Towards a Sustainable Resource Management: A Broader Systems Approach to Product Design and Waste Management

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Licentiate Thesis

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Department of Sustainable Development, Environmental Science and Engineering
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Dedicated to

YOU

Preface

Sometimes, life brings surprises! Coming to Stockholm to pursue a PhD at the Division of Industrial Ecology KTH, was one of several surprises for me. Also, this was a challenging '*twist*' in my educational career after my *totally* technical educational background - Masters in Energy Studies (Renewable Energy Technologies) and Bachelors in Electrical Engineering. However, my Master's program had few courses on environmental aspects of conventional energy systems, prompting my interest in sustainability-oriented research. .

The thesis consists of three papers as summarised in the *kappa*. These papers are the outcome of my experiences at the Division of Industrial Ecology for the last 3 years. The thesis attempts to take a broader perspective on resource flows with its relevant system components. It starts with exploring waste management issues but ends on a resource management note. Therefore, it is debatable whether it belongs to traditional waste management or resource management research? To cover broad system level aspects, the details about individual systems have been compromised. The terms waste and resources are used interchangeably since their meanings are very subjective and could be interpreted differently by different stakeholders.

The main purpose of the thesis is to analyse the global waste management system, both as part of a larger current design, production, consumption and waste management system and an even larger future physical resource management system. The study utilises soft systems methodology by Checkland (2000) and proposes a broader systems approach to resource management. The study emphasises the need to recognise the multitudes of perspectives, cross-scale dynamics and actors' interactions at various levels. The thesis proposes some structural, procedural and attitudinal changes needed during the transition towards a predominantly circular material economy.

There are some limitations in discussing complex environmental issues at a very broad level; for example, often, the broad analysis compromises detailed analysis. The reader might feel that important details have not been discussed in the thesis. Whilst I acknowledge that there are aspects of the work that neglect detailed analysis, this was largely due to the broad focus of the thesis. Finally, I would like to end this preface with a perceptive quote:

"Thoroughly conscious ignorance is the prelude to every real advance in science" - James Clerk Maxwell (1831-1879)

Sincerely,

Jagdeep Singh
11th December 2013
Stockholm, Sweden

Acknowledgements

I started my PhD studies at the Division of Industrial Ecology, KTH Royal Institute of Technology Stockholm, three years ago, when I was shortlisted for India4EU - Erasmus Mundus Scholarship Program. I am very grateful to that program for the financial support I have received to during this time.

I would also like to thank my supervisor Björn Frostell at the Division of Industrial Ecology for guiding this research work and for his critical input as well helping me develop my skills as researcher.

I would also like to thank other professors, staff and my PhD colleagues at the Division of Industrial Ecology for their kindness, help, support and friendship. A special thanks to Rafael Laurenti, Rajib Sinha, Hongling Liu and Graham Aid whose constructive suggestions, comments and ideas have been hugely beneficial.

I am very thankful to Anna Björklund and Per Jakobsson for their constructive feedback on the '*kappa'* of this thesis.

Finally, I would like to express my gratitude to my family and friends for their ongoing unconditional loving support.

Sincerely,

Jagdeep Singh
11th December 2013
Stockholm, Sweden

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Abstract

Rapid economic growth, urbanisation and increasing population have caused (materially intensive) resource consumption to increase, and consequently the release of large amounts of waste to the environment. Numerous technological and operational approaches to resource management have been introduced throughout the system of production, consumption and waste management. This thesis concludes that the current, rather isolated, efforts to influence different systems for waste management, waste reduction and resource management are indeed not sufficient from a long-term sustainability perspective. To manage resources and waste sustainably, resource management requires a more systems-oriented approach, which addresses the root causes of the problems.

This thesis identifies and discusses different sustainability challenges facing the global waste management system. To address these challenges a broader systems approach to waste management is proposed. The thesis argues that there is a need to recognise the multitudes of perspectives, cross-scale dynamics and actors' interactions at various levels. The barriers and limitations to a systems-oriented management of waste generation including design, production, consumption and waste management are discussed. The study utilises soft systems methodology (by Checkland (2000)) within which different concepts and methods are utilised to present a worldwide view on resource dynamics and develop a research heuristic for sustainable resource management. The study emphasises the need for a shared vision among various actors across the chain of production and consumption. To assist better planning, the need for improved databases on resource use and wastes is emphasised.

Keywords: Resource Management, Product Design, Waste Management Challenges, Systems Thinking, Sustainability Science

Contents

List of Appended Papers

Paper 1 Singh, J., Laurenti, R. & Frostell, B. 2013. Progress and challenges to global waste management system. Submitted to *Waste Management and Research*.

Paper 2 Laurenti, R., Singh, J., Sevaldson, B. & Frostell, B. 2013. Moving from incremental improvements in efficiency to Systems-Oriented Design: A Systems Approach to Product Design. Submitted to *Journal of Industrial Ecology*.

