.* 25,700 L ethanol $year^{-1}$ on 1 acre (0.004 km^2) of algal cultivation.

14.2.2.2 Flue Gas Composition

One of the inherent benefits of working with flue gas is that CO_2 is already enriched in the gas mixture as compared to atmospheric gas (0.04%). Wilson et al. (2014) determined the CO_2 content in flue gas from coal fire plants with values between 7 and 10%, while Doucha et al. (2005) found values between 5 and 7% in the flue gas from a natural gas boiler. However, flue gas streams may also contain important amounts of

NO_x and SO_2, which constitute between 28–84% and 53–97%, respectively, of flue gases from coal fire plants. Doucha et al. (2005) did not observe any significant algae growth inhibition effect from the presence of NO_x in flue gas, in accordance with the findings of Matsumoto, Hamasaki, Sioji, and Ikuta (1997). Others, in contrast, did observe negative effects from the acidifying culture medium (Crofcheck, Shea, Montross, Crocker, & Andrews, 2013). Anyhow, what matters is that SO_x cannot be added to the cultivation system faster than its dissolution products (e.g., H_2SO_4) can be utilized by the algae. Another important facet is the heavy metal content in the harvested algal biomass, as many flue gases from combustion processes are enriched with this inorganic matter. No significant enrichment effects in the algal biomass were reported. Wilson et al. (2014) reported heavy metal content at detection levels (0.1 ppm) in algal biomass when using coal fire power plant flue gas.

14.2.2.3 Techno-Economic Assessment

In 2009, the cost of carbon sequestration by burying in saline aquifers in the USA was estimated at *ca.* 40 USD ton^{-1} CO_2, whereas for amine scrubbers the cost was estimated at *ca.* 150 USD ton^{-1} (Alabi, Tampier, & Bibeau, 2009). The authors estimated the mitigation cost via biosequestration at 790 USD ton^{-1}. More recently, the CO_2 mitigation cost by biosequestration using *Scenedesmus acutus* was quantified at 1,600 USD ton^{-1} (Wilson et al., 2014). In the most optimistic scenario, the cost was reduced to 225 USD ton^{-1}, which corresponds to a production cost of 400 USD ton^{-1} biomass, which is in the range of ordinary cultivation systems (Ruiz et al., 2016). Cost breakdown analysis shows that the cost of CO_2 mitigation depends mostly on the productivity of the algal biomass and its carbon content, and on the efficiency of the overall fixation process. The largest cost contributor resides in the capital cost of the photobioreactor system and the associated installation cost. The above findings clearly demonstrate that for CO_2 mitigation via biosequestration using microalgae to become cost-competitive when compared with other sequestration strategies, the revenue of the algal biomass (valorization of coproducts) will be critical in determining the overall economics of CO_2 capture and recycling. It will also depend on the repartition of the carbon credits involved.

14.3 Microalgae for Wastewater Treatment: Recent Developments

14.3.1 Sustainable Microalgae-Based Biofuel Production from Wastewater Resources

In Europe, the European Union IPPC (Directive 2008/1/CE) and the Industrial Emission Related Directive (Directive 2010/75/UE) have requested the application of the best available techniques to evaluate preventive measures, pollution control technologies, and efficient resource consumption. Microalgae bioremediation, based on their ability to scavenge pollutants, has been addressed as a remarkable opportunity to develop and implement new microalgae-based wastewater technologies. Besides the usual organic and inorganic compounds (e.g., nitrates and phosphates), hazardous pollutants such as hydrocarbons, antibiotics, pharmaceutical, and personal care products, endocrine-disrupting compounds, heavy metals, and other micropollutants are still a dreadful concern. Recent microalgae-based research has demonstrated the potential of combining wastewater nutrient removal and biofuel production (Kröger & Müller-Langer, 2012; Quiroz Arita, Peebles, & Bradley, 2015; Woertz, Feffer, Lundquist, & Nelson, 2009; Zhou, Li, Min, Hu, Chen, & Ruan, 2011). In this way, the nutrients needed for microalgae growth are obtained from wastewater, eliminating the need for clean water and minimizing the addition of nutrients, thereby reducing production costs. Furthermore, nutrients are not only removed from the wastewater, but they can also be captured efficiently and returned to the terrestrial environment as agricultural fertilizer. The main drawback of using microalgae in wastewater treatment is the relatively long treatment time needed to reach the desired set values of contaminant concentrations.

14.3.2 Nutrient Removal

Nitrogen from wastewater is removed through the assimilation of ammonium in algal biomass. Indeed, the major "contaminants" found in wastewater are organic matter (COD), nitrogen and phosphorus, as well as iron and manganese. These are the main growth parameters to be considered for the development of a sustainable biofuel production system based on biomass accumulation from wastewater treatment (Acién, Gómez-Serrano, Morales-Amaral, Fernández-Sevilla, & Molina-Grima, 2016; Pittman, Dean, & Osundeko, 2011). Usually, nitrogen is present in wastewater either as NO_3^- or NH_4^+. When microalgae use NH_4^+ as a nitrogen source, they allow pH values to decrease. On the other hand, degradation of NO_3^- leads to slight pH increments. Depending on the microalgae species, either NO_3^- or NH_4^+ is assimilated as the preferred nitrogen source (Arumugam, Agarwal, Arya, & Ahmed, 2013). Phosphorus is also seen as an essential nutrient for algal growth due to its role in the metabolic and anabolic pathways, and in cellular transport. The preferred form of phosphorus for most algae is orthophosphate (PO_4^{3-}). Phosphorus in wastewaters with high levels of iron is more difficult to remove as it shows strong bonding interactions, important when selecting suitable microalgae strains for inoculation.

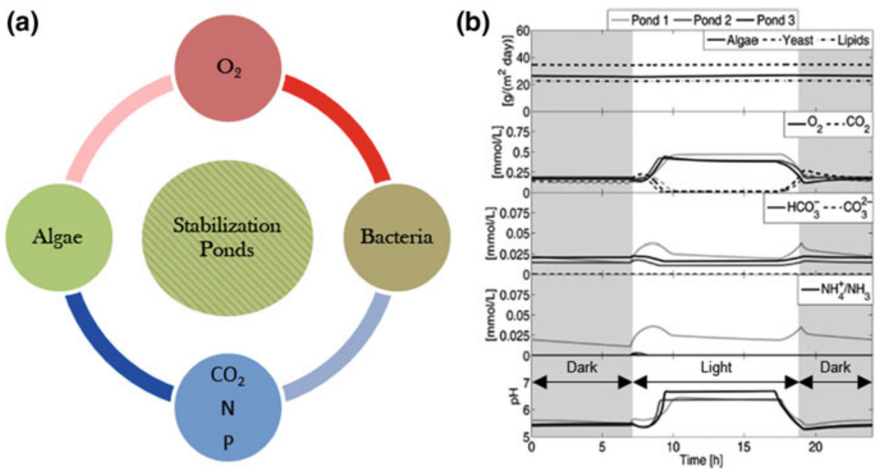


Fig. 14.6 **a** Microalgae and aerobic bacteria mutualism in wastewater stabilization ponds. Adapted from Algal Research, 9, Quiroz Arita et al., Scalability of combining microalgae-based biofuels with wastewater facilities: A review, 160–169, 2015, with permission from © Elsevier B.V.; **b** Concentration profiles of an algae/yeast cultivation system using 3 raceway ponds with cellulosic glucose feeding. Reprinted from Gomez et al., Green Chem., 2016, 18, 461–475, Published by The Royal Society of Chemistry

14.3.3 Stabilization Ponds

Microalgae have been used in microbial consortia for wastewater stabilization ponds (Quiroz Arita et al., 2015), where microalgal photosynthesis converts CO_2 in the organic matter, which is oxidized in synergy by the aerobic bacteria (Fig. 14.6).

14.3.4 Anaerobic Digestion

Anaerobic digestion is a classic process for the treatment of sludge produced from urban wastewater. Biogas is produced along with considerable amounts of nitrogen (NH_4^+) and phosphorus (PO_4^{3-}) in the liquid effluent. Therefore, wastewater treatment plants based on anaerobic digestion processes require specific process technologies for treating this excess of nitrogen and phosphorus, or otherwise, recirculating these effluents into the process, accounting for *ca.* 20% of the total contaminant loading rate (Constantine & Johnson, 2006). Ruiz-Martinez, Martin Garcia, Romero, Seco, and Ferrer (2012) investigated the removal of nitrogen and phosphorus from the effluent of a submerged anaerobic membrane bioreactor (SAnMBR). They used a lab-scale photobioreactor in which algae biomass was cultured in a semi-continuous mode for a period of 42 days, assuring a stable pH in growth medium, maintained by adding CO_2 (Fig. 14.7). Nitrogen and phosphorus concentrations in the SAnMBR

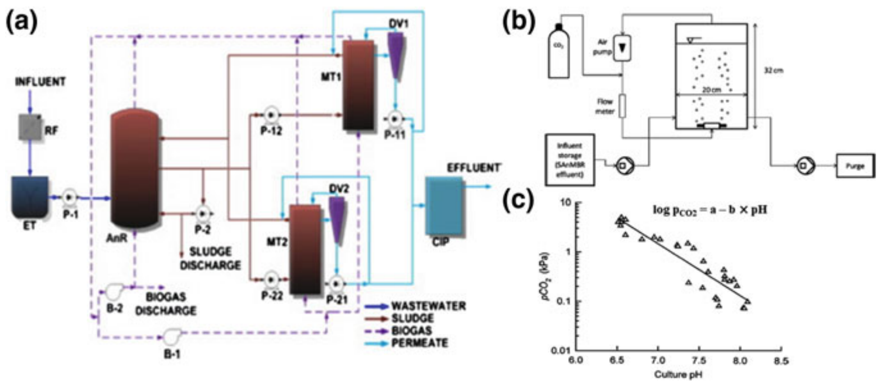


Fig. 14.7 **a** Flow diagram of a SAnMBR pilot plant (RF: rotofilter; ET: equalization tank; AnR: anaerobic reactor; MT: membrane tanks; DV: degasification vessel; CIP: clean-in-place; P: pump; B: blower); **b** Cylindrical photobioreactor with automatic CO_2 injection in headspace and gas recirculation for pH control. Reprinted from Bioresource Technology, 126, (Ruiz-Martinez et al., Microalgae cultivation in wastewater: nutrient removal from anaerobic membrane bioreactor effluent, 247–253, 2012, with permission from Elsevier (2012); and **c** The relationship between dissolved CO_2 partial pressure of dissolved and algal culture pH. Reprinted from Springer ©, Journal of Applied Phycology, Utilization of flue gas for cultivation of microalgae (*Chlorella* sp.) in an outdoor open thin-layer photobioreactor, Doucha et al., 2005

effluent fluctuated, depending on the properties of its actual load in the wastewater. Despite these variations, the anaerobic effluent was suitable for growing microalgae, with biomass productivities reaching 0.23 g L^{-1} day^{-1}, achieving a nutrient removal efficiency of 67% for NH_4^+ and 98% for PO_4^{3-}. At optimal conditions, excellent water quality was achieved.

Similarly, submerged membrane photobioreactors (MPBRs) were reviewed by Luo, Le-Clech, and Henderson (2017) for microalgae cultivation applied to wastewater treatment. The newest MPBR technology combines a conventional photobioreactor (PBR) with a membrane process to grow microalgae. Cultivation of microalgae in MPBRs is more versatile as it can be subjected to different conditions, including wastewater composition and operational conditions. Therefore, MPBR plays an important role in optimization. Membrane fouling is still seen as an operational challenge and has been related to the actual algal organic matter. Applying immobilized microalgal technology in MPBRs has the potential to enhance productivity and mitigate fouling risks (Fig. 14.8).

14.3.5 Environmental Remediation of Wastewaters

Agricultural, municipal, and industrial processes are among the main sources of wastewater production, discharged worldwide in large volumes on a daily basis.

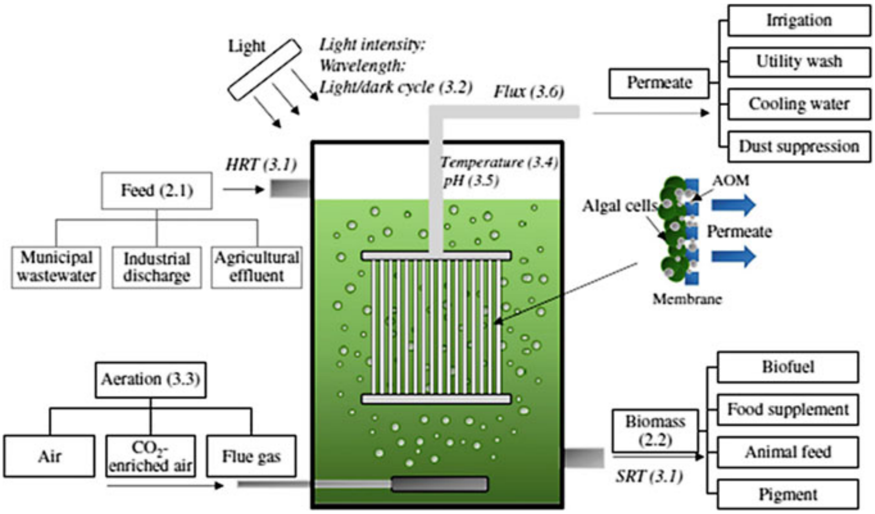


Fig. 14.8 Schematic diagram of MPBR and factors (in italics) affecting process performance. Adapted from Algal Research, 24, Luo et al., 425–437, 2017, with permission from Elsevier B.V

The abundant presence within wastewater of nitrogen and phosphorous can cause eutrophication in lakes and destabilize the balance of ecosystems. Eutrophication can cause 3 different ecological impacts: (1) reduction in biodiversity and replacement by dominant species; (2) increased water toxicity; and (3) increased water turbidity. Algae blooms can seriously affect the fishing and tourism industries which play a significant role in local economies and can generate serious health concerns for local inhabitants. These threats reflect the urgent need to reduce the impacts of nutrients in wastewaters. In this sense, there exists the possibility of importing lipid-rich microalgae species into eutrophic waters for the removal of nitrogen and phosphorous, while at the same time producing biomass for biofuel. On the other hand, microalgae species can be used to remove secondary pollutants and toxic by-products (phycoremediation), which aims to remove carbon, phosphorus, and nitrogen on one hand, and heavy metals or other micropollutants on the other hand through biosorption, bioaccumulation, biodegradation, and/or biotransformation. Tables 14.1, 14.2, and 14.3 list an interesting set of studies conducted on microalgae cultivation using municipal, industrial, and agricultural wastewaters. In general, nitrogen has been found to be the limiting nutrient factor; still, many other factors also influence the final biomass and lipid productivity.

14.3.5.1 Municipal Wastewater

Until now, research has been carried out on primary and secondary treated municipal wastewater, essentially in activated sludge plants, as well as in municipal cen-

Table 14.1 Nitrogen and phosphorous contents reported in various municipal wastewaters and the corresponding removal efficiencies and microalgal biomass productivities

Wastewater source	Microalgae	Reactor	Total N (g L^{-1})	N removal (%)	Total P (g L^{-1})	P removal (%)	N:P ratio	Biomass productivity (g L^{-1} day^{-1})	Lipid productivity (g L^{-1} day^{-1})	References
Municipal (M)	*P. tricornutum*	Continuous	0.50–0.84	80–100	0.076–0.116	50–100	6.6–862.1			Craggs et al. (1995)
M	*Oscillatoria* sp.	Continuous	0.50	100	0.076	100	6.6			Craggs et al. (1997)
M	*C. vulgaris*	Batch	0.05–1.55	55–88	0.004–0.042	12–100	12.5–36.9			Khan and Yoshida (2008)
M	*S. obliquus*	Batch	0.03	79–100	0.012	47–98	2.5	0.23		Ruiz-Marin et al. (2010)
M (before primary settling)	*Chlorella* sp.	Batch	0.04	68	0.006	83	6.7	–	–	Wang et al. (2010)
M (after primary settling)	*Chlorella* sp.	Batch	0.04	69	0.007	91	5.7	–	–	Wang et al. (2010)
M (after activated sludge tank)	*Chlorella* sp.	Batch	0.02	51	0.001	5	20.0	–	–	Wang et al. (2010)
M (after sludge centrifuge: centrate)	*Chlorella* sp.	Batch	0.13	83	0.202	86	0.6	–	–	Wang et al. (2010)
M (50%)+sea water (50%)	*Nannochloro-psis* sp.	Batch	0.11	–	0.005	–	22.0	0.21	0.060	Jiang et al. (2011)
M (centrate)	*Hindakia* sp.	Batch	0.13	62[a]	0.21	–	0.6	0.28[b]	0.078	Zhou et al. (2011)
M (centrate)	*Chlorella* sp.	Batch	0.13	35–63[a]	0.21	–	0.6	0.14–0.24[b]	0.037–0.075	Zhou et al. (2011)

(continued)

Table 14.1 (continued)

Wastewater source	Microalgae	Reactor	Total N (g L^{-1})	N removal (%)	Total P (g L^{-1})	P removal (%)	N:P ratio	Biomass productivity (g L^{-1} day^{-1})	Lipid productivity (g L^{-1} day^{-1})	References
M (centrate)	*Auxenochlorella protothecoides*	Batch	0.13	71[a]	0.21	–	0.6	0.27[b]	0.078	Zhou et al. (2011)
M (centrate)	*Scenedesmus* sp.	Batch	0.13	58–59[a]	0.21	–	0.6	0.19–0.25[b]	0.050–0.075	Zhou et al. (2011)
M	Mixed culture	Semi-continuous	0.06[c]	66[c]	0.01[c]	98[c]	8.0[c]	0.23[c]	–	Ruiz-Martinez et al. (2012)
M	*Desmodesmus* sp.	Batch (20 L)	0.04	80[d]	0.04	–	1.1	0.01	0.002	Komolafe et al. (2014)
M	*Desmodesmus* sp.—mixed	Batch (20 L)	0.04	84[d]	0.04	–	1.1	0.02	0.002	Komolafe et al. (2014)
M	*Cyanobacteria*—mixed	Batch (20 L)	0.04	55[e]	0.04	–	1.1	0.02	0.005	Komolafe et al. (2014)

[a]After 3 days; [b]After 4 days; [c]Average over 6 weeks; [d]Over 22 days; [e]Over 11 days

Table 14.2 Nitrogen and phosphorous contents reported in various industrial wastewaters and the corresponding removal efficiencies and microalgal biomass productivities

Wastewater source	Microalgae	Reactor	Total N (g L^{-1})	N removal (%)	Total P (g L^{-1})	P removal (%)	N:P ratio	Biomass productivity (g L^{-1} day^{-1})	Lipid productivity (g L^{-1} day^{-1})	References
Tannery	*Thiobacillus ferrooxidans*	UASB	0.27	–	0.02	–	13.0	–	–	Durai and Rajasimman (2011)
Paper mill	*S. dimorphus*	Batch	1.1–10.9	–	0.6–5.8	–	3.0–4.3	–	–	Slade et al. (2004)
Olive mill	*Spirulina platensis*	Batch	–	1.15[a]	–	55	–	0.51	0.06	Moustafa and El Shimi (2016)
Carpet	*Botryococcus braunii*	Batch (1000 L)	0.04–0.05			18–22		0.04	0.004	Chinnasamy et al. (2010)
Citric acid	*Chlorella vulgaris*	Batch[b]		96		95		0.98	0.34	Li et al. (2013)

[a] Average over two years of experiments; [b] 20% CAE dilution for 5 days

Table 14.3 Nitrogen and phosphorous content reported in various agricultural wastewaters and the corresponding removal efficiencies and microalgal biomass productivities

Wastewater source	Microalgae	Reactor	Total N (g L^{-1})	N removal (%)	Total P (g L^{-1})	P removal (%)	N:P ratio	Biomass productivity (g L^{-1} day^{-1})	Lipid productivity (g L^{-1} day^{-1})	References
MBBM[a]	*Neochloris Oleoabundans*	Batch	0.01–0.10 (NO_3^-)	90–95	–	–	–	0.01–0.16	0.009–0.017	Levine et al. (2011)
			0.01–0.10 (NH_4^+)	90–95				0.02–0.07	0.003–0.004	
Anaerobic digested effluent (ADE)[b] daily manure	*Neochloris Oleoabundans*	Batch	0.01[d]	90–95	–	–	–	0.04	0.004	Levine et al. (2011)
ADE[c] daily manure			0.04[d]	90–95				0.09	0.003	
Basal glucose medium	*C. pyrenoidosa*	Batch	0.19	78	–	15	–	1.20	0.35	Zhang et al. (2012)
	C. pyrenoidosa + *bacteria*			78		15		1.14	0.25	
Soybean wastewater glucose	*C. pyrenoidosa*	Batche	0.19	70	0.05	93	3.8	1.23	0.35	Zhang et al. (2012)
	C. pyrenoidosa + *bacteria*			90		98		1.07	0.24	
Soya whey	*Chlorella vulgaris*	PBR (6 L)[f]	1.2	58	–	–	–	1.6	0.18	Mitra et al. (2012)
Ethanol tin stillage			5.5	91				2.5	1.10	
Soybean processing wastewater	*C. pyrenoidosa*	Fed-batch	0.27	87–89[g]	0.056	70	–	0.64	0.40	Hongyang et al. (2011)

(continued)

Table 14.3 (continued)

Wastewater source	Microalgae	Reactor	Total N (g L^{-1})	N removal (%)	Total P (g L^{-1})	P removal (%)	N:P ratio	Biomass productivity (g L^{-1} day^{-1})	Lipid productivity (g L^{-1} day^{-1})	References
Brewary (synthetic)	*Chlorella* sp. *Chlorella vulgaris*	Two stage bioreactor	0.05–0.08	–	0.02–0.02	–	–	3.5	1.08	Faroq et al. (2013))
Dairy industry and pig farming wastewater	*C. vulgaris*	Batch	3–36	30–95[d]	112	20–55	–	–	–	Gonzalez, Olivia, and Baena (1997)
Dairy manure	*Chlorella* sp.	Batch	0.13–3.46	76–83	0.02–0.25	63–75	7.0–13.8	–	–	Wang et al. (2010)
Dairy manure with polystyrene foam	*Chlorella* sp.	Batch[h]	0.12	76	0.29	62	–	2.57[i]	0.23[i]	Johnson & Wen, (2010)
Fermented swine urine	*Scenedesmus* sp.	Batch[j]	0.86	87	0.20	83	–	–	0.01	Kim et al. (2007)
Piggery	*Chlamydomonas mexicana*	Batch[k]	0.05	62	0.01	28	4.1	0.31[l]	0.10[l]	Abou-Shanabab, Ji, Kim, Jung Paeng, and Jen (2013)

[a]Modified Bold's Basal Medium; [b]Dilution rate 1:200; [c]Dilution rate 1:50; [d]NH^{4+} ; [e]Over 6 days; [f]Over 4 days; [g]Over 5 days; [h]196% Bristol solution, over 15 days; [i]g m^{-2} day^{-1}; [j]Over 51 days in CT medium; [k]Dilution rate 1:20, over 20 days; [l]In g L^{-1} after 20 days incubation

trate obtained from the sludge centrifuge. Municipal centrate has been found to be an encouraging growth medium for good productivities in microalgae, including *Chlorella*, which was reported having the highest lipid productivity (Zhou et al., 2011). Normally, when it comes to the tertiary municipal treatment, high levels of N and P are eliminated, and these nutrients could be applied in later stages during microalgae cultivation. In fact, many studies have confirmed that microalgae are able to efficiently remove N and P from municipal wastewater. Municipal wastewater can be seen as a sustainable nutrient source in microalgae cultivation for biofuel production (Cho, Luong, Lee, Oh, & Lee, 2011; Wang et al., 2010). In wastewater facilities, anaerobic digestion can be a pivotal process, allowing organic carbon to be consumed by a consortium of bacteria. At a later stage, the organic matter could be digested by microalgae and be converted into biofuels and high-added-value products. Kong, Ling, Martinez, Chen, and Ruan (2010) cultivated *Chlamydomonas reinhardtii* in municipal wastewater. Around 0.56 g L^{-1} day^{-1} N and 0.02 g L^{-1} day^{-1} P were effectively removed from wastewater producing biomass productivity and lipid content of *ca.* 2.0 and 0.5 g L^{-1} day^{-1}, respectively.

14.3.5.2 Industrial Wastewater

Unlike municipal wastewater, industrial wastewater contains much lower levels of phosphorous and ammonia, but in many occasions, it is enriched with heavy metals which can affect microalgae biomass growth rates. Consequently, the application of industrial wastewater in microalgae-based biofuel production is limited. Growth stimulators can improve the growth rates in certain conditions (Taştan, Duygu, & Dönmez, 2012). In practice, few works have reported involving microalgae cultivation in industrial wastewater for biofuel production. Examples include the production of microalgae with palm oil mill effluent (Lam & Lee, 2012), carpet mill wastewater (Bhatnagar, Chinnasamy, Singh, & Das, 2011; Chinnasamy, Bhatnagarab, Hunt & Das, 2010), and olive mill wastewater (OMW) (Hodaifa, Martínez, & Sánchez, 2008). The maximum specific growth rate of *Scenedesmus obliquus* in OMW was 0.044 h^{-1} and the highest carbohydrates content reached 66 wt% (Hodaifa, Martínez, & Sánchez, 2009). Importantly, Ammary (2005) demonstrated earlier that at total N and P concentrations in OMW of 0.53 and 0.18 g L^{-1} (corresponding to an N:P ratio of 2.9), respectively, N would act as the limiting nutrient for microalgae growth. Considering the large volumes of OMW produced worldwide (5.4 × 106 m^3 $year^{-1}$) (Beccari, Bonemazzi, Majone, & Riccardi, 1996; Benitez, Beltran-Heredia, Torregrosa, Acero, & Cercas, 1997), the maximum annual microalgae biomass (50% C by weight) and lipid (25% by weight) yields theoretically produced using OWM would be 3.3 × 105 and 8.2 × 104 tones, respectively. The presence of phenolic compounds in OMW should be taken into account since the direct application to soils can impact on plants, soil microbial activity and diversity, and aquatic ecosystems. To address this, a mix of 3 cyanobacteria (*Nostoc muscorum*, *Anabaena oryzae*, and *Spirulina platensis*) was cultivated in different OMW dilutions (50, 75, and 100%). The best results were obtained in the 50% dilution, from which an algal cake was isolated after flocculation. The algal cake was successfully employed as a solid biofertilizer and as animal fodder (Moustafa & El Shimi, 2016). Tarlan, Dilek, and Yetis (2002) documented that a consortium from a stabilization pond was able to remove up to 58% of the chemical oxygen demand (COD) and 80% of absorbable organic halogens (AOX) within diluted pulp from the paper industry. Microalgae were also applied to process carpet wastewaters. The process could efficiently reduce the pollution load in 10 days in four 950 L raceway ponds (Chinnasamy et al., 2010), including COD (from 1.41 to 0.11–0.18 g O_2 L^{-1}), the biological oxygen demand (BOD) (from 0.33–0.49 to 0.01–0.02 g O_2 L^{-1}), Total Kjeldahl Nitrogen (TKN, from 0.04–0.05 to 0.03–0.04 mg L^{-1}) and PO_4^{3-} (from 0.020–0.035 to 0.018–0.022 mg L^{-1}). In tannery wastewater treatment, anaerobic digestion is a more favorable process as it is less energy intensive than aerobic treatment (Durai & Rajasimman, 2011). It seems that the combination of physical/chemical and biological processes can give satisfactory results in terms of COD, NH_4–N and total suspended solids (TSS) removal, up to 97, 98, and 100%, respectively. Another key example of industrial wastewater remediation was demonstrated by Li et al. (2013) using a selected strain of *Chlorella* sp. to efficiently treat citric acid effluent, maximizing the biomass production up to 1.04 g L^{-1}. At the same time, it was possible to promote nutrient removal (TKN, P, TOC, COD and BOD) above 90%. Industrial wastewater may also be mixed with organic compounds from other sources (Kothari, Pathak, Kumar, & Sing, 2012). A study was conducted using wastewater containing 85–90% carpet industry effluents with 10–15% municipal sewage, to evaluate the feasibility of algal biomass and biodiesel production. The potential biomass and lipid production of the consortium cultivated in wastewater were estimated at *ca.* 9.0–17.8 and 0.6–1.2 tons ha^{-1} $year^{-1}$, respectively. About 64% of the algal oil obtained could be converted into biodiesel.

14.3.5.3 Agricultural Wastewater

Agricultural wastewater is one of the major sources of wastewater, mainly produced from livestock production systems. An important difference between agricultural and municipal wastewater is the higher N and P concentrations in the former. In fact, the N/P ratio present in the animal manure is so high that it cannot be remediated by crops only. An excess of nutrients accumulating in the soil can increase nutrient losses through run-off. Moreover, agricultural operations may bring particles, dissolved ions, molecules and living microorganisms to interact with water, drastically reducing its quality. Agricultural wastewater can also be used as nutrient source for algae-based biofuel production. As an example, *Chlorella* sp. cultivated in dairy manure wastewater resulted in a fatty acid productivity of 0.23 g m^{-2} day^{-1} (Johnson & Wen, 2010). However, it is crucial that agricultural wastewater is not too turbid, otherwise, it would reduce the light penetration necessary for algal growth. As a result, wastewater should be diluted during storage and before use (Attasat, Wanichpongpan, & Ruenglertpanyakul, 2013; Fenton & Uallacháin, 2012), but dilution has a great impact on biomass accumulation and nutrient removal from agricultural wastewater (Cheng & Tian, 2013). Interestingly, the dilution rate was correlated with lipid productivity (Wang et al., 2010; Wang, Xiong, Hui, & Zeng, 2012; Zhu et al., 2013). When the initial organic matter content was diluted to 1.9 g L^{-1} COD, a maximum lipid productivity of 0.111 g L^{-1} day^{-1} was achieved using *Chlorella zofingiensis* in piggery wastewater (Zhu et al., 2013). Another representative example was demonstrated by Kim et al. (2007), who after 31 days of cultivating *Scenedesmus* in 3% v/v fermented swine urine mixed with 10% Bold's Basal Medium, observed significant increases, with respect to the control medium, of growth rate (3-fold), dry weight yield (2.6-fold), amino acid levels (2.7-fold), and secondary metabolites including chlorophyll a (2.1-fold), astaxanthin (2.8-fold), lutein (2.7-fold), and β-carotene (>5-fold). Also, an increased quantum yield of photosystem II of the aquatic microalgae was registered. Therefore, although implying higher hydraulic volumes and thus energy consumption, dilution of agricultural media can improve the cost efficiency and attenuate the negative environmental impact risks. Microalgae have also been studied in the treatment of dairy wastewaters. For example, Kothari et al. (2012) reported that the level of NO_3^- could be reduced by 90%, NH_4^+ by 90%, PO_4^{3-} by 70%, and COD by 60% in dairy wastewater, using *Chlamydomonas polypyrenoideum* over 10 days in 0.25 L flasks. Despite all these good results, the majority of them are acquired from lab-scale experiments. There is an urgent need for data acquired on a long-term and pilot-scale basis. Finally, interesting research opportunities exist in the field of anaerobic digestion combined with thermochemical liquefaction, because the latter avoids the need for costly harvest and drying process steps, one of the bottlenecks on the road toward the cost-effective production of algal biofuels.

14.3.5.4 Removal of Micropollutants

Numerous studies have been conducted to explore the potential of microalgae to degrade specific pollutants, including pharmaceutical and personal care products, endocrine disrupting compounds, heavy metals, etc. For example, 2 species (*Chlorella vulgaris* and *Coenochloris pyrenoidosa*) isolated from a water source containing aromatic pollutants could degrade p-chlorophenol at a rate of 10 mg L^{-1} day^{-1} (Lima, Raposo, Castro, & Morais, 2004). A correlation was observed between the photosynthetic activity of *Scenedesmus obliquus* and the degradation rate (141 mg L^{-1}) of dichlorophenols (Papazi & Kotzabasis, 2013). Hormones could also be transformed by microalgae via hydroxylation, hydrogenation, and dehydrogenation (Peng et al., 2014). In a 5-day experiment, *Scenedesmus obliquus* and *Chlorella pyrenoidosa* degraded 1.6 μM (0.5 mg/L) progesterone (95%) or 1.6 μM norgestrel (100% for *S. obliquus* and 60% for *C. pyrenoidosa*). Endocrine disruptors are another important group of micropollutants. *Chlorococcum* sp. and *Scenedesmus* sp. have been shown to degrade α-endosulfan (a cyclodiene insecticide with endocrine activity) through biosorption and biotransformation (Sethunathan et al., 2004). However, at high concentrations, these compounds can interfere with the photosystem II energy fluxes, affecting the microalgae's overall photosynthetic activity (Perron & Juneau, 2011). Heavy metals represent another serious problem present in industrial wastewaters. The mechanism of heavy metal accumulation and detoxification was addressed in the review of Perales-Vela, Peña-Castro, and Cañizares-Villanueva (2006), including U^{6+}, Cu^{2+}, Cd^{2+}, Zn^{2+}. Table 14.4 illustrates examples of micropollutant remediation studies using microalgae. Delrue, Álvarez-Díaz, Fon-Sing, Fleury, and Sassi (2016) published an up-to-date review in this research field.