Paper 3 Singh, J., Frostell, B. 2013. From waste disposal to a global resource management paradigm – a conceptual discussion. *To be Submitted.*

List of Abbreviations

DPSIR	Driver-Pressure-State-Impact-Response Framework
EIP	Eco Industrial Park
EPR	Extended Producer's Responsibility
ESCAP	Economic and Social Commission for Asia and the Pacific
EU	European Union
GNI	Gross National Income
HDI	Human Development Index
MEA	Millennium Ecosystem Assessment
MSW	Municipal Solid Waste
OECD	Organisation for Economic Co-operation and Development
PAYT	Pay As You Throw
SDSOD	Sustainability-Driven Systems-Oriented Design Framework
SSM	Soft Systems Methodology
UN	United Nations
UNEP	United Nations Environment Program
USEPA	United States Environmental Protection Agency
WB	World Bank
WM	Waste Management

1. Introduction

In the last few decades, rapid economic development and urbanisation have resulted in substantial improvements in well being for large sections of the world population. At the same time, we have seen increased materially-intensive resource consumption and consequently the release of large amounts of waste to the environment (Wenheng and Shuwen, 2008, Gerbens-Leenes et al., 2010, Blanchard, 1992). Bylinsky (1995) reports that according to the American National Academy of Sciences, 94 % of the substances that are pulled out of the earth enter the waste stream within months. At the same time, society desires to preserve, restore, and rehabilitate natural ecosystems (Weinstein and Turner, 2012). This "*paradox of the dual mandate*" (Roe and Eeten, 2002) has been constantly bringing the sustainability discussions into global political agendas since the 1990s.

Numerous technological and operational approaches have been introduced throughout the system of production, consumption and waste management (WM) to address resource management issues. The technological approaches include, for example, improved waste recycling and incineration technologies within the WM system. The operational reforms comprise a range of new social-material relations between companies and society, such as extended producer responsibility (EPR), product stewardship and eco-industrial parks (EIPs) to name a few. Nevertheless, current global resource management faces several challenges. Due to the lack of aligned long-term goals between various socio-technical systems, the current approaches fail to provide long-term solutions to these resource management issues.

Resource dynamics is governed by a complex system comprising a multitude of actors (consumers, producers, recyclers and WM authorities etc.); industries (manufacturing companies and mining industries); and different perspectives (social, economic, ecological and political). These actors/institutions engage through various intricate interactions at multiple scales and levels, generally, with competing goals. Indeed, in today's world, these interactions between production and consumption systems span the globe. Thus, addressing resource management issues requires a holistic understanding of the entire system of production and consumption by recognising these multitudes of perspectives, cross-scale dynamics and actors' interactions at all the levels. In a long-term sustainability perspective, there is a need to discern sustainability challenges associated with (over) consumption of resources and generation of wastes and pollution in society.

1.1 Aim and Objectives

The aim of this thesis is to study and analyse the global waste management (WM) system, both as part of a larger design, production, consumption and waste system and an even larger future physical resource management system. A broader systems approach to waste/resource management is discussed to address global WM challenges.

Within this larger scope, the *objectives* of the thesis are to:

- Study the current WM system in a global perspective
- Identify the major challenges to the current global WM
- Propose a broader systems approach to physical resource management
- Discuss essential changes needed for a transition towards a more sustainable waste management

To achieve these objectives, the following *research questions* are used as a guide:

1. What is the status of the current waste management system in a global perspective?
2. What are the sustainability challenges to the current global resource management system?
3. How could a broader systems approach be employed to address the challenges to the current resource management system?
4. How could the barriers and limitations to a systems-oriented management of physical resources including design, production, consumption and waste management be addressed?

1.2 Scope

In this thesis, the term 'waste' has been used to represent the negative externality to the production and consumption system. Within the scope of this thesis, the definition of waste given by the European Union Directive on Wastes (2008), "*waste is regarded as by-products or end products of the production and consumption processes respectively*", fits very well. Therefore, the term '*waste*' used in this thesis covers various solid, liquid and gaseous residues produced during, for example, resource extraction, manufacturing, and consumption processes.

1.3 Structure of the Thesis

The remainder of the thesis is divided into 4 chapters.

Chapter 2: Theoretical Background

This chapter describes the terms and the concepts necessary to understand the thesis.

Chapter 3: Methodology

This chapter gives an overview of the research design and important concepts used in the thesis to obtain the research objectives.

Chapter 4: Results and Discussions

This chapter presents and discusses the results of the thesis.

Chapter 5: Conclusions

This chapter concludes the thesis.

2. Theoretical Background

This chapter describes the terms and the concepts necessary to understand the thesis.