14.3.6 Role of Biotechnology

Biotechnology will play a major role in the development of algae-based wastewater treatment technologies, and more in general, in various algae-based technologies. Since the biodiversity of microalgae is immense, they hold a huge potential. Nevertheless, high-throughput screening methodologies are required to screen for strains with high potential for nutrient and pollutant removal. Two strategies have been adopted for screening microalgae: either select a suited microalgae strain through the use of selective screening methods or allow natural indigenous consortiums to evolve to a stable culture. A fascinating example was demonstrated by Abdelaziz, Leite, Belhaj, and Hallenbeck (2014), who screened 100 local strains from Quebec (Canada) on 12-well plates using an artificial medium (Bold's Basal Medium) and a real secondary effluent from a wastewater plant at 10 and 22 °C. The authors used numerous criteria such as biomass productivity, lipid content, and nutrient removal. Advances in molecular algae biology are crucial to efficiently characterize and select microalgae strains. However, the outcome of such screening results cannot always be extrapolated to a large scale, depending on the robustness of the selected strain, as wastewaters are contaminated with various microorganisms which are adverse to fast microalgae growth (competition). Moreover, in such wastewaters, the environmental conditions to which microalgae need to adapt fluctuate continuously. For this reason, currently, there is a research trend to employ consortia of microorganisms to enhance their robustness in wastewater treatment. Different consortia, either bacterial-microalgal or fungal-microalgal, have shown their benefits (Muradov et al., 2015; Ren, Liu, Kong, Zhao, & Ren, 2015). The robustness of such consortia is based on the competitive advantage originating from the symbiosis between bacteria (CO_2 production through respiration) and microalgae (O_2 production through photosynthesis). Besides their symbiosis, microalgal-microbial aggregates settle more easily than pure microalgal aggregates, which can have drastic effects on the harvesting cost of the resulting biomass. Moreover, the use of such consortia allows better removal of both macro- and micropollutants. Halfhide, Åkerstrøm, Lekang, Gislerød, and Ergas (2014), for instance, demonstrated that microalgae were very effective in terms of removing nitrogen from aquaculture, while the bacteria were the major removers of other organic pollutants. Olguín, Mendoza, González-Portela, and Novelo (2013) treated a polluted urban river and screened the population dynamics of *Neochloris oleoabundans* and native green microalgae, and isolated consortiums with diatoms for the production of lipid-rich biomass, while efficiently removing N and P. Another strategy was demonstrated by Halfhide et al. (2015) who left a natural microalgal con-

Table 14.4 Illustration of the potential of microalgae for micropollutant degradation. Adapted from Delrue et al. (2016)

Microalgae	Pollutant	T (°C)	Culture	Light source	Carbon source	Removal rate (μmol L^{-1} day^{-1})
Chlorella vulgaris + *Coenochloris pyrenoidosa*	p-chlorophenol	25	0.15 L, 100 rpm	53[a], 16 h day^{-1}	CO_2	77
Scenedesmus obliquus	Dichlorophenols	30	0.05 L	50–60[a], 24 h day^{-1}	Glucose	0–260
	Progesterone	25	0.15 L, 150 rpm	3000[b], 24 h day^{-1}	Carbonate/CO_2	2
Chlorella pyrenoidosa	Norgestrel	25	0.15 L, 150 rpm	3000[b], 12 h day^{-1}	Carbonate/CO_2	1
	Triclosan	22	0.10 L, 120 rpm	4000[b], 16 h day^{-1}	Acetate	2
Chlorella vulgaris consortium	Tetracycline	10–18	14 L fed-batch, HRAP	10[c], 24 h day^{-1}	Atmospheric CO_2	continuous
Chlorococcum sp.	α-endosulfan	22	0.15 L, 100 rpm	2000[b], 24 h day^{-1}	Atmospheric CO_2	0.3
Selenastrum capricornutum	PAHs + heavy metals	22	0.15 L, 100 rpm	40[a], 16 h day^{-1}	Atmospheric CO_2	0–1378[d]

[a]In μmol m^{-2} s^{-1}; [b]In lux; [c]In W PAR m^{-2}; [d]In mg g^{-1}

sortium evolving with bacteria into a new consortium to reduce the N and P pollutants of a centrate obtained from anaerobically digested and dewatered municipal sludge. Finally, it is important to stress the need to use real wastewaters where possible, as in real-life conditions, the nutrient and microbial composition can rapidly modify the colonization. Many studies have employed synthetic rather than real wastewaters. In these cases, results should be interpreted accordingly.

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Simona Francesca Consoletti obtained a B.Sc. in Sciences of Agriculture, Food and Environment at the University of Foggia (2015). Driven by her curiosity on microbial ecology and technology, she graduated as M.Sc. in Design and Management of Bio-based Rural Systems (2016). She joined the Nanoval Group led by Rafael Luque in July 2016 and worked on "Microalgae-based valorization of fine chemicals in flow systems, using heterogeneous catalysis" project. Later, after having worked on the dehydration of sorbitols, Simona graduated as M.Sc. in Nanochemistry at the University of Cordoba in 2017.

Pepijn Prinsen is a postdoctoral researcher in the Group of Nanoscale Chemistry and Biomass/Waste Valorization (University of Cordoba, Spain). He graduated as Bioengineer at the University of Ghent (Belgium) and he holds a Ph.D. in Chemistry from the University of Seville in the Group of Lignocellulosic Materials of Industrial Interest at the Institute of Natural Resources and Agrobiology. His postdoctoral research project at the University of Amsterdam (The Netherlands) focused on lignin depolymerization and carbon synthesis.

Chapter 15
Utilizing Different Forms of Waste Sludge in Eco-construction Material Production

Nengxiong Wang, Yiu Fai Tsang, Hong Chua, Haakrho Yi, Yi Yang, Chun-Fai Yu and Peter Hoi Fu Yu

Abstract Large volume of sludge generated from drinking water purification and domestic/industrial wastewater treatment processes is disposed to landfills. This leads to severe environmental problems and secondary pollution, particularly in highly urbanized cities. Diverting the waste sludge from landfills would alleviate the shortage of landfill sites. Utilization of properly treated waterworks and sewage sludge to produce sustainable construction materials is a win-win strategy. It not only converts such wastes into useful materials but also helps solve the disposal problems in the world to achieve volume reduction and stabilization. The purpose of this chapter is to provide a critical review on utilization of waste sludge as raw material or resource for construction material production. It has been studied and analyzed that more than hundreds of publications about the eco-construction material production from waterworks and sewage sludge. This chapter has given a comprehensive analysis about this issue in the perspective of waste sludge characteristics, waste sludge pretreatment, production process, mechanisms, feasibility, and case studies about the production for bricks, concrete blocks, lightweight aggregates, cement, and glass-ceramics. Studies have concluded the sludge forms and additional amounts can affect

N. Wang · Y. F. Tsang (✉) · Y. Yang
Department of Science and Environmental Studies, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong
e-mail: tsangyf@eduhk.hk

N. Wang · H. Chua · P. H. F. Yu
Faculty of Science and Technology, Technological and Higher Education Institute of Hong Kong, Tsing Yi Island, Hong Kong

Y. F. Tsang
School of Environment, Nanjing Normal University, Nanjing, Jiangsu Province, People's Republic of China

H. Yi
Department of Gwangyang Research Group, RIST, Gwangyang City, Republic of Korea

C.-F. Yu
Environmental Science Program, Division of Science and Technology, BNU-HKBU United International College, Zhuhai, Guangdong Province, People's Republic of China

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the quality and specifications of different kinds of final products, however, the overall approach can contribute to waste management improvement and environmental remediation.

Keywords Resource recovery · Waterworks sludge · Sewage sludge · Sludge pretreatment · Stabilization

15.1 Introduction

15.1.1 Overview of Waste Sludge

Waste sludge is the residue produced during water and sewage treatment. Waterworks sludge comes exclusively from the coagulation process during color or turbidity removal of raw water and the purification of backwash water using chemical coagulants (i.e., $Al_2(SO_4)_3$) (Ahmad, Ahmad, & Alam, 2016). Sewage sludge is mainly produced from sewage treatment processes, including the physical settling process, biological process and chemically enhanced treatment processes (Von Sperling & Augustos, 2017). Sludge, whether in semi-solid or solid form, contains high moisture content (90–99%), organic and inorganic constituents, colloidal and chemical coagulants, as well as pathogens, bacteria, and many other complex components (Zhou, Thompson, & Meschke, 2016). Sludge that has not been properly disposed of and treated can have serious environmental and human health consequences. Toxic chemicals in sludge, including heavy metals and organic chemicals, can pollute the receiving water bodies and the surrounding environment, further causing secondary pollution. Many parasites and pathogens in the sludge can also impact on human health. Therefore, proper treatment processes and management of waste sludge are critical and necessary.

Sludge can be concentrated, dehydrated and dried for final disposal to stabilize it and make it harmless to the environment and human health. The sludge treatment facilities in T-Park, Hong Kong, can handle approximately 2,000 tons/d of sludge based on the "waste-to-energy" strategy (Swann, Downs, & Waye, 2017). Treated sludge can actually be further utilized owing to its desirable properties. Treated sludge can be utilized for the production of eco-construction materials due to their mineral content, such as Si, Al, Fe, and Ca. For example, Velasco, Ortíz, Giró, and Velasco (2014) stated that alum sludge could be 20% substituted in commercial clay brick production without compromising the mechanical strength of the bricks. Japan applied this technology in the early 90s to produce bricks and cement, while European countries have conducted a feasibility analysis of this technology and have vigorously developed it in their construction industries. The production of building materials from sludge and its residues can reduce the environmental and health impacts of pollution, promote industrial and economic development and achieve a "win-win" strategy. However, in the immature stage of this technology, market exploration is necessary. The application of the required environmental standards, the proportion of sludge and other substances, and the consideration of the solids in the sludge are also huge challenges.

15.1.2 Classification of Waste Sludge and Its Characteristics

15.1.2.1 Waterworks Sludge

Drinking water treatment usually undergoes coagulation, flocculation, sedimentation, filtration, and disinfection to remove suspended solids, colloids, and toxic and harmful constituents. Chemical coagulants, such as aluminum salts (e.g., $Al_2(SO_4)^3 \cdot 18H_2O$) or iron salts (e.g., $FeSO_4 \cdot 7H_2O$, and $FeCl_3$), are used to coagulate the fine particles in water through charge neutralization to form flocs and undergo gravity filtration (Satish, Habibunnisa, & Sultana, 2017). According to Table 15.1, there are about 40–70% of total sludge, containing mineral salts, which can form their respective precipitates that carry sand, clay, or other humic particles. The more coagulants that are applied, the higher the solid content of the sludge. Moreover, too much aluminum will be toxic to the aquatic system (under extremely low pH) and to human health (Oladoja, Unuabonah, Amuda, & Kolawole, 2017). Certain quantities of lime or soda can also be used for water-softening processes, while sludge can result from the precipitation of calcium or magnesium carbonate as well (Johnson, Napiah, & Kamaruddin, 2014). Moreover, during the backwash process, the remaining chemical coagulants, inorganic and organic debris will concentrate in the waste sludge. Waste sludge generally contains more than 80% moisture content and 500 mg/L of organic constituents. Depending on the raw water quality, some quantities of heavy metals (e.g., Cd, Cu, and Ni) can also be found in waterworks sludge.

15.1.2.2 Sewage Sludge

Sewage treatment generally entails preliminary, primary, and secondary treatments. Some treatment plants apply an advanced tertiary treatment. Physical treatment involves removing suspended substances, debris, and other screenings. Primary sludge usually contains pathogens, parasites, heavy metals, and other types of inorganic constituents (Zhou et al., 2016). During secondary treatment, a large amount of secondary sludge is produced from the organic matter removed via microbial metabolism, such as activated sludge and biofilm processes. Also, there are plenty of sludge forming during the nitrogen removal processes. Typically, sewage sludge contains a large amount of organic matter (40–70%, Table 15.1), over 95% moisture content, and certain amounts of heavy metals. The heating value of sludge is relatively high (13,000–24,000 kJ/dried sludge kg) and easily results in odor and rotting issues. Secondary sludge is hydrophilic, which results in dewatering difficulties and poor compressibility. Chemical processes, such as coagulation and flocculation, can

Table 15.1 Typical compositions found in waste sludge

Waterworks sludge								
Compositions	Average percentage	Examples	Average percentage (in sample)	Major sources	Formation	Possibility of construction material production	Reasons	References
Organic matter	0.1–5%	–	–	Raw water	Coagulation, flocculation, and backwash	Yes	Heating value provision but causes pores	Fang et al. (2017)
Sand, clay, silt, etc.	40%	–	–	Raw water	Coagulation, flocculation, and backwash	Yes	Can be ingredients of the major raw materials	Ahmad et al. (2016)
Minerals	40–70%	SiO_2	40–55%	Chemical coagulants or other means	Coagulation, flocculation, water-softening process, and backwash	Yes	Improves the quality of products but should restrict the added amounts	Ahmad et al. (2016), Hwang et al. (2017)
		Al_2O_3	14–20%					
		$FeCl_2$	5%					
		K_2O	3%					
		CaO	4%					
Heavy metals	0.1–2%	Cd	0.1–2%	Raw water	–	No	Toxic	Johnson et al. (2014)
		Cu	0.1–2%					
		Zn	0.1–2%					
Pathogens, parasites, and other microbes	–	–	–	Raw water	–	No	Harmful and useless	Johnson et al. (2014)

(continued)

Table 15.1 (continued)

Waterworks sludge								
Compositions	Average percentage	Examples	Average percentage (in sample)	Major sources	Formation	Possibility of construction material production	Reasons	References
Other harmful and toxic constituents	–	Cyanides	<1%	Raw water	Coagulation, flocculation, water-softening process, and backwash	No	Toxic and harmful	Sharma et al. (2013)
		Chlorine	<1%					
		–	–					
Sewage sludge								
Organic matters	40–70%	–	–	Sewage	Secondary treatment	Yes	Heating value provision but causes pores	Von Sperling and Augustos (2017)
Sand, clay, silt, screenings, etc.	14–25 g/L	–	–	Sewage	Preliminary treatment and primary settling	Yes	Can be ingredients of the major raw materials	Oladoja et al. (2017)
Minerals	20–40%	Al_2O_3	14–20%	Chemical coagulants or other means	Chemical treatment	Yes	Improves the quality of products but should restrict the added amounts	Johnson et al. (2014)
		$FeCl_3$	5%					
Nutrients	10–60 g/kg	N	10–60 g/kg	Sewage	Advanced tertiary treatment	No	Useless	Zhou et al. (2016)
		P	10–60 g/kg					
		–	–					

(continued)

Table 15.1 (continued)

Waterworks sludge								
Compositions	Average percentage	Examples	Average percentage (in sample)	Major sources	Formation	Possibility of construction material production	Reasons	References
Microorganisms, pathogens, etc.	3,000–5,000 mg MLSS/L	–	–	Organic matter	Secondary treatment	No	Harmful and useless	Djafari et al. (2017)
Heavy metals	3–2,000 mg/kg	Cd	0.3–2 mg/kg	Sewage	Chemical treatment	No	Toxic	Zhang et al. (2017)
		Ni	20–70 mg/kg					
		Zn	>1,800 mg/kg					
		Cu	300–500 mg/kg					
Other toxic and harmful constituents	0.01–20 mg/kg DW	PCBs	0.5–10 mg/kg	Sewage (especially in industrial sewage)	Chemical treatment; Advanced tertiary treatment	No	Toxic and harmful	Fang et al. (2017)
		Radioactive elements	0.1–5 mg/kg					
		Other EDCs	–					

also produce sludge for sewage treatment with similar characteristics to waterworks sludge (Johnson et al., 2014). On the other hand, the sludge generated from industrial wastewater treatment processes usually contains higher concentrations of oil and grease aside from its moisture content and organic and inorganic constituents.

15.1.3 Valuable Ingredients of Waste Sludge for Eco-construction Material Production

Sludge generated from water and sewage treatment plants comprises minerals, such as SiO_2, Al_2O_3, Fe_2O_3, and CaO, which have properties similar to those of raw materials in the production of construction materials. Appropriate minerals improve product quality by preventing shrinking and cracking, and ensuring easy binding and molding (Chakraborty, Jo, Jo, & Baloch, 2017). However, excessive amounts of minerals will bring negative effects, such as brittleness with excessive silica, shrinking and warping of raw materials during burning and drying with excessive aluminum and melting of products with excessive calcium (Shui, Yu, Bao, & Wang, 2017). Sand, clay, silt, and limestone found in sludge can be ingredients in the production of building materials as well. The properties of construction materials depend exclusively on the ratio of sludge and clay and the sintering temperature, whereas other building materials (e.g., cement, bricks, and lightweight aggregate) require different ratios of ingredients and physical properties. For example, the compressive strength and resistance of products in appropriate mixtures of dried sludge and cement are worse than those without any cement replacement (Jiang, Wu, Liu, Lu, & Chen, 2015). The fibers in the sludge can improve the compression strength, impact resistance, workability, and cohesion of building materials. However, the compressive strength of the eco-construction products decreases with the increase in dried desalination sludge ratio in the mix (Tyagi & Lo, 2016). In addition, heavy metals can be stabilized and solidified in a ceramic matrix, while pathogens can destroy and achieve oxidization of organic pollutants (Sharma, Thornberg, & Andersen, 2013). Simultaneously, organic matter in sludge with high heating value can save a certain amount of energy during the sintering of construction materials.

15.2 Pretreatment Processes of Waste Sludge for Eco-Construction Materials

15.2.1 Sludge Thickening

Sludge thickening removes a portion of the water fraction and reduces the sludge's volume by increasing its solid content (Hu et al., 2015). Typically, the solid content after thickening only amounts to 1–5%, while the compositions of organic matter (40–80%), pathogen (10%), and heavy metals in sludge do not change greatly (Table 15.2) (Atay & Akbal, 2016). Additionally, oily matters or other radioactive materials may also be present in thickened sludge. Sludge thickening containing such toxic and harmful constitutes cannot meet the requirements of stability and harmlessness; thus, the production of construction materials using sludge thickening is not advised. Sludge thickening just helps reduce the loading and costs of the following sludge treatment, transport, and disposal for construction material production (Jiang et al., 2015).

Sludge thickening can be applied by gravity settling and dissolved air flotation (DAF). Gravity settling thickens sludge through its gravitational forces applied for dense sludge thickening. The sludge should be stirred gently to enable water and air bubbles to escape among particles (Machnicka & Nowicka, 2016). DAF is appropriate for light sludge removal from the liquid surface using a skimmer. The formed bubbles in the tank overcome the gravitational forces of particles and carry them to the surface for removal (Bratby, 2013).

15.2.2 Sludge Conditioning and Dewatering

Sludge conditioning is necessary prior to dewatering to enhance the sludge dewatering characteristics. Sludge conditioning is usually applied by using different types of chemicals to provide positive charges (e.g., lime, H_2SO_4, PAM, etc.) for neutralizing the charges and reducing the zeta potential for sludge aggregation (Zhou, Jiang, Wang, & Yuan, 2014).

The conditioned sludge can then be dewatered further. Sludge dewatering can achieve about 25–30% of dried solid content (Table 15.2) (Niu, Zhang, Wang, Chen, & Chen, 2013). According to Table 15.2, the amounts of Si, Al, and Fe salts can still achieve 39.7, 17.9, and 9.2% (Mulchandani & Westerhoff, 2016) in dewatered sludge. Similar compositions in addition to clay, sand, and silt found in the sludge provide the sources for the production of building materials. Heavy metals in dewatered sludge will also be stabilized during the production of building materials, which reduces the impacts on the surrounding environment and on human health. However, according to Yang, Zhang, and Wang (2015), the amounts of organic matter (40%–80%) and pathogens or other microorganisms (9–10%) will not change significantly (Table 15.2) after sludge dewatering which cannot meet the stability and harmlessness requirements of sludge. Simultaneously, the organic matter will reduce the quality of the construction materials and provide a certain amount of heating value. Such organic matter and water are volatile and will generate gas during material sintering, resulting in higher porosity and water absorption ability, as well as corrosive and ruptured products (Yu et al., 2016). Sludge dewatering could significantly reduce the loading and costs of the following pretreatment processes. Therefore, the production of construction materials by dewatered sludge is more feasible.

Table 15.2 Changes in sludge composition in the different pretreatment stages

	Solid content (%)	Organic matter (%)	Pathogens or other means (%)	Reliability for the production of construction materials	Major application countries or regions	References
Thickening	1–5	40–80	10	No	–	Atay and Akbal (2016)
Dewatering	25–30	40–80	9–10	Slightly reliable	China	Niu et al. (2013)
Drying	90	40–80	1–3	Approximately reliable	China	Shao et al. (2015)
Incineration	>99	0–3	<0.1	Yes	Japan, US, European countries	Inoue and Uchida (2017)

Sludge dewatering can be operated by vacuum filters and filter presses. Vacuum filters can have a rotary configuration (Yang et al., 2015), while filter media cover the drums, which submerge the feeding sludge. With the introduction of a vacuum, the filtrate is collected and discharged, then, the dewatered sludge is collected. Filter presses can be continuous. The sludge mixed with polymers or chemicals is transferred by a moving belt. Dewatering processes are conducted where the sludge passes through the rollers and is squeezed (Gray, 2016). The obtained dewatered cakes are collected by scrapers.

15.2.3 Sludge Drying

The dried sludge, which has undergone significant volume reduction, contains 90% or more solid content (Table 15.2) (Shao et al., 2015). Transport and handling are not just easy but are also more reliable for construction material production. Moreover, the dried sludge is biologically stable (1–3% microorganisms, Table 15.2) (Shao et al., 2015). Furthermore, minerals can certainly be enriched in dried sludge. For example, the concentrations of SiO_2 and Al_2O_3 increased after sludge drying (Table 15.3, e.g., SiO_2: dewatered sludge: 39.2%; dried sludge: 43.6%; Al_2O_3: dewatered sludge: 17.9%; dried sludge: 21.2%) (Li, Wang, Chi, & Yan, 2014; Liu, Liu, & Chang, 2014). Heavy metals such as Cr (9.8%) and Cu (16.5%) (Table 15.3) (Zhang, Chen, Mao, & Wu, 2017) can likewise be found in dried sludge; these will group together for easy disposal and can also be solidified in the construction materials. The use of dried sludge contributes to waste harmlessness, resource recovery, and economic development. As with dewatered sludge, the main concern for dried sludge is the huge amount of organic matter (Table 15.2, 40–80%) (Shao et al., 2015) resulting in possible product rupture (Yu et al., 2016), given that the operation temperature of sludge drying is not sufficient to oxidize the organic matter. Therefore, the production of construction materials by dried sludge is roughly reliable.

Sludge drying can be classified as belt, fluidized bed, and drum drying systems. For the belt drying system, the sludge is broken and mixed with already-dried sludge. Then the granulates are fed into the system by feeding modules, while the sludge evenly distributes on the belts so that drying air (~150 °C) can pass through it (Bennamoun, Arlabosse, & Léonard, 2013). The dried sludge is discharged and collected after cooling. For the fluidized bed drying system, the sludge, broken by a breaker, is mixed with granulates and moved by fluidizing gas. This system is actually indirect for the sludge and heat transfer medium because the heat for water evaporation is sent to the system with a heat exchanger (Hosseini & Wahid, 2016). The system operates only from 85 to 90 °C, and the gas flows in an enclosed loop. The operation of the drum system is similar to other applications, but this system involves rotary cylinders that slowly rotate for water evaporation. The drum system operates at about 300 °C (Rao, Zhao, Huang, Duan, & He, 2015).

Table 15.3 Metal salts and heavy metals in various types of pretreated sludge

Metal salts					
	Dewatered sludge (%)	Dried sludge (%)	Bottom ash (%)	Fly ash (%)	References
SiO_2	39.2	43.6	42.7	47.8	Yu et al. (2016)
Al_2O_3	17.9	21.2	26.6	24.4	Yu et al. (2016)
Fe_2O_3	9.2	8.5	12.8	17.6	Mulchandani and Westerhoff (2016)
CaO	–	6.8	9.9	5.3	Tyagi and Lo (2016)
MgO	1.3	–	2.4	1.5	Mulchandani and Westerhoff (2016)
Others	–	–	5.4	3.4	Li et al. (2014)
Heavy metals					
Cu	8.3	16.5	37	12.5	Zhang et al. (2017)
Ni	4.6	6.1	7.1	4.2	Gu et al. (2016)
Cd	–	2.3	0.4	0.4	Yu et al. (2016)
Cr	6.1	9.8	27.6	16.9	Zhang et al. (2017)
Mn	–	7.7	16.5	48.4	Gu et al. (2016)
As	0.75	0.3	0.1	0.96	Yu et al. (2016)
Hg	4.9	5.5	2.1	3.2	Yu et al. (2016)
Others	–	51.8	11.3	13.4	Gu et al. (2016)

15.2.4 Sludge Incineration

Sludge incineration is used for sludge treatment in the incinerators where the temperature is extremely high (e.g., 800–950 °C) within a short period of time (Coulomb, 2015). It can destroy specific pathogens and greatly oxidize organic matter. The bottom ash obtained from sludge incineration is only 10% of the original sludge volume and contains 99% or more solid content, 0–3% of organic matter, and 0.1% or less of microorganisms (Table 15.2) (Inoue & Uchida, 2017). Such stabilized and harmless ash is more reliable than sludge drying in the application of building materials.

Minerals in sludge (e.g., Al, Fe, and Si) can be highly enriched in bottom ash and fly ash. For instance, Al salts are largely produced in the bottom ash after incineration (Table 15.3, Al_2O_3: dewatered sludge: 17.9%; dried sludge: 21.2%; bottom ash: 26.6% fly ash: 24.4%) (Teng, Wang, Yang, & Zhang, 2016), but more Fe salts are produced in the fly ash (Table 15.3, Fe_2O_3: bottom ash: 12.8; fly ash: 17.6) (Mulchandani & Westerhoff, 2016). These minerals, which are the main elements required for building material production, can be integrated for disposal and resource recovery. On the other hand, heavy metals are enriched in bottom ash and fly ash in the forms of oxides, hydroxides, sulfide, and so on. Table 15.3 indicates that several kinds of heavy metals will be greatly enriched in bottom ash (Cu: 16.5% in dried sludge; 37% in bottom ash; Cr: 9.8% in dried sludge; 27.6% in bottom ash) (Gu, Wong, & Tyagi, 2016). However, As and Hg are enriched in fly ash (Table 15.3: As: 0.3% in dried sludge; 0.1% in bottom ash; 0.96% in fly ash; Hg: 5.5% in dried sludge; 2.1 in bottom ash; 3.2% in fly ash) (Fan, Zhang, & Hu, 2017; Yu et al., 2016). Such heavy metals in the bottom ash can be stabilized in the construction materials. Regarding the enriched minerals in fly ash, these materials should be further treated (e.g., further combustion, melting in higher temperature) for use as building materials because fly ash has serious environmental and human health impacts (Fan et al., 2017). At the same time, the direct disposal of building materials is relatively low, even though the desirable items in fly ash are rich.

The common types of incinerators are multiple hearths, fluidized bed, and electric infrared. Multiple hearth furnaces involve three zones. The first, the dry zone (about 400–750 °C), evaporates water from sludge (Inoue & Uchida, 2017). The second, the combustion zone (900–950 °C), is for sludge combustion, while the lower region is the cooling zone for bottom ash collection (Aadraoui, Elbaghdadi, Rais, Barakat, Ennaji, Karroum, & Oumenskou, 2017). The fluidized bed mainly contains the fluidized refractory bed (sand) to locate sludge and tuyeres for delivering hot combustion air from heat exchangers, while the temperature of the combustors is about 750–950 °C (Qin et al., 2017). The major characteristic of electric infrared incinerators is that the heat source comes from the infrared heating matter. A woven wire belt is located in the furnaces to feed the sludge, which will be sequentially dried and burned under the heating elements. Afterward, the ash is collected at the end of the furnace. The temperature in the furnace can also reach approximately 900 °C.

15.3 Eco-Construction Material Production Using Waste Sludge as Raw Materials

15.3.1 Production of Bricks or Concrete Blocks

Bricks are usually rectangular materials used in the masonry industry. They are commonly produced by mixing clay, lime, soil, and concrete materials via fired or non-fired works. Concrete blocks, made of similar components with additives and adjutants, are generally products that are precast before they are brought to the construction site. Concrete blocks have better insulation ability and are larger, lighter, and stronger (Caruana, Yousif, Bacher, Buhagiar, & Grima, 2017) than conventional clay bricks. Both bricks and concrete blocks can be classified as solid and hollow types (Netula, Singh, & Bhomia, 2017).

15.3.1.1 Ingredients, Production Methods, and Mechanisms

Dewatered sludge, dried sludge, bottom ash, or fly ash from waterworks, sewage, and industrial sewage sludge can be mixed with raw materials to produce bricks or concrete blocks. The pH of the sludge has a range of 5–6.5, and it is almost all non-plastic materials (Kaosol, 2013). The moisture content of the sludge can differ (see Sect. 15.2). The sludge can also be brown or blackish based on water sources (Praspaliauskas & Pedišius, 2017). Raw materials for the production of clay bricks and shale bricks can be clay, murrum, shale, clay-bearing soil, and so forth. Such pretreated raw materials have specific properties. The moisture content ranges from 1 to 20%, and the pH ranges from 7 to 7.5 (Kulovaná, Vejmelková, Pokorný, Siddique, & Keppert, 2016). The plastic limit of clay, shale, and clay-bearing soil is 20–40 (Kaosol, 2013), while murrum is nonplastic. Raw materials used for producing non-sintering bricks (e.g., lime-sand bricks), can be quicklime, quartz sand, silica, or crushed stone dust (Pavagadhi, Bhargav, & Katariya, 2015). These are nonplastic materials when subjected to water, and they generate slaked lime or other weak alkaline mixtures (pH of 8–9) (Kulovaná et al., 2016). They can also be used for concrete block production by adding cement, chemical additives, and adjutants.

The general brick manufacturing process includes mixing and molding, followed by firing for fired-work bricks or curing and cubing for non-fired bricks (e.g., lime-sand bricks, concrete blocks) (Kaosol, 2013). During the mixing process, weight batching methods (Pavagadhi et al., 2015) are more feasible for thorough mixing of the raw materials using a shovel and evenly spreading the sludge on the surface of mixtures. Different percentages of sludge are mixed with the raw materials to test the product features. For example, Pavagadhi et al. (2015) conducted an experiment by mixing different amounts of dried sewage sludge (10, 20, 30, 40, and 50%) and keeping the sand, soil, fly ash, and water constant in the manufacture of clay bricks. Water should be added while mixing until it approaches suitable moisture content. Then, the mixture is put into molds [for bricks: 90 × 90 × 190 mm (Ahmad et al., 2016); for concrete blocks: 90 × 190 × 390 mm (Caruana et al., 2017)] with lubrication, while excess mixture is scraped off. After removal from the molds, the traditional bricks should be covered by PE bags for seven days and undergo natural drying for another seven days (Kaosol, 2013). For fired works bricks, the mixtures are fired in a kiln from 850 to 1,050 °C holding for 3 h (Nkolika, 2013); then, the brick is slowly cooled overnight. For non-fired blocks, the mixtures are put into a curing kiln to harden for 1–3 h followed by 60 °C/h of steam to cure the blocks at 66–85 °C (Ahmad et al., 2016). Next, the blocks are soaked in hot air for half a day. Finally, the blocks are dried by exhaust air and subjected to further curing for 24 h. The non-fired lime-sand bricks can be cured under a high-pressure curing kiln (150–190 °C, 5.5–12.8 bar) (Kulovaná et al., 2016). The cured blocks or bricks are placed on a chain conveyor and then passed through a cuber for stacking three to six blocks high, and then are finally stored.

15.3.1.2 Characteristics of Products

The compressive strength can be tested on Day 7, Day 14, and Day 28. The more sludge that is applied in brick manufacturing, the lower the compressive strength of the products (whether bricks or concrete blocks) (Rabie, 2016). According to the study of Pavagadhi et al. (2015), the controlled bricks (without sludge) had the highest compressive strength (4.0 N/mm^2), and the compressive strength of bricks mixed with dried sewage sludge was lower (e.g., 10% sludge: 3.2 N/mm^2; 20%: 2.8 N/mm^2; 30%: 2.0 N/mm^2). Another experiment regarding hollow concrete block production by mixing dried sludge also proved this state regardless of whether the products were tested at 7, 14, or more days. The reason is that numerous organic matters and water in sludge volatilize during the production process, resulting in more pore sizes on the bricks (Kaosol, 2013). Therefore, bottom ash containing few kinds of organic matter and moisture content is better than dewatered and dried sludge for brick production. On the basis of this finding, the density of bricks and concrete blocks is inversely proportional to the amount of mixed sludge in the raw materials. Owing to the high porosity that occurs in products by organic matters and water, the products display a large pore size and light density. An experiment by Rabie (2016) showed that the density of concrete mix with 5% mixture of dewatered sludge was 2,347 kg/m^3 but only 2,260 kg/m^3 with 10% mixture, and it decreased continuously for 28 days.

Under the same amounts of mixing sludge, the sludge with higher amounts of Al and Si salts (>10%) can increase the bricks' compressive strength because of the formed mullite ($Al_2O_3 \cdot SiO_2$) (Hino, Matsunaga, & Watanabe, 2017). However, too much Si (>25%) in sludge also make products brittle (Vu, Le, Satomi, & Takahashi, 2017), and too much Al (> 25%) tends to twist and crack the products (Zhao, Ren, O'bri, & O'toole, 2016). Excessive Si salts (nonplastic) reduces the plasticity of raw materials and destroys the cohesion of particles. Due to the high glass transition temperature of Al salts, excessive Al requires a higher sintering temperature and forms the secondary mullite, therefore the bricks expand and crack easily. The restriction on the use of sludge with high Al content for brick production is necessary.

Higher water absorption ability of bricks increase the durability of products. The water absorption ability increases with an increase in sludge content during the production of bricks or concrete blocks. For instance, during the production of hollow concrete blocks by mixing 10–50% of dried sludge, the water absorption amounts were the highest (18.7%) for 50% sludge but only 6.6% for 10% sludge (Rabie, 2016). Sludge even reduces the plasticity of clay and retards the cohesion of particles. Furthermore, during the sintering of bricks, the increased temperature can ensure the completion of the crystallization of bricks and reduce the porosity (Kulovaná et al., 2016); thus, decreased temperature increases the water absorption ability. Additionally, the sludge with higher water content will bring more energy during sintering, causing the instability of the sintering temperature and consuming more energy. Sludge with less water content will therefore be better for the production of conventional bricks.

15.3.1.3 Feasibility Analysis

Production of brick materials by waste sludge can contribute to resource recovery, waste stabilization, and harmlessness. It will likewise save on disposal costs of landfills, the costs of raw materials, and the total costs of brick/block production (Hamood & Khatib, 2016). However, the utilization amount of sludge should be limited during each production. As discussed, a high amount of mixed sludge with raw materials will greatly influence the quality of the bricks. The addition of just 5, 10, and 20% of dried sludge into the raw materials is proposed for brick production met the China National Standards (Zhang et al., 2017). the minimum requirements of NIS 74 (Sharma & Joshi, 2016) and BS 3921, respectively (Goel & Kalamdhad, 2017). However, such low utilization percentage of waste sludge cannot deliver the benefits of resource recovery, and even reduces the awareness of industries. Additionally, direct applications by mixing dewatered or dried sludge may release toxic organic pollutants, such as PAHs and dioxins, during brick sintering. Perhaps sludge with little water content (e.g., bottom ash) can promote more utilization value (i.e., 50% or more) (Ahmad et al., 2016). However, this ratio is not really feasible for some regions where incineration techniques have not been well developed (e.g., China, India, and Africa). It may also meet some drawbacks such as harmful constituents from fly ash (with the release of As and Hg) and higher energy and cost requirements. Moreover, waste sludge used for bricks can greatly reduce the concentration of heavy metals through the solidification process. Some researchers have concluded that the types of heavy metals in leaching experiments meet the United States Environmental Protection Agency (USEPA) requirements by using the toxicity characteristic leaching procedure (TCLP) (Huang et al., 2016; Jin, Zhang, Zhang, & Li, 2016).