2.1 Sustainability

The term 'sustainability' has been regarded as both vague and politicised (Lant, 2004) in its variety of meanings in different contexts (Graedel and Klee, 2002). The number of terms continues to increase along with the rapidly increasing awareness of the importance of sustainability (Glavič and Lukman, 2007). However, basic principles/concepts that are the basis for fundamental actions/strategies/approaches to achieve sustainability remain environmental/ecological, economic and societal in nature. Within the scope of the thesis, various environmental principles such as resource scarcity; ecological principles for example industrial ecology, sustainable production and consumption system etc.; and societal principles such as social responsibility[1] and extended producer responsibility act as guiding principles for the study.

Natural resources provide raw materials for the production of goods and services and are fundamental to every economy. Wastes and emissions cause adverse environmental, economic and social impacts, and are directly linked to the issue of resource scarcity. This thesis adopts a similar view of sustainability as given in the Brundtland Commission's report (1987)– "*sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

2.2 Scales and Levels of Analysis

The terms *'level'* and *'scale'* have been frequently used interchangeably with different understandings among disciplines and scholars (Gibson et al., 2000). Gibson (2000) defines scale as *"the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and level as the units of analysis that are located at different positions on a scale"* (see Table 2.1).

Numerous human activities have root causes and consequences at different levels along multiple scales. Historically, human actions have resulted in unintended consequences due to the failure to *completely* recognise the cross-level and cross-scale dynamics in the human-environment systems, for example, collapsing fisheries, environmental problems and human-induced disease outbreaks (MEA, 2005).

Thus, the scale at which an assessment is undertaken significantly influences the definition of the problem and the assessment results (MEA, 2005). Failure to acknowledge the driving forces at different scales can lead to unworkable and inequitable policies or programs at all scales. Thus, an adequate overview of the problem(s), associated driving forces, and resulting effects at a variety of levels must be developed (Ness et al., 2010). Within the scope of this thesis, various system boundary issues in the area of resource management have implicitly been highlighted - temporal

[1] According to Glavič and Lukman (2007) social responsibility "*refers to safe, respectful, liberal, equitable and equal human development, contributing to humanity and the environment.*"

(long-term or short-term), jurisdictional (local or national), institutional (regulatory or ethical), network (individual or societal).

Table 2.1. Different scales and levels of Analysis[2]*. Adapted from Gibson et al. (2000)*

	Scales of Analysis					
	Spatial (Areas)	*Temporal (Rates, durations)*	*Jurisdictional (Administrations)*	*Institutional (Rules)*	*Management (Plans)*	*Network (Links)*
Levels	Globe	Annual	Inter-Governmental	Constitutions	Plan	Trans-society
	Regions	Seasonal	National	Laws	Strategies	Society
	Landscape	Weekly	Provincial	Regulations	Projects	Kin
	Patches	Daily	Localities	Operating rules	Tasks	Family

2.3 Sustainability Science

Kates et al. (2001) argues that a *new field of sustainability science is emerging that seeks to understand the fundamental character of interactions between nature and society*. This new field integrates industrial, social, and environmental processes in a global context (Mihelcic et al., 2003). Sustainability science proposes that the science must be focused on the character of nature-society interactions; our ability to guide those interactions along a sustainable trajectory and on the ways to promote social learning to navigate the transition to sustainability; and be connected to global political agendas (Kates et al., 2001). Such problem-solving efforts may require an approach different from the traditional research strategies. As described by Weinstein and Turner (2012):

> *"[………Any solution to the emerging conflicts arising on the path of long-term sustainability will, in part, require the integration of the biophysical and social sciences into a new transdisciplinary science referred to as "sustainability science", continued development and refinement of a number of new approaches and concepts including a systems approach to problem-solving, social learning, resolution of the "paradox of the dual mandate" and enhanced incorporation of human dimensions into resource management……..]"*

Kates and colleagues (2001, 2010) propose research strategies which would need to differ from the conventional scientific activities. Ness and colleagues (2010) have summarised these strategies as follows:

- *(i)* *"covering the range of spatial scales between diverse phenomena,*
- *(ii)* *accounting for temporal inertias and urgency of processes,*
- *(iii)* *dealing with functional complexity resulting from multiple stresses, and*
- *(iv)* *the recognition of a wide range of outlooks equating to usable knowledge in both science and society."*

[2] There can be other classifications of scales and more levels.

In this thesis, the above sustainability science principles and strategies have been utilised to design the research heuristic to develop a broader systems approach to resource management (Paper 3).

2.4 Life Cycle Thinking and Systems Thinking

Frostell (2013) contends that *"Life cycle thinking is a strive to think in a more holistic way and consider a broader set of interactions between human activities and the global system, be they of physical, economic, or social character."* From a life cycle thinking perspective, the human activity system uses raw materials (including the materials for energy production) to operate production and consumption systems; therefore, instead of focusing on a specific part of a production and consumption chain, all the different phases in a combined production and consumption chain need to be recognised (Frostell, 2013). In this sense, resource management objectives are impossible to achieve without the adoption of a worldwide view on resource flows.