15.3.1.4 Case Studies and Applications of Products

The sludge incineration technology in Japan has been well developed, with over 70% of total sludge being incinerated and about 30% of sludge used for construction material production (Fang, Guo, Li, Giesy, Wang, & Shi, 2017). The production of bricks by mixing bottom ash is the main approach. Since 1991, more than eight sewage treatment plants have introduced waste sludge for brick or block production (full scale) (Iizuka et al., 2017), and the Japanese government has invested significant funds in this technology. The first plant was owned by the Tokyo government and produced 5,500 bricks from 15 tons of bottom ash per day (Rahman, Khanm Uddin, & Islam, 2017). Those treatment plants apply 100% of bottom ash for brick production without any additives, and little leaching out of heavy metals occurs. However, such materials contain excessive minerals, resulting in high-pressure requirement (i.e., 98 MPa) and energy consumption (i.e., 1,020–1,080 °C) for production, as well as cracks and scumming of the products (Ahmad et al., 2016). With the maturity of the production technology, the products are usually used for paving, plazas, parks, or other public facilities (Iizuka et al., 2017). The major concern of the brick production is the economic return since the processing costs are usually higher than the market price and it consumes more energy.

In recent years, China has devoted efforts to promoting brick production using dewatered and dried sludge. Since 2011, Zhejiang Runtu Co. Ltd. has developed a disposal approach for 360,000 tons of dried sludge from dye sewage each year to produce 44,800,000 concrete blocks, earning a profit of RMB 17,400,000 (Chakraborty et al., 2017). In Taizhou, 520,000 tons of dewatered sludge per year (Yang et al., 2015) and in Yuzhou, 250,000 tons of dewatered sludge (Velasco et al., 2014) are used in clay and shale brick production to greatly promote the stability and harmlessness of the sludge. The local government has subsidized approximately 20–40% of the total costs of those industries, while their products are applied for paving, government buildings, and public facilities (Yang et al., 2015). However, many residents often complain about odor and air pollution issues during brick sintering. Many companies state that the costs of sludge transportation and treatment exceed the costs of producing one brick (Johnson et al., 2014). The promotion of brick production using waste sludge therefore needs improvement in China.

15.3.2 Production of Lightweight Aggregates

Lightweight aggregates (LWAs) are light granular materials used for support and filling a purpose in concrete or mortar. LWA can be classified as natural or artificial. Waste sludge can be used for LWA production through the thermal treatment of industrial furnaces. Artificial products can be clay ceramsite, shale ceramsite, and expanded perlite (Giro-Paloma, Ribas-Manero, Maldonado-Alameda, Formosa, & Chimenos, 2017). LWA has features such as high compressive strength, insulation, and refraction, among many others.

15.3.2.1 Ingredients, Production Methods, and Mechanisms

The production of LWA can be mixed with dewatered sludge, dried sludge, and bottom ash or fly ash from sludge incineration (Lau, Teo, & Mannan, 2017). Some valuable components in sludge are similar to the proportions of LWA and the pH and plasticity. Some amounts (2–5%) of organic content (Lynn, Dhir, Ghataora, & West, 2015) in sludge are useful for making LWAs expand. LWA manufacture involves numerous primary materials, such as natural clay, river or reservoir sediments, shale, and industrial by-products (e.g., fly ash, waste glass, and red mud) (Franus & Barnat, 2015; Wu et al., 2015). Clay-formed matter is plastic materials when present in water, and the pH ranges from neutral to weak alkaline. The inorganic content (e.g., Si, Al, and Fe salts) in these materials is rich. Some additives, such as lime and iron ores, may be required to produce ultralight products.

For LWA production, the raw materials are first pulverized and put into a mixer for homogeneous mixing with different proportions of pretreated sludge. One experiment made clay ceramsite by adding 30% clay, 50% dewatered sewage sludge, and 20% blast furnace slag (Wei & Ko, 2017). Afterward, the materials were pelletized by a pelletizer or a granulating pellet machine. Such pellets should then be air-dried and then oven-dried (about 105 °C) followed by preheating (300–600 °C) and sintering (850–1,200 °C) (Pacheco-Torgal, 2014; Wu et al., 2015). Liu, Xu, and Li (2017) conducted an experiment by putting the fresh pellets into an oven (105 °C) for 24 h, then putting them into electric kilns under various temperatures (1,050–1,250 °C) for 20 min, and cooling them down in room temperature. The size of the products usually ranges from 10 to 20 mm.

15.3.2.2 Characteristics of Products

LWAs produced from mixing sludge usually have high porosity (40–70%) (Lynn et al., 2015) because of organic matter volatilization in sludge during sintering at high temperatures. For instance, Franus, Barnat-Hunek, & Wdowin (2016) conducted an experiment to obtain 45% porosity (materials mixed with reservoir sediment, shale, fly ash, and dewatered sewage sludge). The high porosity of products results in low apparent and bulk densities (and specific gravity). Thus, the manufacture of LWAs by mixing sludge can obtain lighter products than commercial aggregates, whereas dewatered and dried sludge containing additional organic matters may result in higher porosity than bottom ash. For example, Wei and Ko (2017) noted that the apparent and bulk densities of clay ceramsite obtained by mixing dried sewage sludge were only 0.812 and 0.414 g/cm^3, respectively, which were considerably smaller than the standard (apparent density, 2.00 g/cm^3; bulk density, 1.20 g/cm^3). Moreover, the open pores in grains will absorb water, whereas the products with isolate size inside or glassy film do not tend to absorb additional water. The water absorption ability of LWAs produced from sludge is typically smaller than that of common products. For instance, the water absorption ability was 15.9% (market standard: <37%) (Suchorab, Barnat-Hunek, Franus, & Lagod, 2016) (mixing with sewage sludge for clay ceramsite production). However, the lower the density of LWAs, the lower their compressive strength will be. The thermal stress caused by high sintering temperature will also worsen the strength, which forms predominantly large irregular pores. According to Lo, Cui, Memon and Noguchi (2016), the products obtained under 1175 °C (34.7% of crushing strength) sintering have more cracks than those obtained under 1150 °C (41.2% of crushing strength). Frost resistance is also high when sludge is added. One experiment showed that the frost resistance of LWAs is 0.9% by adding sludge additives but 0.2% without addition (Suchorab et al., 2016). The manufacture of LWAs by applying sludge can also stabilize heavy metals. Colangelo, Messina and Cioffi (2015) reported that the concentration of heavy metals (e.g., Cr, Cd, Cu, Ni, Pb, and Zn) in LWAs mixed with dewatered sewage sludge and bottom ash was lower than the tolerance levels of water extracted by a leachability test. For instance, the presence of Zn and Cu is 0.12 and 0.19 mg/L, respectively, but both tolerance levels are 2 mg/L. The shale ceramsite obtained from bottom ash and shale presents only 0.001 mg/L for both Pb and Cr (tolerance level: 0.5 mg/L).

15.3.2.3 Feasibility Analysis

Based on the previous discussion, the utilization of waste sludge for LWA manufacture can significantly reduce the impacts of harmful and toxic constituents (e.g., heavy metals and organic pollutants) in sludge on the environment and human health, as well as the approaching resource recovery. Similar to brick production, waste sludge may also release harmful gas during sintering, although such gas is required for further treatment. Furthermore, the LWAs obtained from waste sludge will have enhanced characteristics compared with common products, such as lower density, better frost resistance, and water absorption ability. In this way, LWA production can utilize more waste sludge but save raw materials consumption and cost than that of brick materials, which will increase the industrial awareness contributing to resource recovery of sludge. Moreover, dewatered and dried sludge can be appropriately used for LWA production because they hold additional organic matter and moisture content but may greatly increase the porosity and decrease the compressive strength of products (Ling, Qu, & Wang, 2016). Thus, proper mixing of raw materials with different waste sludge proportions can achieve favorable LWAs. However, the strength and abrasive value of such products are lower than those of commercial products (the strength of commercial products is also low); therefore, the utilization types of LWAs should be based on their applications. For example, low-strength LWAs should be used for the moderate performance of LWA concrete (Zhang & Poon, 2015). Otherwise, the proportions of LWAs with cement and water should be further designed to mix concrete, which will increase the costs for increasing the strength of LWA concrete.

15.3.2.4 Case Studies and Applications of Products

LWA production using waste sludge is widely applied in Western countries. S.J. Hayde in the USA has studied the production of shale ceramsite since 1913, and found that such products could withstand high pressure (30–35 MPa) and had been applied in the construction industry (Chen, Huang, Lin, & Young, 2014). In 1994, the first company that used municipal sewage sludge (mainly bottom ash from incineration) for LWA production was established in Wisconsin; currently, the annual production amount is 10 million m^3. At present, about one-fourth of the total sewage sludge is used for LWA production, while the main applications come from sludge incineration. Those LWAs are used for 40–60% of concrete block production (Ahmad et al., 2016). Among them, 12–15% of prefabricated and casting concrete building units are produced by ultralight and common aggregates, such as wall panels and roofs (e.g., seismic, heat, and water insulation). Other LWAs (5–8%) are used for the production of high-strength concrete, such as high-rise buildings, bridge engineering, and highway construction. The other applications of approximately 10–20% are used for fillers, gardening, and noise barriers (Tyagi & Lo, 2016).

Many scholars in European countries, such as the UK, Germany, and Norway, are interested in LWA production using waste sludge. For example, in 1985, Elkin and St. George reported that the production of lightweight construction aggregates could be applied using clay and sewage sludge (González-Corrochano et al., 2016). This sludge contained about 45% of solids mixed with clay for sintering at 1,070–1,095 °C; the products were similar to ceramsite. In 1992, Bahtty's team found that the LWAs with moderate strength could be produced by using granular bottom ash at 1,050–1,100 °C (Yu et al., 2015). Currently, many European countries have applied this technology in their construction industries, while the major sludge application comes from incineration. Since the late 1990s, Denmark has had two factories for LWA production by mixing 30–50% of bottom ash from sewage sludge (Dondi et al., 2016). In addition, the UK utilizes 25–40% of incineration sludge for LWA production, such as clay ceramsite and expanded perlite (Nakić, Vouk, Donatello, & Anić Vučinić, 2017). These LWA products are mainly applied for concrete mixing and block production in the building industry.

15.3.3 Production of Cement

Cement is the powdery inorganic substance used for binding aggregate, sand, and crushed stone together. Cement is generally a calcium carbonate or lime-based material, which can be a hydraulic or non-hydraulic matter (Robl, Duvallet, Rathbone, & Zhou, 2015). Cement is widely applied in the civil and hydraulic engineering and construction industries, such as for concrete production and building.

15.3.3.1 Ingredients, Production Methods, and Mechanisms

Cement production can utilize dewatered, dried, or incinerated sludge. The sludge, enriched in minerals (Si, Al, and Ca salts), is a cementitious material for clinker preparation. Such sludge delivers the exact levels of pozzolanic activity, that is, the Si and Al salts, presented in water, will chemically react with lime to generate new substances of binding properties (Gómez, Pavlik, & Costa, 2014). The containment of organic matters in waste sludge can likewise provide high calorific value during clinker production in cement kilns (Cao, Liu, Li, Huang, & Li, 2014). However, the hydraulic characteristic of sludge (less CaO content) is poorer than that of raw materials for cement production (Djafari et al., 2017).

Raw materials for the manufacture of cement are usually the enriched mineral matter such as limestone, sandstone, iron powder, clay, and gypsum (Serdar, Donatello, & Cheeseman, 2017). Sometimes, some additives such as mineralizers and grinding agents (Huang et al., 2017) will also be used. Some of them are plastic materials, such as clay and shale. These large and hard materials should first be crushed into small (100 mm or smaller) particles and then crushed into 25 mm or smaller and uniform particles to reduce the loading in the later grinding processes (Gómez et al., 2014). Then, the raw materials are combined with waste sludge for preheating in the furnace or kiln. One experiment mixed various amounts of incinerated sewage sludge (2, 4, 6, and 8%) with raw materials (limestone, sand, copper slag) at 900 °C for 15 min (Yang et al., 2016). After preheating, the temperature was continuously raised to the required calcination for materials and maintained for one to two hours for sintering and clinkerization. Hwang et al. (2017) conducted an experiment by increasing 1,000–1,500 °C at the rate of 15 °C/min and maintaining the temperature for 1.5 h. During the heating processes, the carbonate was further decomposed and underwent a series of solid phase reactions for clinkers generation. Subsequently, clinkers obtained from kilns are sent to coolers for cooling. Finally, the clinkers are ground and mixed with small amounts of limestone or gypsum to delay the cement setting time.

15.3.3.2 Characteristics of Products

By presenting additional sludge content, the cement porosity will increase because of vaporization of volatile matter and water during material sintering and clinkerization. The products' compressive strength, bulk, and matrix density will decrease with additional sludge content as well. Gómez et al. (2014) concluded that the strength of products decreased from 55 to 28 MPa with a 10% increase in bottom ash in 28 days. The matrix density also reduced from 2010 to 1870 gr with a 10% increase in sludge additions. Moreover, the compressive strength will reduce by about 30, 50, and 25% with the 20% Portland cement replacement by bottom ash (Tsakiridis, Samouhos, & Perraki, 2017).

Furthermore, the workability of cements will reduce by increasing the sludge content. The water demand of sludge is high, and the sludge particles exhibit irregular morphology (Ahmad et al., 2016), which will negatively influence the workability of products. The workability can be tested through a slump. According to Smol, Kulczycka, Henclik, Gorazda, and Wzorek (2015), with a 5% increase in dried sludge (from 5 to 20%) during cement production, the slump height moderately decreased from 60 to 50 mm. The slump test in another experiment showed 16–25% reduction in slump height by increasing 4, 8, 12, and 16% of the bottom ash (Chatziaras, Psomopoulos, & Themelis, 2016). Thus, product workability is affected by sludge content.

Nevertheless, the fineness of sludge will contribute a positive impact on the strength of cement with the same quantity of sludge content. Moreover, the pozzolanic activity is increased due to the improved contact between the sludge and raw materials for binding purposes. Thus, the finer the sludge, the better the strength and workability of the products. Garcia-Lodeiro, Carcelen-Taboada, Fernández-Jiménez, and Palomo (2016) reported that by adding 20 and 40 mm bottom ash (25% quantity for all) to the raw materials, the compressive strength reached 36 and 17 Mpa, respectively. Additionally, the slump heights of two types of bottom ash were 70 and 55 mm.

The water absorption ability will increase by increasing the sludge content because of the high porosity and low durability (Johnson et al., 2014). The mixtures of dried sewage sludge content (e.g., 0, 5, 10, 15, and 20%) influenced the mass of final products, that is, the mass incremental ratio was almost 5.5% of the 10,15, and 20% of content but 4.6–5.1% of the 5% content for 5–240 min (Fell & Nordby, 2017).

Heavy metals are enriched in clinkers as the mixture loses weight during ignition. Through a leachability test by TCLP, researchers (Cao et al., 2014; Faure et al., 2017) have concluded that only Cr (0.0005 mg/dm^3) is detected (lower than the regulatory standard). However, other researchers (Tsakiridis et al., 2017) have stated that Ni (0.012 mg/dm^3) and Cd (0.0008 mg/dm^3) can also be detected (within regulatory standard). Hence, heavy metals are significantly concentrated in cement products.

15.3.3.3 Feasibility Analysis

In the case of construction material production, the utilization of waste sludge for cement manufacture approaches environment-friendly disposal and resource recovery. As previously mentioned, sludge can be treated as an energy resource because of its high calorific value while dried sludge can provide the highest heat value compared with dewatered and incinerated sludge contributing to energy efficiency and cost-saving. Additionally, the provision of minerals in waste sludge saves the raw materials (e.g., clay and limestone) for cement production as well as the cost. Sludge also has lower CO_2 emissions than conventional materials (Oh, Noguchi, Kitagaki, & Park, 2014) treated in a cement furnace. Moreover, cement sintering and clinkerization processes require high temperatures (i.e., 1450 °C or higher), which can significantly destroy the toxic and harmful organic matter and microorganisms in addition to heavy metal solidification in cement products (except for the suspended particles, Pb and Hg, which need further treatment) (Cao et al., 2014), thus contributing to sustainable management. The cement production process is also conducted under an alkaline and high heating environment, whereas the inorganic constituents (Cl^-, S, and F) in waste sludge will react with alkaline matter and generate harmless and odorless products (e.g., $CaSO_4$, $CaCl_2$, and CaF_2) (Lin et al., 2016). Thus, cement matrix production by mixing waste sludge is a green approach.

The compressive and bonding strength, matrix, and bulk density, and the workability of cement products are slightly (or even moderately) influenced by adding waste sludge. The utilization of waste sludge should be limited by their amounts, as excessive additions will affect the applications of cement; otherwise, the cement products should be practically considered according to their actual applications. Thus, the cement products with high sludge content should be applied in low-strength concrete or materials. Fine waste sludge may increase their utilization amounts or slightly improve the characteristics of cement on the basis of the previous discussion; however, additional crushing time, energy, and cost may be required.

15.3.3.4 Case Studies and Applications of Products

The production of cement matrix by applying waste sludge is popular in Japan. In 1993, "eco-cement" was studied and proposed (Oh et al., 2014). The high Cl^-

and low SiO_2 concentration restricts the application of such products (e.g., causing corrosion of concrete, easily binding). With the modification of production in 2001, the first factory for eco-cement production was established in Chiba, Japan. The factory utilizes 30,000 tons of waste incinerated sludge to produce 11 million tons of eco-cement per year. The production of eco-cement in Tokyo also started in 2004, with the production amounting to 16 million tons per year (Miyazaki, Yoshikawa, Atarashi, Tanaka, & Ota, 2017). Nowadays, with the further utilization of incineration plants for waste treatment in Japan, incinerated sludge is widely used in cement production. The eco-cement will easily cause the corrosion of reinforced concrete materials. Thus, eco-cement is only applied in building mortar and as a soil curing agent in wetland foundations.

In European countries, waste sludge has many applications for cement products. The utilization quantities of dewatered sewage and waterworks sludge (including alternative fuels) increased from 40,000 to 230,000 tons per year from 2002 to 2006 in Germany (Brunke & Blesl, 2014). In 1986, researchers (Song, Yang, Chen, Hayat, & Alsaedi, 2016) in Switzerland found that waterworks or sewage sludge exceeding 95% moisture content would increase energy use and loading of the cement kiln; the dried sludge was applied later on. Currently, the use of dried sewage sludge amounts are 20,000 tons per year. The main sludge addition pathway in European countries is directly through kilns or precalciners. Since 1997, ENC Cement Ltd. in the Netherlands has utilized multiple coolers, while sludge (<90 μm) was added to kilns (Kemp, Barteková, & Türkeli, 2017). The clinker production amounts to 970,000 tons per year by using 100,000 tons of dried sewage sludge. This sludge cement can be applied in concrete, bricks, and LWA areas for large-scale buildings and in civil and other construction industries. However, in the case of poor features of cements (e.g., low compressive strength density), these are applied in moderate- to low-performance products, such as low-strength concrete blocks/bricks, home decorations, and green environments.

15.3.4 Production of Glass-Ceramics (GCs)

GCs are the composite materials formed from nucleating a series of crystals in the glass matrix by adding nucleating agents or catalysts. GCs, which are widely applied in the construction, medical, aerospace, and optical industries (Marangoni et al., 2017), have high mechanical strength, a low dielectric constant, thermal stabilization, wear resistance, and anti-corrosion, among many other properties (De Goes & Murillo-Gómez, 2017; Yano, Nanataki, & Hirai, 2014).

15.3.4.1 Ingredients, Production Methods, and Mechanisms

The raw materials used for GC production are usually natural industrial chemicals containing minerals, such as quartz sandstone, feldspar, industrial Al_2O_3, CaO powder, Basalts, metallic oxides, and additives (Tarrago, Garcia-Valles, Aly, & Martínez, 2017). Many researchers have studied the production of GCs by combining waste sludge and glass. Nandi, Raupp-Pereira, Montedo, and Oliveira (2015) utilized dried sewage sludge and various types of waste glass (e.g., windows, bottles, and plates), whereas Daigo, Kiyohara, Okada, Okamoto, and Goto (2017) applied bottom and fly ashes mixed with waste glass for GC manufacture. The glass is enriched in 70% SiO_2 and portions of MgO, CaO, and Na_2O. SiO_2 is needed compound in GCs, while the proper increase of SiO_2 will delay the crystallization to a high temperature but excessive amounts of SiO_2 will increase the viscosity and make crystallization difficult (Yang et al., 2014). Additionally, excessive additions of Al_2O_3 will increase viscosity and restrict crystallization, but insufficient Al_2O_3 will cause uneven crystallization and reduce product stabilization (Gabel, Hochrein, Weiss, Dudek, & Martens, 2015). Therefore, proper ingredients from waste sludge and glass are required for GC production.

GC production transpires through the thermal treatment of prepared glass for nucleation and crystallization. For glass preparation, the SiO_2 with other mixtures sinters at extremely high temperatures (1300 °C or more) for homogenization and crystallization (Bernardo & Dal Maschio, 2011). In our laboratory works sludge, the prepared glass was mixed with waste sludge in different proportions, which can then be put into the furnace for preheating at the nucleation rate, sintering for nuclei growth and finally cooling.

Crystallization phases have different types, with the proportions in the phases based on the parent of glass and sludge. GC crystallization consists of two phases: nucleation and growth (Lu, Shih, & Cheng, 2013). The crystallization phase is formed within the interfaces of the parent glass in the nucleation stages. The increased surface areas by grinding glass and the provision of nucleating agents (e.g., TiO_2, Cr_2O_3, and Fe_2O_3) (Marangoni et al., 2017; Tarrago et al., 2017) in waste sludge and glass enhance the nucleation. Then, with the temperature increase, the phased growth includes the movement of molecules across the interfaces.

15.3.4.2 Characteristics of Products

The compressive strength of GCs increases with increasing sintering temperature. Yoona and Yunb (2011) stated that the compressive strength of GCs was 209.5, 245.6, and 269.6 MPa at 850, 900, and 1000 °C sintering, respectively, while the bending strength also increased with temperature (e.g., 134.5 MPa at 850 °C and 152.3 MPa at 1000 °C) (the applied materials were glass powder and dried sewage sludge powder, respectively). This case was because the acicular wollastonite crystals were formed and increased during sintering. Within 850 °C, which is the low temperature, porosity with round grains could be observed, which was caused by the organic matters and water vaporization of sludge during thermal treatment at insufficient annealing (Yoona & Yunb, 2011). However, by increasing the sintering temperature, the pores disappeared and crystals were formed. The hardness also increased with temperature. In an experiment, Ponsot et al. (2015) concluded that by utilizing waste glass and dewatered sludge powder totaling 250 g, the Vickers hardness of GCs was 4,500, 5,200, and 5,600 MPa at 800 °C, 900 °C, and 1000 °C, respectively, which also accounted for the crystals formed (hematite and cristobalite) in the furnaces. Some researchers, by using different percentages of dried sludge (i.e., 0, 10, 20, 30, and 40% by weight) (Wolff, Schwabe, & Conceição, 2015), have concluded that the compressive (approximately 192 MPa at different sludge contents) and bending strength (approximately 145 MPa at different sludge contents) were almost the same under 1100 °C. Furthermore, the product density also increased with increasing temperature. Zhang, Zhang and Li (2015) found that the specimen density was 2.12 g/cm^3 at 850 °C but 2.56 g/cm^3 at 950 °C. The principle is also the same as the mechanical strength (i.e., the pores disappear in the matrix with increasing temperature). In addition, the amounts of waste sludge used are not critical for GC density. Regardless of the sludge content applied, no slight change in the density of GCs (2.03–2.09 g/cm^3) at the same temperature is observed (Zhang et al., 2015).

15.3.4.3 Feasibility Analysis

As previously discussed, the sludge content used for GC production will not significantly influence the properties of GCs. Thus, applying more waste sludge for GC manufacture can contribute to resource recovery and efficient waste utilization which waste sludge may reduce landfill disposal costs as well as promoting industrial development of GC production sludge. Nevertheless, the compositions of phases in the GCs depend on the parent of glass and sludge. Therefore, by applying different types of sludge and glass, the crystallization phases in GCs will be different, such as Li_2O–Al_2O_3–SiO_2 (Yoona & Yunb, 2011), Na_2O–SiO_2 (Zhang et al., 2015), and MgO–Al_2O_3–SiO_2 (Ponsot et al., 2015) system formations based on ZnO, Na_2O, and MgO in the sludge and glass. Moreover, both amounts of SiO_2 and Al_2O_3 will impact the formation of GCs; therefore, the proper content of SiO_2 and Al_2O_3 in sludge with a combination of glass or nucleating agent should be required. For example, the use of the sludge with excessive amounts of Al_2O_3, such as waterworks and sewage sludge containing coagulants, should be limited. Furthermore, high heating temperature is necessary to obtain improved features of products (high mechanical strength, high density, and hardness) but energy use and cost may be increased. Perhaps the types of sludge are also important, while the dried and incinerated sludge with less water and organic matter may promote better effects on the products.

15.3.4.4 Case Studies and the Application of Products

Many researchers have studied GC production, specifically in Western countries. Germany was one of the earliest countries to apply bottom ash after incineration for GCs, and the first report was promoted in 1994 (Cusidó & Cremades, 2012). With the increase in sewage sludge production and the development of incineration technology, researchers in Germany considered the utilization of bottom ash for GC production. Results concluded that the product features met the market requirements (Bach & Krause, 2013). Furthermore, researchers in both the UK and Spain have studied the feasibility of GC manufacture by bottom ash. For instance, the bottom ash and waste glass from an urban incineration plant in Mallorca, Spain, were used for GC production (Gabaldón-Estevan, Criado, & Monfort, 2014), which can achieve relatively hard and stable products. Many practical GC productions by waste sludge are present in Europe as well. In the UK, 15–20% of total bottom ash is applied in glass or GC production (Smol et al., 2015), whereas in Germany, the utilization amounts to >30% (Cusidó & Cremades, 2012). The produced GCs, besides other industries, are also widely applied in the construction industry, such as glass curtain walls, window and home decoration, and building construction (Tarrago et al., 2017; Yano et al., 2014).

Waste sludge treatment is also a major environmental issue in Taiwan. Besides the environmental concern, the costs of treatment by incineration (US$ 289/ton) and landfill disposal (US$ 237/ton) are relatively high (Cheng, Tu, Ko, & Ueng, 2011; Tyagi & Lo, 2013). Studies on applying bottom ash for GC production were conducted for resource and cost recovery in Taiwan in 2003. Researchers have concluded that applying fly and bottom ash for GC purposes has good potential (Cheng et al., 2011), and the obtained products are favorable for the application. In addition, the leaching test of heavy metals, including Zn, Cr, Cu, and Cd, met the standards of the Environmental Protection Administration of Taiwan (Cheng et al., 2011). However, few studies have been conducted on the practical applications of GC production using waste sludge; perhaps the studies in this aspect have not been widely promoted yet.

15.4 Conclusions

The production of eco-construction materials using waste sludge can achieve waste stabilization and harmlessness, altering direct landfill disposal for a win-win strategy. Typical pretreatment methods of both sewage and waterworks sludge include thickening, dewatering, drying, incineration, volume reduction and the removal of water and organic harmful/toxic constituents. The pretreated sludge for construction material production can significantly enrich the contained heavy metals in the sludge, meeting the standard of leachability testing and reducing the impacts on the surrounding environment and on human health.

Both sewage and waterworks sludge are rich in minerals, including Si, Al, and Ca salts, which are the basic components for construction material production. These minerals are usually mixed with raw materials containing abundant minerals and some additives for production. However, the amounts of those components affect product quality. The use of waterworks sludge with excessive coagulation should be limited. Additionally, the user types and amounts of waste sludge influence product characteristics. Dehydrated sludge containing more than 75% moisture, 40–80% organic matter, and dry sludge with 10% moisture and 40–80% organics increases porosity, decreases mechanical strength and density, and increases water absorption ability. For bricks or concrete blocks and cement production, the utilization amounts should be 15% or less. For LWAs, the lighter one is reliable for application; hence, the utilization amounts of dewatered or dried sludge can be high (30% or more). The bottom ash has only 1% of moisture and 0–3% of organic matter, which reduces the impacts on the characteristics of the construction materials. Nevertheless, organic matter can be an alternative energy source for heat value provision during the sintering of materials. Thus, applying bottom ash may increase production costs. For GC production, the organic matter and water of sludge will not exactly influence the product quality, but can still generate pores during GC sintering.

Producing construction materials by waste sludge is relatively popular in developed countries or regions. As the incineration technology is still being developed, countries in Europe widely promote the production of bricks/concrete blocks, LWAs, and cement by bottom ash, contributing to waste reduction and resource recovery. Developing countries apply dewatered or dried sludge for construction material production, although their incineration technology remains immature. Those eco-construction materials are feasible for the construction industries, including building engineering, civil engineering, and home decoration.

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Nengxiong Wang received a Bachelor's degree in Environmental Engineering from Technological and Higher Education Institute of Hong Kong (THEi). He is passionate at academic research and laboratory works in waste management issues, including wastewater treatment, waste-to-energy, and resource recovery from wastes. He had worked as research assistant at City University of Hong Kong in 2017 for studying of waste-to-energy issues about cellulosic materials for butanol production, and assisting the research works for waste hydrolysis and bacterial cultivation.

Yiu Fai Tsang is an Associate Professor in the Department of Science and Environmental Studies at The Education University of Hong Kong (EdUHK). He received his B.Eng. and Ph.D. in Environmental Engineering from The Hong Kong Polytechnic University. Currently, he is the Editor-in-Chief of Energy & Environment (SAGE), Subject Editor of Process Safety and Environmental Protection (Elsevier), and Editorial Board Member of Chemical Engineering Journal (Elsevier). His research interests are water and wastewater treatment, resource recovery from organic waste, and microbial CO_2 fixation.

Hong Chua is the Dean of Research and Enterprise, Technological and Higher Education Institute of Hong Kong (THEi). Before joining THEi in 2012. He was Professor of the Department of Civil and Structural Engineering at the Hong Kong Polytechnic University (PolyU) from 1992 to 2012. He has published over 200 papers in SCI-listed international journals and refereed conference proceedings. He has successfully secured research and high-level consultancy projects, for total funding of over HK$56M and won the PolyU Outstanding Consultant Award for 1999, 2000, 2001, 2002, 2004, and 2006.

Haakrho Yi is the Senior Researcher in RIST, Gwangyang City, Korea. He graduated the Seoul National University with a Bachelor's degree in Agricultural Biology in 1997 and Master's degree in Environmental Microbiology in 1999. Then he graduated University of California, Riverside with a Ph.D. in Bioinformatics. He worked a Post Doc in California Institute of Technology and Oak Ridge National Lab., respectively. After returning to RIST in Korea, he has been researched on anaerobic digestion, bioethanol, and biohydrogen. Recently he started to slag recycling and wastewater treatment with advanced oxidation processes (AOPs).

Yi Yang is currently a Ph.D. candidate in the Department of Science and Environmental Studies at The Education University of Hong Kong. She received a Master's degree from the Hong Kong University of Science and Technology in 2015. Her current research interest is water and wastewater treatment, including occurrence and fate of pharmaceuticals and personal care products in sewage treatment plants, bioremediation, and biochar treatment technology.

Chun-Fai Yu is Associate Professor and Research Associate Fellow in the Environmental Science Program of United Internal College. He obtained his Ph.D. degree from the Hong Kong Polytechnic University with research area of environmental toxicology. After receipt of a research fellowship from the Japan Society for the Promotion of Science, he worked as a postdoctoral fellow

in the Fisheries Department of Nagasaki University in Japan before teaching in the College. His research mainly focuses on the microbial production of biotoxins for medical applications with 2 patent awards.

Peter Hoi Fu Yu received his Ph.D. in Biochemistry from Texas A & M University, and conducted a Postdoctoral Fellowship at Cornell University. He returned to teach at the Hong Kong Polytechnic University (PolyU) in 1992, and he was awarded the President Award for excellence in Research and Scholarly activities in 2002. Currently, he is a Visiting Professor at the South China Agriculture University and Honorary Fellow at PolyU. He has published over 100 papers in refereed international journals. He was also a past Chairman of the Hong Kong Food Science and Technology Association.

Chapter 16
Evaluation of Nutritional Values of Food Waste-Based Feed Pellets and Common Feeding Materials for Culturing Freshwater Fish

Wing Yin Mo, Yu Bon Man and Ming Hung Wong

Abstract There are 3,600 tonnes of food waste (FW) disposed at landfill sites daily, and the existing landfills in Hong Kong will be successively exhausted by 2020. Recycling of FW can partially ease the disposal pressure. This study aims at investigating the feasibility of using FW-based feed pellets for culturing freshwater fish, with a focus on nutritional values. Freshwater fish such as grass carp (*Ctenopharyngodon idella*), Nile tilapia (*Oreochromis niloticus*), and grey mullet (*Mugil cephalus*) have relatively lower dietary protein requirements than carnivorous fish. Local freshwater fish farmers prefer to use unconsumed food, agricultural by-products or leftovers from household kitchens as feed in order to reduce their operation costs. The nutritional values (essential amino acid [EAAs], crude protein, crude lipid, crude carbohydrate, total phosphorous) of Napier grass, breads, rice bran, instant noodles, soybean dregs, a commercial fish feed pellet (Jiefeng® 613) and two FW-based feed pellets were compared. FW-based feed pellets consist of meals of recycled cereal, meat, vegetable, and bone which account for 70% (w/w) of the ingredients. Formulation A (FWA) is mainly composed of 53% cereals as the major protein sources, while Formulation B (FWB) has a more balanced ratio of meat (25%) and cereal (28%). The amino acid scores of feed items for grass carp and Nile tilapia were calculated to validate whether they contained sufficient amounts of EAAs. The results demonstrated that common fish feeds are insufficient in terms of nutrient content, in particular the lysine content (except for Jiefeng® 613), crude protein (except for Jiefeng® 613 and soybean dregs) and lipids (except for the two noodle samples). In contrast, FWA and FWB contain sufficient amounts of lysine and crude protein, indicating their suitability for low trophic level fish. The result was also confirmed by the growth performance of the fish fed with different diets.

Keywords Grass carp · Nile tilapia · Food waste · Fish feed · Polyculture

W. Y. Mo · Y. B. Man · M. H. Wong (✉)
Consortium on Health, Environment, Education and Research (CHEER), and Department of Science and Environmental Studies, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, Hong Kong SAR, China
e-mail: minghwong@eduhk.hk

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16.1 Introduction

Hong Kong is suffering from environmental problems associated with solid waste generation. In 2012, 9,278 tonnes per day of solid waste (including 3,337 tonnes of food waste) was disposed in landfill sites, and it is predicted that the existing landfills will be exhausted by 2020 (Environmental Protection Department, 2017). Food waste is food that is discarded or left uneaten (Wong, Mo, Choi, Cheng & Man, 2016). As dumping food waste into landfills will definitely shorten the lifespan of the existing landfill sites in Hong Kong, making use of food waste for farming fish may ease part of the pressure of disposing of waste in landfills.