Systems thinking is a way of shifting that focus onto systems, rather than their parts, in order to define, frame and solve complex problems (Sweeney and Meadows, 2010). Checkland (2000) argues that systems thinking is founded upon two pairs of ideas, those of *emergence and hierarchy*, and *communication and control* (Checkland, 2000). A system under study should be addressed at hierarchical levels to explore various causal connections *within* a sub-system and *between* sub-systems. This is important to achieve a holistic understanding of their linkages from sub-systems to the unified *complex* system. The maintenance of the hierarchies entails a set of processes in which there is *communication* of information for the purpose of *control* or *regulation*.

In this thesis, life cycle thinking and systems thinking have been utilised to explore the various links between socio-technical systems – product design, production, consumption and WM (Paper 1); actor interactions in order to develop a conceptual model of resource flow dynamics and a suitable framework for product design (Paper 2); and to propose a broader systems approach to resource management (Paper 3).

2.5 Drivers–Pressure–State–Impact–Response (DPSIR) Framework

The DPSIR framework is a functional analysis scheme for structuring the cause-effect relationships in connection with environmental and natural resource management problems. The framework is useful in describing the relationships between the origins and consequences of environmental problems and to understand their dynamics through the links between DPSIR elements (European Environmental Agency, 1999). In terms of this framework, socio-economic development and socio-cultural forces function as drivers (D) of human activities that increase or mitigate pressures (P) on the environment. Environmental pressures then change the state of the environment (S) and result in impacts (I) on human health, ecosystems and the economy (see figure 2.1). Those may lead to societal responses (R) to the corresponding drivers, pressures, state of the environment or impacts via various mitigation, prevention or adaptation measures with regard to the environmental problems identified (European Environmental Agency, 1999).

The DPSIR framework summarises complex system interactions into the form of a linear causal chain (cf. Figure 2.1). This helps in structuring communication between scientists and end users of the environmental information. The framework serves as a heuristic device to facilitate engagement, communication and understanding between different stakeholders. Therefore, it helps to deal with functional complexities resulting from competing goals.

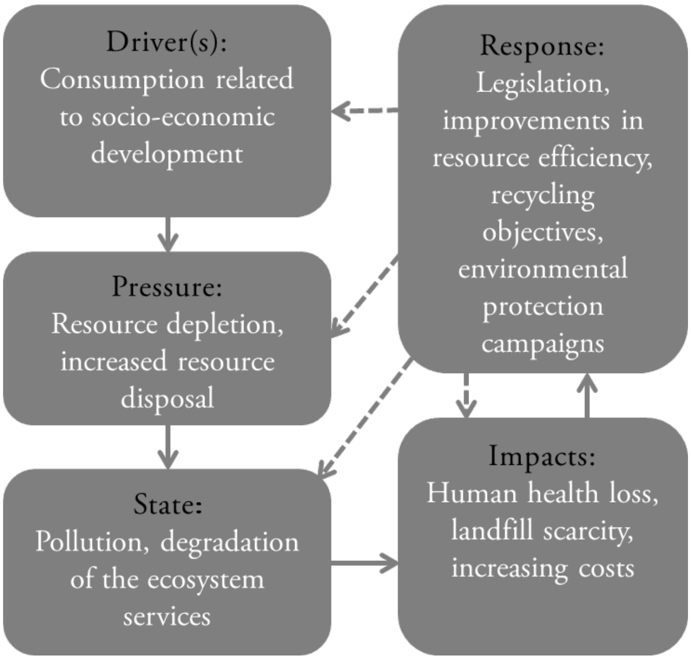


Figure 2.1 A causal illustration of the DPSIR framework. Adapted from European Environmental Agency (1999)

Often there is an admission of ignorance or unwillingness to address particular levels and/or cross-scale interactions (Cash et al., 2006). To identify the root causes of the problem and the leverage points within a system, the recognition of the levels of causal interactions is also essential. In this thesis, the DPSIR framework is proposed as a tool to engage various actors at a particular level in a purposeful activity meeting their respective interests as well as the system's sustainability goals.

3. Methodology

Traditional research design includes three phases: the conceptual, the experiential and the inferential phase (Teddlie and Tashakkori, 2009, Tashakkori and Teddlie, 2003). The conceptual phase is the sphere of concepts which includes the formulation of research purpose, questions and so forth. The experiential phase includes concrete observation through methodological operations or data generation (in case of quantitative research) or analysis. The inferential phase includes emerging theories, explanations, inferences and so on (see Figure 3.1).

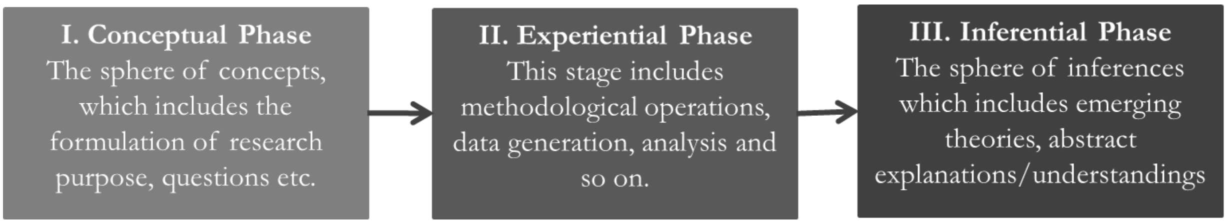


Figure 3.1 Graphical Illustration of various phases in a traditional research

Soft Systems Methodology (SSM) (Checkland, 2000) constitutes the '*backbone'* of the whole thesis. The methodology has been utilised as a guiding framework rather than a '*recipe',* which allows the inclusion of radical ideas and novel possibilities. The thesis utilises a mix of research methods/concepts on an *ad hoc* basis to cover the broad aspects discussed. These concepts and research methods have been utilised within various stages of SSM (described later in the chapter). Relating to the main aim of the thesis, concepts such as systems thinking, sustainability science and life cycle thinking have been utilised to develop the inferences in a pragmatic way in order to broaden the discussion on aspect of waste management. The thesis is mainly supported by the qualitative inferences derived from the worldviews based on a selective literature survey and group brainstorming sessions among the research group members. Therefore, the thesis makes use of both narrative and numeric data.

3.1 Research Methods

The following methods have been utilised to achieve the thesis objectives:

1. literature survey
2. group brainstorming
3. causal loop diagram development
4. data collection and compilation

Table 3.1 Research methods used in the appended papers

Research Methods	**Appended Papers**		
	Paper 1	Paper 2	Paper 3
Literature survey	X	X	X
Group brainstorming	X	X	X
Causal loop diagram		X	
Data collection and compilation	X		

3.1.1 Literature Survey

A systematic literature survey has been conducted in all the appended papers (Table 3.1). This Literature survey comprises collecting, analysing, evaluating and summarising scholarly material on a specific topic (Fink, 2010). In Paper 1 the literature survey encompassed global waste generation and management. In Paper 2, the literature survey related to the analysis of sustainability issues linked to the current product design paradigm. The literature survey covered in Paper 3 focused on systems thinking, life cycle thinking and sustainability science and provided a theoretical background for the discussion.

3.1.2 Group Brainstorming

The term brainstorming (Osborn, 1963) was popularised in the 1953 book *Applied Imagination.* It is a group or individual creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its member(s). In this thesis, this technique has been used in a slightly different way. Instead of gathering spontaneous ideas, a literature review was carried out and the important findings were discussed among the research group members[3].

Group brainstorming sessions were utilised during the development of all appended papers to analyse and discuss the results from the literature survey. These sessions were carried out to provide a reference point to identify and discuss: various challenges to global WM system (Paper 1); sustainability issues related to current product design paradigm (Paper 2); and a theoretical basis for a broader systems approach to WM (Paper 3). The brainstorming sessions were also used to develop process and framework diagrams (Figure 4.1, 4.7, 4.8, 4.9 and 4.10).

3.1.3 Causal Loop Diagram

A causal loop diagram represents the feedback structure of systems through arrows and polarities (Sterman, 2000). An arrow denotes the causal link between two variables and the polarity indicates how the dependent variable changes when the independent variable changes. In a positive link ("+" sign) both variables change in the same direction; that is, if one variable

[3] Apart from the Author, the group members included Björn Frostell, Rafael Laurenti and Rajib Sinha of the Division of Industrial Ecology, KTH Royal Institute of Technology Stockholm. Björn Frostell is an Associate Professor at the division and is an expert in the field of life cycle thinking and systems thinking. Rafael Laurenti is doing research in the field of sustainability-driven product design and is a PhD student at the Division of Industrial Ecology. Rajib Sinha is doing his PhD research in the field of household metabolism. This research group has contributed diverse perspectives on the waste/resource issues during the brainstorming sessions.

increases, the other one also increases and vice-versa. In a negative link ("-" sign), the variables change in the opposite direction; if one increases, the other decreases and vice-versa (Figure 3.2). A causal loop diagram is useful to identify various *feedback loops* in the system – *positive or reinforcing* loops and *negative or balancing* loops.

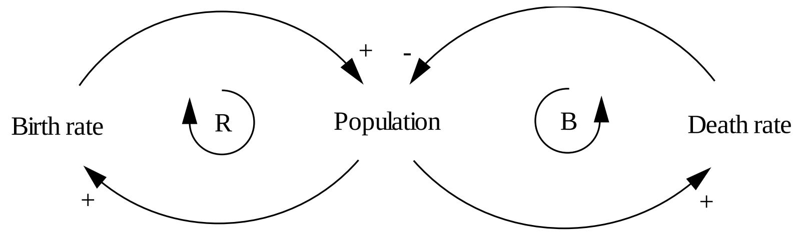


Figure 3.2 An example of variables (birth rate, population and death rate) connected by causal link with a polarity. R and B represent reinforcing and balancing feedback loops. Adapted from Sterman (2000)

Causal loop diagrams were utilised in Paper 2 to represent how various sustainability issues identified during the literature survey link to each other.