In fact, the use of waste materials as feed is not a new concept. Examples of unconsumed food or agricultural by-products used by local fish farmers for feeding fish include rice bran, wheat bran, peanut cake, bread, expired instant noodles, or leftovers from household kitchens. Traditionally, excreta from poultry, food waste, and agricultural waste were used in polyculture ponds as feed (Lau, Lee, & Young, 2003; Wong, Cheung, Yediler, & Wong, 2004). However, backyard poultry farming in Hong Kong was banned in 2006 in order to prevent Avian Flu (Legislative Council, 2013), which rendered poultry excreta less available for fish farming. Most of the fish farms in Hong Kong are engaged in polyculture (grass carp, bighead carp, common carp, and silver carp in combination with tilapia or grey mullet), and it is the dominant farming practice (98%) adopted by local inland fish farmers (Agriculture, Fisheries and Conservation Department, 2017).

Grass carp is an herbivore in the natural habitats that primarily consume aquatic macrophytes, but it prefers pellet diets in fish pond culture where they are provided (Lopinot, 1972; Masser, 2002). Tilapia is an omnivore which consumes plankton, aquatic macrophytes, invertebrates, larval fish, detritus, and decomposing organic matter. It can digest animal protein more efficiently than plant protein (Popma, 1999). Both omnivorous and herbivorous fish require relatively lower protein (about 30%), compared with carnivorous fish (more than 40%) (Cai, Luo, Xue, Wu, & Zhan, 2005; Wang, Takeuchi, & Watanabe, 2005). They can also tolerate higher amounts of carbohydrates in their diets, making them suitable fish species to feed with a food waste-based diet.

The protein quality of fish feed is important for fish growth. Essential amino acids (EAA) are important factors in determining the quality of a particular fish feed. Essential amino acids refer to amino acids that cannot be synthesized by the animal itself and so have to be replenished via diet. Ten essential amino acids are required by fish: arginine, histidine, isoleusine, leusine, lysine, methionine, phenylalanine, threonine, typtophan, and valine (Li, Mai, Trushenski, & Wu, 2008). Other than protein and amino acids, other compositions of fish feeds are also important for fish. Lipids and carbohydrates can be used as energy sources, and they possess protein sparing effects (using carbohydrates or lipids before instead of protein for energy generation) (De Silva, Gunasekera, Gooley, & Ingram, 2008; Skalli, Hidalgo, Abellan, Arizcun, & Cardenete, 2004). Phosphorous is essential to fish for proper bone mineralization (Lim, Klesius, and Webster, 2001). As there are no published reports available on the essential amino acid content of common fish feeds used by local inland fish farmers, the nutritional profiles and essential amino acid content of the common fish feeds used locally were determined and compared to the requirements of both grass carp and Nile tilapia to evaluate their quality in the present experiment.

The objectives of this experiment are to evaluate and compare the quality of fish feeds commonly used by Hong Kong fish farmers. These included commercial fish feed pellets, breads, rice bran, instant noodles, soybean dregs, and food waste-based fish feeds developed by us, by (1) testing the essential amino acid content, (2) evaluating the limiting essential amino acid, (3) measuring the proximate compositions of the fish feeds, and (4) conducting a feeding trial to study the effects of the vitamin-mineral premix as a feed supplement.

16.2 Materials and Methods

16.2.1 Production of Food Waste-Based Feed Pellets

Food wastes were collected from local sources. They were mainly food processing waste and partly post-consumed waste, which were classified into four major categories: (1) fruit peel and vegetables, (2) meat, (3) bone meal, and (4) cereal wastes. Fruit waste contained mainly peel with some flesh of various fruits, about 25% pineapple, 25% watermelon, 15% cantaloupe, and 35% others (e.g., strawberries, bananas, apples). Meat wastes included 60–70% beef, pork, and chicken, and 30–40% fish such as salmon and grouper. Vegetables comprised various types of leaf vegetables such as lettuce and spinach. Cereals usually included soybean meal, rice grain, and spaghetti.

The food waste-based feeds were manufactured by Kowloon Biotechnology Ltd based on our formulations. The individual ingredients described above were chopped and the surplus water was squeezed out. After drying for 6 h, the dried food waste was powdered, and different ratios of food waste powders were mixed with starch and fish meal to make fish feed pellets. Food waste constituted 75% (w/w) of the final fish feed pellets. Food waste-based formulation A (FWA) consisted of 53% cereal, 10% fruit and vegetables, 8% bone meal, 10% fish meal, and 15% corn meal. Food waste-based formulation B (FWB) consisted of 25% meat, 28% cereal, 10% fruit and vegetables, 8% bone meal, 10% fish meal, and 15% corn meal. No vitamin-mineral premix was added to the diets.

16.2.2 Feed Items and Commercial Feed Pellets Commonly Used by Local Fish Farmers

Common fish feeds adopted by local fish farmers include fish feed pellets, breads, rice bran, instant noodles, and soybean dregs, according to Dr. Jim CW Chu and Dr. Eric PM Yau of AFCD (personal communication, April 3, 2014). A commercial fish feed pellet (Jiefeng® 613, containing flour, wheat middling, fish meal, rapeseed meal, bean pulp, bean oil, fish oil, and vitamin-mineral supplement) was purchased from a local animal feed supplier, rice bran was purchased from mainland China, and bread (white bread and hamburger buns) and soybeans were purchased from a local market. Noodles and Napier grass were collected from a local fish farm. Fish feed pellets, bread, and noodles were crushed to obtain a fine powder. The soybean dregs were prepared by cooking soybeans in water. The soybeans (300 g) were soaked in tap water for 8 h before cooking with additional tap water (500 ml) and then mixed with a food blender. The soybean–water mixture was filtered to obtain raw soybean dregs. The soybean dregs were then dried in a 65 °C oven for 24 h and thoroughly mixed in a food blender. All fish feed items were stored in a desiccator prior to chemical analysis.

16.2.3 Chemical Analysis of the Fish Feed Items

Total Kjeldahl nitrogen and total phosphorous were determined following the methodology of APHA (2002). Crude protein was calculated by multiplying total Kjeldahl nitrogen by 6.25, moisture content was determined by a dry oven (105 °C for 24 h), and ash content was determined by a furnace muffler (550 °C for 4 h) (Association of Official Analytical Chemists, 2000). Crude fibre was determined by the loss on ignition (Association of Official Analytical Chemists, 1984) of defatted feeds (2 g) after digestion of H_2SO_4 and then NaOH. The lipid content was determined using the ultrasound-assisted extraction method according to Metherel, Armstrong, Patterson, and Stark (2009) and modified by Choi, Lam, Mo, and Wong (2016). The nitrogen-free extract (non-fibrous carbohydrate) was calculated by subtracting the sum of (moisture % + crude protein % + crude fat.% + crude fibre % + ash %) from 100.

16.2.4 The Essential Amino Acid Profiles of the Feed

The essential amino acid profile of the feed items was determined according to GB/T18246-2000 (Standardization Administration of China, 2001). Briefly, the sample was digested with 6 N hydrochloric acid at 110 °C for 24 h. The digested sample was filtered through a 0.45 μm filter, and the amino acid content of the sample was analysed by an amino acid analyser (Hitachi, 835–850).

16.2.5 Calculation of Amino Acid Scores for Feed Items

Amino acid scores of feed items were calculated according to Tacon (1987), using the dietary essential amino acid requirements of grass carp and Nile tilapia as references (Santiago & Lovell, 1988; Wang et al., 2005), according to the following equation:

$$\text{Amino acid score} = \text{Amount of EAA in feed]}/[\text{EAA requirement of fish (grass carp or Nile tilapia)}] * 100$$

Cystine and tyrosine were included in the calculation because they are involved in the metabolic pathway of methionine and phenylalanine (Ogino, 1980).

16.2.6 Fish Feeding Trials

Two separate feeding trials were conducted involving grass carp (Ctenopharyngodon idella) and Nile tilapia (Oreochromis niloticus) using one of the food waste-based diets (FWB). Thirty individuals of each species were obtained from local fish farms in both Hong Kong and mainland China, respectively. The fish were treated with 3% salt solution for 60 s to eliminate parasites before dividing them into 12 200 L plastic fish tanks. Each tank was connected to an external filter and continuously aerated. The fish were acclimatized for at least 2 weeks before introducing them into the experimental tanks (60 L). Jinfeng® 613 formulated feed was provided to fish twice per day at approximately 2% body mass of fish. One-third of the water was replaced with de-chlorinated tap water twice a week. The salinity of water was maintained at about 4 ppt, using raw salt. The light–dark cycle was set at 12L:12D, using florescent lamps as a primary lighting source. Initial weights of grass carp and Nile tilapia were 59.4 ± 3.2 g and 56.2 ± 5 g, respectively, and they were approximately 12 cm long.

Chromium(III) oxide (0.5% w/w) and vitamin-mineral premix (VMP) (0.3% w/w) (Centrum, USA) (contained Vitamin A, B1, B3, B5, B6, B7, B9, B12, C, D, E, K1, calcium, chromium, copper, iodine, iron, magnesium, manganese, molybdenum, potassium, selenium, and zinc) were mixed with ground FWB (FWBV). The detailed content of the VMP is listed in Table 16.1. Ingredients were mixed with DI water and re-pelletized using a meat grinder. Re-pelletized feeds were dried at 60 °C in an oven, until completely dried. Two control diets, Jinfeng® 613 feed pellets with 0.3% α-cellulose (Cont613) and FWB with 0.3% of α-cellulose (ContB), were also produced similarly to the other experimental diets, except no VMP was added. The fish were fed twice per day manually at 2.5% body mass of fish. The formulations of each experimental diet are listed in Table 16.2.

Table 16.1 Detailed compositions of the experimental diets

Ingredients (%w/w)	Experimental diets		
	Cont613	ContB	FWBV
Jinfeng® 613*	99.2		
Food waste diet B		99.2	99.2
α-cellulose	0.3	0.3	
Chromium(III) oxide	0.5	0.5	0.5
Vitamin-mineral premix			0.3

Cont613 Jinfeng® 613 with 0.3% α-cellulose; *ContB* Food waste-based formulation B with 0.3% α-cellulose; *FWBV* Food waste-based formulation B with 0.3% vitamin-mineral premix

Table 16.2 Amounts of vitamins and minerals in DietB and suggested values

Vitamins	Amount (unit)	Suggested requirements (Chow, 1982)#
Vitamin A	10000 IU	1000 IU
Thiamine	4.5 mg	4 mg
Vitamin B3	40 mg	20 mg
Vitamin B5	10 mg	10 mg
Vitamin B6	6 mg	4 mg
Vitamin B7	0.045 mg	0.02 mg
Vitamin B9	0.4 mg	1 mg
Vitamin B12	0.018 mg	0.004 mg
Vitamin C	180 mg	40 mg
Vitamin D	800 IU	200 IU
Vitamin E	60 IU	10 IU
Vitamin K1	0.05 mg	2 mg
Calcium	324 mg	–
Chromium	0.2 mg	–
Copper	4 mg	3 mg
Iodine	0.3 mg	0.1 mg
Iron	54 mg	50 mg
Magnesium	200 mg	–
Manganese	10 mg	20 mg
Molybdenum	50 mg	–
Potassium	60 mg	–
Selenium	0.05 mg	0.1 mg
Zinc	30 mg	30 mg

Fish from the same fish tank were measured in bulk at day zero and then once every 2 weeks for 8 weeks. Prior to weighing, all fish were anesthetized with 100 mg/L MS222. The growth performance of the fish was calculated according to the following equations:

$$\text{Relative weight gain, RWG (\%)} = [\text{final weight (g)} - \text{initial weight (g)}]/\text{initial weight} \times 100$$

$$\text{Feed conversion ratio FCR} = \text{feed provided (g)} / [\text{Final biomass} - \text{Initial biomass (g)}]$$

$$\text{Protein efficiency ratio, PER (\%)} = \text{wet body weight gain (g)/protein intake (g)} \times 100$$

Six fish from each treatment were sacrificed for proximate analysis and assessing the digestibility of the fish feeds. The internal organs in the abdominal cavity of the fish were removed using dissection scissors and forceps. The fish carcass was then cut into several smaller pieces and wrapped individually with aluminium foil. The fish carcass was frozen and then freeze-dried for up to 2 weeks.

The crude protein content of the fish feeds and the fish faecal matter were determined as described above. The chromium (Cr) content in the fish feed and faeces were analysed by spectrometer (UV-1601, Shimadzu, Tokyo, Japan) after acid digestion of the samples according to Furukawa and Tsukahara (1966).

16.2.7 Statistical Analysis

Proximate compositions of feed, the growth parameters, proximate compositions of the fish carcasses, and the protein digestibility of the fish were analysed using one-way ANOVA and Duncan's multiple range tests (SPSS Statistics 19.0, IBM, USA). Significant differences between feeds are expressed at the significance level of $p < 0.05$.

16.3 Results

Table 16.3 shows the amino acid content of the studied feed items. The lysine content of the diets: Jiefeng® 613, FWA, and FWB was 5.83%, 5.76%, and 5.79%, respectively, and was significantly higher than that of the other common diets ($p < 0.05$). Tables 16.4 and 16.5 show the amino acid scores of the feed items for grass carp and Nile tilapia, respectively. The amino acid score of a particular EAA that equals 100 means that the diet contains a sufficient amount of that particular amino acid. For grass carp, lysine is always the first limiting amino acid in all of the tested fish feeds, while lysine, methionine, cystine, and threonine are all limiting to tilapia, with lysine being the most frequently limiting EAA.

Table 16.3 Essential amino acid content of fish feeds

Essential amino acid	Amino acid content of feed items (% protein)									
	Napier grass	Rice bran	Soybean dreg	Noodle 1	Noodle 2	White bread	Hamburger bun	Jiefeng® 613	FWA	FWB
Arginine (Arg)	2.18 ± 0.05^{a}	5.49 ± 0.32^{d}	3.38 ± 0.16^{b}	3.32 ± 0.20^{b}	4.46 ± 0.24^{c}	3.65 ± 0.11^{b}	4.67 ± 0.06^{c}	6.92 ± 0.21^{e}	7.55 ± 0.30^{f}	7.59 ± 0.30^{f}
Histidine (His)	1.99 ± 0.10^{c}	2.48 ± 0.08^{e}	1.35 ± 0.06^{a}	1.75 ± 0.06^{b}	3.15 ± 0.07^{g}	2.26 ± 0.13^{d}	$2.41 \pm 0.09^{d, e}$	2.55 ± 0.08^{f}	2.80 ± 0.14^{f}	2.83 ± 0.09^{g}
Isoleusine (Ile)	4.72 ± 0.13^{d}	5.45 ± 0.25^{e}	2.01 ± 0.09^{a}	1.96 ± 0.08^{a}	4.36 ± 0.18^{b}	4.42 ± 0.19^{b}	4.37 ± 0.17^{b}	$4.44 \pm 0.09^{b, c}$	$4.65 \pm 0.14^{c, d}$	$4.69 \pm 0.09^{c, d}$
Leusine (Leu)	6.23 ± 0.13^{a}	6.79 ± 0.18^{b}	6.08 ± 0.29^{a}	6.08 ± 0.29^{a}	7.86 ± 0.16^{d}	6.73 ± 0.23^{b}	7.40 ± 0.46^{c}	8.28 ± 0.25^{d}	8.82 ± 0.31^{e}	8.91 ± 0.27^{e}
Lysine (Lys)	$3.11 \pm 0.33^{a, b}$	4.65 ± 0.08^{c}	3.54 ± 0.12^{b}	3.44 ± 0.21^{b}	3.13 ± 0.11^{b}	2.85 ± 0.14^{a}	2.79 ± 0.17^{a}	5.83 ± 0.23^{d}	5.76 ± 0.29^{d}	5.79 ± 0.2^{d}
Methionine (Met)	1.43 ± 0.20^{b}	2.65 ± 0.09^{e}	0.84 ± 0.15^{a}	0.79 ± 0.11^{a}	1.97 ± 0.25^{c}	1.62 ± 0.05^{b}	2.28 ± 0.15^{d}	3.81 ± 0.11^{f}	3.60 ± 0.12^{f}	3.63 ± 0.18^{f}
Phenylalanine (Phe)	7.27 ± 0.17^{d}	4.84 ± 0.16^{b}	4.46 ± 0.28^{a}	4.36 ± 0.18^{a}	5.74 ± 0.11^{c}	5.00 ± 0.14^{b}	5.03 ± 0.23^{b}	8.44 ± 0.30^{e}	9.08 ± 0.32^{f}	9.16 ± 0.28^{f}
Threonine (Thr)	3.73 ± 0.33^{c}	$2.89 \pm 0.12^{a, b}$	2.64 ± 0.10^{a}	2.74 ± 0.07^{a}	$3.00 \pm 0.19^{a, b}$	3.14 ± 0.05^{b}	2.69 ± 0.16^{a}	4.30 ± 0.22^{d}	4.30 ± 0.15^{d}	4.34 ± 0.15^{d}
Typtophan (Typ)	0.52 ± 0.03^{a}	1.75 ± 0.06^{d}	$0.75 \pm 0.10^{a, b}$	$0.75 \pm 0.10^{a, b}$	0.85 ± 0.12^{b}	1.13 ± 0.17^{c}	2.68 ± 0.28^{e}	4.37 ± 0.13^{h}	3.09 ± 0.09^{f}	3.44 ± 0.17^{g}
Valine (Val)	6.00 ± 0.39^{f}	4.76 ± 0.26^{b}	3.93 ± 0.08^{a}	3.93 ± 0.08^{a}	$4.95 \pm 0.08^{b, c}$	$5.35 \pm 0.25^{d, e}$	4.63 ± 0.06^{b}	$5.20 \pm 0.17^{c, d}$	5.57 ± 0.11^{e}	5.59 ± 0.23^{e}

Mean ± SD having the same letters (a, b, c, d, e, f) in the same row are not significantly different ($p < 0.05$). *FWA* Food waste-based formulation A; *FWB* Food waste-based formulation B

Table 16.4 Amino acid scores of the feed items compared to the requirements of grass carp

EAA	Amino acid score									
	Napier grass	Rice bran	Soybean dregs	Noodle 1	Noodle 2	White bread	Hamburger bun	Jinfeng® 613	FWA	FWB
Arg	61*	170	93	93	129	107	141	199	218	219
His	102	139	67*	93	151	117	130	136	150	151
Ile	165	204	73	112	155	139	172	156	164	165
Leu	121	130	66*	115	165	137	142	161	172	173
Lys	57*	83	58*	35*	59*	49*	45*	107	106	106
Met + Cys#	60*	128	79	38*	106	144	184	144	136	137
Phe + Tyr#	270	192	89	98	131	174	162	187	201	203
Thr	152	132	60*	108	128	119	98	172	172	174
Typ	83	278	63*	39	138	163	339	607	429	478
Val	182	166	68*	113	157	137	150	160	171	172
First limiting AA	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys	Lys

Asterisk (*) indicates that the EAA is insufficient for the dietary requirements of grass carp. EAA requirement (expressed as % of total protein) of grass carp: threonine 2.50; valine 3.25; methionine + cystine 2.65; isoleucine 2.84; leucine 5.14; phenylalanine + tyrosine 4.52; lysine 5.11; histidine 1.87; arginine 3.47; and tryptophan 0.72 (Wang et al., 2005). #Cys and Tyr are included as they are involved in Met and Phe metabolism pathways, respectively (Ogino, 1980). *FWA* Food waste-based formulation A; *FWB* Food waste-based formulation B

Table 16.5 Amino acid scores of the feed items compared to the requirements of Nile tilapia

EAA	Amino acid score									
	Napier grass	Rice bran	Soybean dreg	Noodle 1	Noodle 2	White bread	Hamburger bun	Jinfeng® 613	FWA	FWB
Arg	50*	140	77	76	106	88	116	165	180	181
His	110	151	73	101	164	127	142	148	163	165
Ile	151	186	66*	102	142	127	157	143	150	151
Leu	183	198	99	174	250	208	216	244	260	263
Lys	61*	88	62*	38*	62*	53*	48*	114	113	113
Met + Cys#	50*	106	65*	32*	88	119	152	119	112	113
Phe + Tyr#	220	157	73	80	107	142	132	152	164	165
Thr	101	88	40*	72	85	79	65*	115	115	116
Typ	60*	200	45*	28*	99	118	244	437	309	344
Val	211	193	79	131	183	159	174	186	199	200
First limiting AA	Met + Cys	Lys	Thr	Met + Cys	Lys	Lys	Lys	Lys	Met + Cys	Lys/Met + Cys

Asterisk (*) indicates the EAA that is insufficient for the dietary requirements of grass carp. EAA requirement (expressed as % of total protein) of Nile tilapia: threonine 10.6; valine 9.5; methionine 5.4; cystine 2.7; isoleucine 7.5; leucine 13.5; phenylalanine 9.5; tyrosine 6.5; lysine 16.8; histidine 4.8; arginine 11.6; and tryptophan 1.7 (Santiago & Lovell, 1988). #Cys and Tyr are included as they are involved in Met and Phe metabolism pathway, respectively (Ogino, 1980). *FWA* Food waste-based formulation A; *FWB* Food waste-based formulation B

Table 16.6 shows the proximate compositions of the studied fish feeds. All the feed items (except soybean dregs) had significantly lower ($p < 0.05$) crude protein content than all three fish pellets. No significant differences ($p > 0.05$) in the crude protein content of the three fish feed pellets were noted. Soybean dregs had the highest protein content among all tested fish feeds (35%), followed by the three fish feed pellets.

Table 16.7 shows the growth performance and protein digestibility of grass carp consuming the three experimental diets (Cont613, ContB, and FWBV). Grass carp fed with FWBV showed significantly better growth (RWG, SGR, FCR, and PER) ($p < 0.05$) than groups fed with Cont613 and ContB. No significant differences ($p > 0.05$) were noted between the groups fed with Cont613 and ContB. There were no significant ($p > 0.05$) differences in the growth performance of grass carp fed with Cont613 and ContB, without the addition of VMP. Grass carp fed with a diet supplemented with VMP (FWBV) showed approximately 10% higher RWG than groups fed with Cont613 and ContB. The group fed with FWBV showed significantly better digestibility than the groups fed with Cont613 and ContB ($p < 0.05$).

Table 16.7 also shows the growth performance of Nile tilapia that were fed with the three experimental diets. Similar to grass carp, Nile tilapia fed with FWBV showed significantly better RWG, SGR, FCR, and PER ($p < 0.05$), followed by the two control diets. However, no significant differences ($p > 0.05$) in protein digestibility were noted among the three treatment groups. Table 16.8 shows the carcass proximate compositions of grass carp and Nile tilapia. There were no significant differences ($p > 0.05$) in dry matter, ash, crude protein, or crude lipids among the three treatment groups in both grass carp and tilapia.

16.4 Discussion

Among all of the essential amino acids (EAA), lysine is the most important one, as it is the EAA found at the highest level in the carcass of many fish species (Wilson & Cowey, 1985; Wilson & Poe, 1985; Kim & Lall, 2000). Lysine is one of the most limiting amino acids in the ingredients used for the production of commercial fish feeds, especially in those with fish meal replaced by plant proteins (Mai et al., 2006). Inadequate lysine in the diet could seriously affect the growth and health of fish (Li et al., 2008). Wang et al. (2005) observed that the dietary lysine requirement of grass carp juveniles should be 5.44% of the dietary protein, while Santiago and Lovell (1988) noted that Nile tilapia requires 5.12% of the dietary protein. In the present study, except for the three fish feed pellets (Jiefeng® 613: 5.83%; FWA: 5.76%; FWB: 5.79%), none of the common fish feeds contained sufficient lysine for either grass carp or Nile tilapia.

It has been recommended that the optimal dietary protein level for grass carp should be about 22–30% (Cai et al., 2005), while for Nile tilapia it is 30% (Wang et al., 1985), with casein as the primary protein. If the principal fish feeds cannot satisfy their nutritional requirements, fish would also consume other food sources to replenish

Table 16.6 Proximate composition of the fish feed items studied in this experiment

Proximate compositions	Feed items									
	Napier grass	Rice bran	Soybean dregs	Noodle 1	Noodle 2	White bread	Hamburger bun	Jinfeng® 613	FWA	FWB
Total phosphorous (mg P/g)	21.72 ± 2.49^{b}	27.85 ± 5.96^{c}	35.34 ± 0.89^{d}	9.05 ± 0.3^{a}	10.19 ± 0.2^{a}	11.43 ± 0.7^{a}	12.93 ± 0.55^{a}	9.67 ± 3.1^{a}	27.7 ± 4.7^{c}	19.4 ± 4.8^{b}
Crude protein (% DM)	12.75 ± 1.44^{b}	4.14 ± 0.35^{s}	35.82 ± 6.54^{c}	$8.45 \pm 0.41^{a,b}$	10.04 ± 0.21^{b}	13.07 ± 0.41^{b}	13.16 ± 0.81^{b}	30.2 ± 1.55^{c}	31.4 ± 0.44^{c}	31.4 ± 3.36^{c}
Crude lipid (% DM)	2.3 ± 0.8^{a}	11.2 ± 2.7^{c}	1.5 ± 0.5^{a}	21.3 ± 4.2^{d}	19.5 ± 3.2^{d}	3.2 ± 0.6^{a}	6.0 ± 0.8^{b}	5.2 ± 0.9^{b}	13.3 ± 1.8^{c}	6.1 ± 1.7^{b}
Crude fibre (% DM)	32.4 ± 4.2^{d}	27.4 ± 4.3^{d}	5.8 ± 1.1^{b}	1.5 ± 0.2^{a}	1.7 ± 0.3^{a}	2.4 ± 0.6^{a}	3.7 ± 0.7^{a}	9.6 ± 0.2^{c}	5.7 ± 0.9^{b}	10.1 ± 0.6^{c}
Moisture (% DM)	5.05 ± 0.04^{b}	5.64 ± 0.52^{c}	5.63 ± 0.12^{c}	4.98 ± 0.06^{b}	4.25 ± 0.61^{a}	6.43 ± 0.08^{c}	5.91 ± 0.12^{c}	6.3 ± 0.04^{c}	4.3 ± 0.03^{a}	6.8 ± 0.12^{c}
Ash (% DM)	10.65 ± 0.88^{c}	12.86 ± 0.33^{d}	$3.88 \pm 0.53^{a,b}$	3.17 ± 0.14^{a}	5.49 ± 2.43^{b}	2.25 ± 0.56^{a}	11.08 ± 0.54^{d}	9.24 ± 0.09^{c}	9.18 ± 0.46^{c}	18.9 ± 0.03^{e}
Non-fibrous carbohydrate (%)	36.9	66.2	47.4	60.6	59.0	72.7	60.2	40.5	39.9	24.2

Mean ± SD having the same letters (a, b, c, d, e) in the same row are not significantly different ($p < 0.05$). *FWA* Food waste-based formulation A; *FWB* Food waste-based formulation B

Table 16.7 Growth performance and protein digestibility of grass carp and Nile tilapia fed with various experimental diets

Growth performance	Diet		
X′	Cont613	ContB	FWBV
Grass carp			
Relative weight gain (%)	52.5 ± 1.0^{a}	51.3 ± 4.3^{a}	60.5 ± 2.2^{b}
Feed conversion ratio	1.59 ± 0.05^{a}	1.56 ± 0.05^{a}	1.29 ± 0.04^{b}
Protein efficiency ratio	2.1 ± 0.06^{a}	2.14 ± 0.07^{a}	2.59 ± 0.07^{b}
Protein digestibility (%)	82.5 ± 7.4^{b}	65.2 ± 1.6^{a}	79.0 ± 8.4^{b}
Nile tilapia			
Relative weight gain (%)	39.6 ± 10.8^{a}	40.6 ± 4.3^{a}	61.6 ± 2.2^{b}
Feed conversion ratio	1.66 ± 0.39^{a}	1.5 ± 0.18^{a}	1.04 ± 0.04^{b}
Protein efficiency ratio	2.09 ± 0.56^{a}	2.24 ± 0.25^{b}	3.21 ± 0.12^{b}
Protein digestibility (%)	86.4 ± 2.9^{a}	84.0 ± 1.0^{a}	85.7 ± 1.0^{a}

Mean ± SD having the same letters (a, b) in the same row are not significantly different ($p < 0.05$). *Cont613* Jinfeng® 613 with 0.3% α-cellulose; *ContB* Food waste-based formulation B with 0.3% α-cellulose; *FWBV* Food waste-based formulation B with 0.3% vitamin-mineral premix

Table 16.8 Proximate compositions of grass carp and Nile tilapia carcasses fed with various experimental diets after 4 weeks

Proximate compositions	Diet group		
	Cont613	ContB	DietB
Grass car			
Dry matter (% w/w)	93.5 ± 0.7^{a}	94.9 ± 0.2^{a}	96.1 ± 0.5^{a}
Ash (% DM)	13.0 ± 0.8^{a}	14.2 ± 0.4^{a}	13.1 ± 1.1^{a}
Crude protein (% DM)	54.9 ± 2.6^{a}	58.6 ± 4.0^{a}	57.1 ± 0.6^{a}
Crude fat (% DM)	15.3 ± 0.2^{a}	14.6 ± 0.3^{a}	15.7 ± 3.2^{a}
Nile tilapia			
Dry matter (% w/w)	97.6 ± 1.1^{a}	96.1 ± 0.5^{a}	98.6 ± 0.5^{a}
Ash (% DM)	18.0 ± 1.5^{a}	17.7 ± 0.7^{a}	19.6 ± 0.5^{b}
Crude protein (% DM)	59.1 ± 5.6^{a}	57.6 ± 3.4^{a}	59.8 ± 1.7^{a}
Crude fat (% DM)	12.7 ± 0.5^{a}	12.2 ± 1.2^{a}	13.3 ± 0.6^{a}

Mean ± SD having the same letters (a, b) in the same row are not significantly different ($p < 0.05$). *Cont613* Jinfeng® 613 with 0.3% α-cellulose; *ContB* Food waste-based formulation B with 0.3% α-cellulose; *FWBV* Food waste-based formulation B with 0.3% vitamin-mineral premix the insufficient nutrients. Pandit, Shrestha, Yi, and Diana (2004) conducted a study on the food utilization of grass carp and tilapia reared in a polyculture environment, using Napier grass as the primary fish feed. Other than Napier grass, multicellular algae, detritus, and sometimes copepods could be found in the gut contents of the fish.

Among all common fish feeds, soybean dregs contained the highest amount of crude protein (about 35%) and it is a popular feed used by local fish farmers. However, the non-essential amino acids consist of a large proportion of total protein in soybeans. Aspartic acid and glutamic acid contributed to 11.7 and 19.5% of protein, respectively, of dried soybean dregs (Chan & Ma, 1999). Even though soybean dregs contain rather high protein content, supplementation with lysine would be essential as it is inadequate in plant-based protein sources (Mai et al., 2006). Items with low protein content are adopted by local fish farmers as price is the major governing factor. Inadequate amounts of nutrients (such as lipids, protein, EAA, and minerals) in fish feed would hinder fish growth, which will in turn reduce the turnover rate of fish ponds and lower the income of fish farmers.

The use of food waste-based diets could provide sufficient nutrients for the fish. The lysine content as well as the EAA profiles of the food waste diets were sufficient for both grass carp and Nile tilapia. In general, crude protein, crude lipids, carbohydrates, and total phosphorous met the requirements of both species (except for the crude lipids of FWB, which was about three times higher than the suggested value for grass carp, compared to other common fish feeds). Both the commercial and food waste-based feed pellets contained sufficient and comparable essential amino acids. The FCR of commercial diets should be lower than 2 (Craig & Helfrich, 2009). The FCR values from this experiment indicated that the food waste-based diets, even without VMP, could generally satisfy the needs of both grass carp (1.56) and tilapia (1.50). With VMP, the FCR values of both grass carp and Nile tilapia were further improved from 1.56 to 1.29 and 1.50 to 1.04, respectively. Addition of VMP to formulated diets is a common practice in order to provide sufficient micronutrients to farmed animals (Hardy & Barrows, 2002). Although there were 10% of vegetables and fruits included in the food waste-based feeds, the superior fish growth in groups fed with the VMP supplemented diet indicated that food waste could be improved by adding micronutrients. Inclusion of vitamin supplements for Nile tilapia is necessary in order to achieve optimal growth and health when limited natural food sources are available (Food and Agriculture Organization of the United Nations, 2017). In the present study, VMP appears to be essential for inclusion in the food waste-based diets, because of the significant better growth of both fish species in terms of RWG, FCR, PER, and improved protein digestibility (observed in grass carp only).

16.5 Conclusions

The results of this experiment clearly demonstrate that the common fish feeds: Napier grass, rice bran, soybean dregs, noodles, and breads, are nutritionally insufficient, with insufficient lysine (except for Jiefeng® 613), crude protein (except for Jiefeng®

613 and soybean dregs) and lipids (except for the two noodle samples) content. All the fish feed pellets (Jiefeng® 613, FWA, and FWB) contained sufficient amounts of essential amino acids, crude protein, crude lipids, and total phosphorous for both grass carp and Nile tilapia. This indicates that both commercial and food waste-based fish feed pellets are more suitable, compared with the traditional feed items used by local fish farmers. In the feeding trials, the FCR values and protein digestibility of ContB (non-supplemented) used for feeding grass carp and for Nile tilapia were 1.56 and 1.5, and 65.2% and 84%, respectively. Inclusion of VMP in the food waste-based pellets significantly improved FCR for both fish (grass carp = 1.29; Tilapia = 1.04) and the protein ADC of grass carp (79%). Whole carcass proximate compositions (crude lipids, crude protein, and ash) of both grass carp and Nile tilapia did not significantly differ among all treatment groups. Considering the fact that growth performances of both grass carp and Nile tilapia were significantly improved with the inclusion of vitamin-mineral premix, it is essential this supplement be included in food waste-based pellets.

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Wing Yin Mo is currently a Post-doctoral Fellow at The Education University of Hong Kong. He participated in three research projects in a series to culture freshwater and marine fish using food waste as major ingredients in the past few years. He has published 19 SCI papers, with 6 as first author.

Yu Bon Man is currently Assistant Professor at The Education University of Hong Kong. He has published more than 50 SCI papers and has substantial experience in conducting extensive studies on human health assessments via exposure to food contaminants, especially fish in South China. He has involved in research projects related to food safety, recycling food waste for fish culture as well as wastewater treatment (sewage treatment plants and constructed wetlands).

Ming Hung Wong is currently Advisor of Environmental Science at The Education University of Hong Kong, Chang Jiang Chair Professor of Ministry of Education, China, and Editor-in-Chief of Environmental Geochemistry and Health (Springer). He has published more than 650 SCI papers in the areas of ecotoxicology, remediation of contaminated sites, and recycling of organic waste, with emphasis on upgrading food waste as fish feed.