3.1.4 Data Collection and Compilation

During the development of Paper 1, data on global waste generation and composition has been collected from different sources, for example World Bank and Euro Stat. The data has been organised to answer the research questions in Paper 1.

3.2 Soft Systems Methodology (SSM)

SSM has developed, since its birth in the late 1960's at Lancaster University, to apply the principles of systems engineering to management situations. The methodology has been shaped by two characteristics of problematic situations: multiple, interacting perceptions of reality or worldviews; and people trying to act purposefully. The main activities in SSM can be classified into two types - '*real world*' activities which are stages 1, 2, 5, 6, and 7; and '*systems thinking*' activities which are stages 3 and 4 to further the understanding and unravelling of the real world complexities (see Figure 3.3). The research methods described earlier were utilised at different stages of SSM.

Stages 1 and 2: Problem Expression

Stages 1 and 2 in SSM serve to provide the *richest possible picture* of the current situation (Paper 1, 2 and 3). At these stages, a literature review followed by focused group brainstorming (Osborn, 1963) sessions among the research group was carried out to study the current status of resource flows (Paper 1). In addition to this, important actors, systems and systems interactions were overviewed (Paper 2 and 3). This step gives a concise description of a human activity system (in this case the resource management system) based on the view of it developed during these stages. A causal loop diagram has been developed to illustrate the resource flow dynamics (Paper 2).

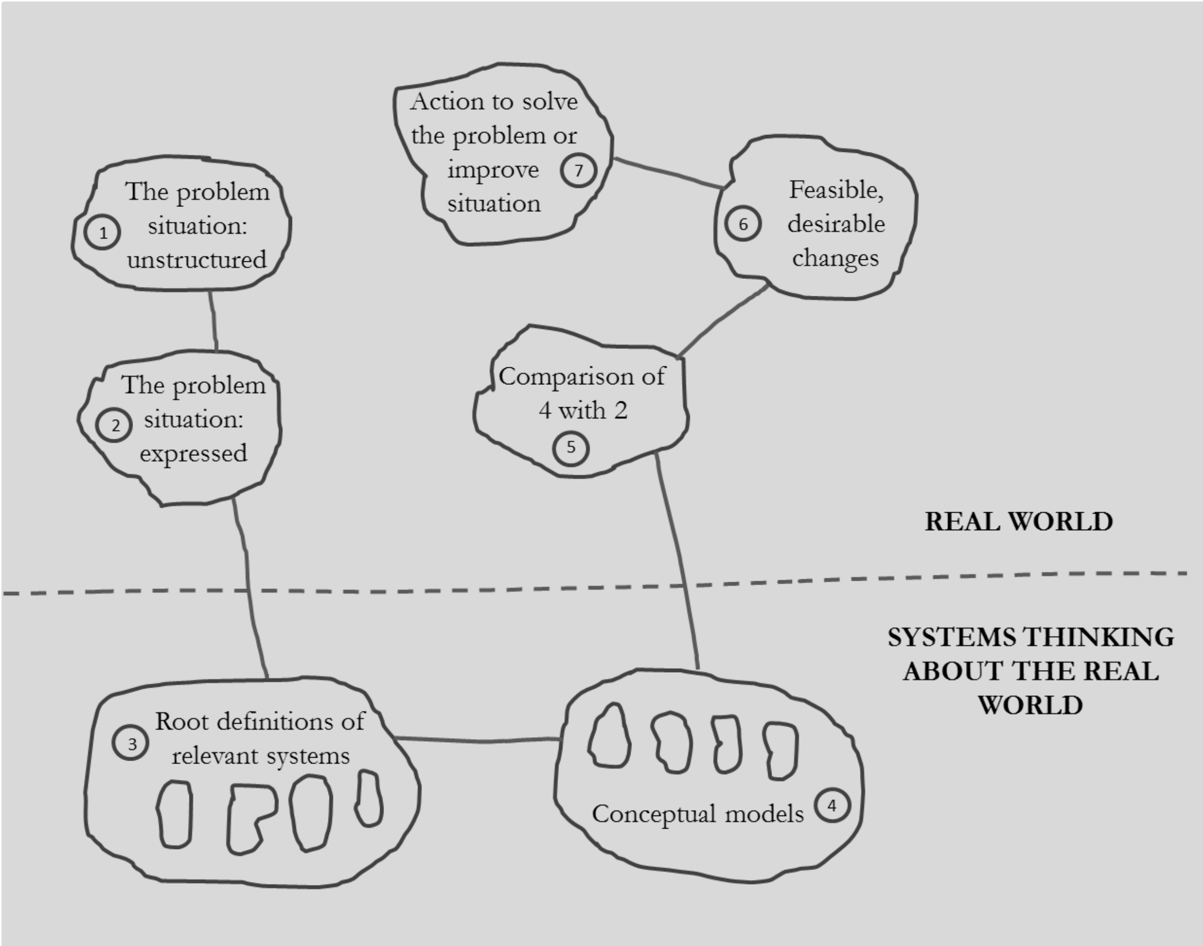


Figure 3.3 The different stages in Soft Systems Methodology. Adapted from Checkland (2000).

Stages 3: Root definitions of the Relevant Systems

In stage 3, the systems components seemingly relevant to the problem situation are identified. Based on the research objectives, the transformations needed for the current system to be sustainable are being defined (Paper 2 and 3). The main concepts utilized during these stages were life cycle thinking and systems thinking.

Stage 4: Conceptual Models

In Stage 4, the conceptual models have been developed regarding the activities which the system must undertake in order to achieve the desired goals, such as maximum resource recovery. In this context, a broader systems approach to waste/resource management (Paper 3) and a conceptual framework for product design - sustainability driven systems-oriented design framework (Paper 2) have been proposed.

Stage 5: Conceptual World and Reality

In this stage, the problem situation analysed in stages 1 and 2 is compared with the conceptual models. Here, the basic differences between the conceptual models and the real scenario are identified and discussed.

Stages 6 and 7: Feasible and Desirable Interventions

In the work of this thesis, stage 5 led to a discussion of some desirable structural, procedural and attitudinal changes in the resource management system as a necessary system intervention (cf. Checkland (2000)). The structural changes, in the thesis, refer to the changes suggested in the organisational aspects, functional responsibility and reporting structures of various actors in the system. The procedural changes are the changes in the data collection and reporting system. Lastly, the attitudinal changes such as the roles and responsibilities of the actors in the system have been discussed.

3.3 Traditional Research Design, SSM and Thesis

The traditional research design illustrated in Figure 3.1 is implicitly embedded in the SSM applied in this thesis (see Figure 3.4). Figure 3.4 illustrates how different *stages in SSM* relate to various *phases of traditional research*.

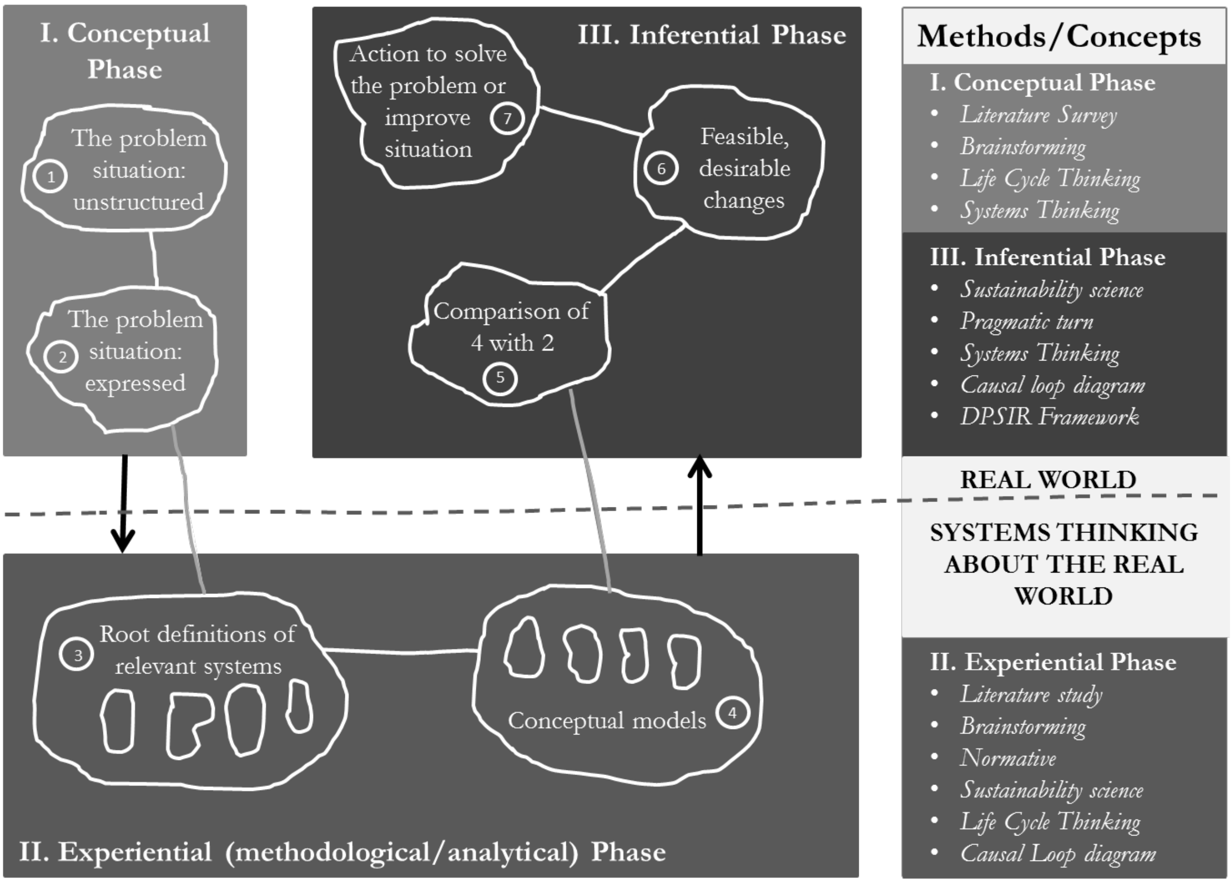


Figure 3.4 Graphical representation of the traditional research phases and the SSM methodology applied in the thesis.

Referring to the thesis, the traditional research phases (Figure 3.1) applied within the SSM can be summarised as shown in Figure 3.5.

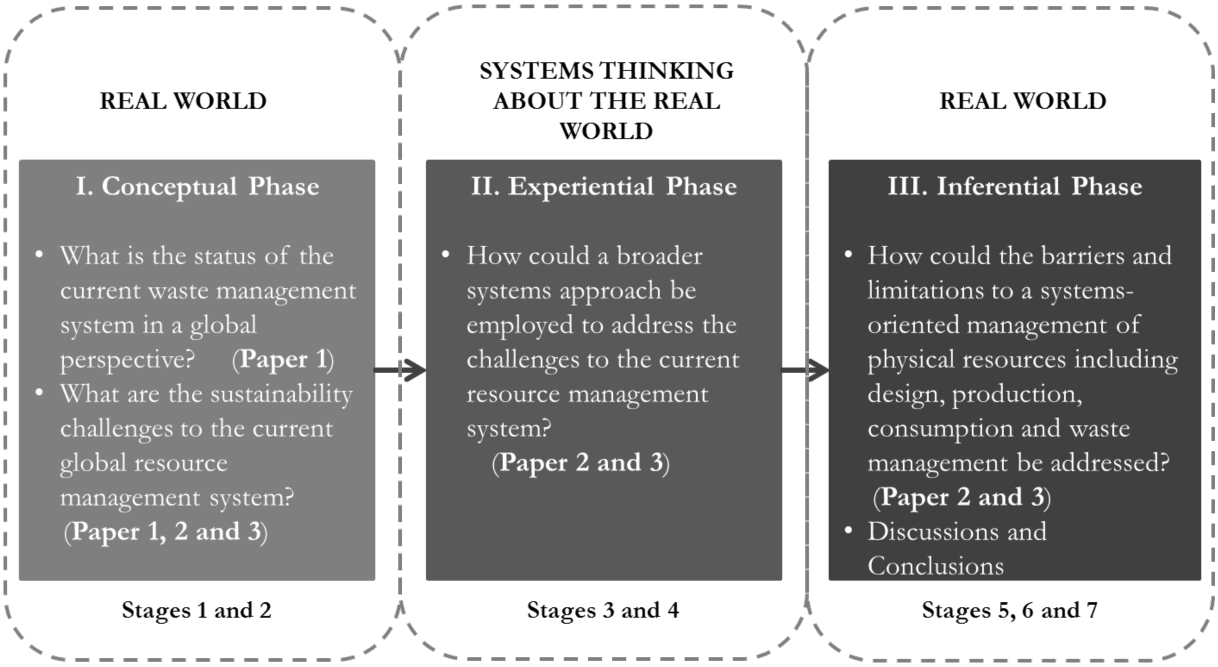


Figure 3.5 Traditional research design phases and SSM utilised in the thesis. Phases 1 and 2 investigate the research questions and phase 3 discusses the implications of the results and concludes the thesis.

4. Results and Discussions

This section presents and discusses the results of the thesis based on the appended papers. Subsections 4.1 and 4.2 present the outcomes of the stages 1 and 2 in the SSM. These stages were aimed at gathering information on the main systems and their structures, processes and actors relevant to the problem. Further, subsection 4.3 defines the systems relevant to the problem and the transformations required to address the problem. Subsection 4.4 attempts to suggest a systems-oriented approach for resource management and discusses the implications of the broader systems approach. Finally, subsection 4.5 discusses some of the feasible and desirable actions and limitations of the thesis respectively. The purpose of the subsections 4.4 and 4.5 is to advance the worldviews presented in the thesis to address the resource management issues.

4.1 Waste Management System in a Global Perspective

This subsection discusses the current status of waste management systems in a global context based on the literature survey, data collection and brainstorming sessions (Paper 1).

4.1.1 Waste Generation, Sources, and Composition

Rapid economic growth, urbanisation and increasing population have caused materially intensive resource consumption to increase, and consequently the release of large amounts of waste to the environment (Blanchard, 1992, Wenheng and Shuwen, 2008, Gerbens-Leenes et al., 2010) From a life cycle perspective, production of unintended gaseous, liquid and solid by-products or end-products takes place during the extraction, manufacturing, consumption and final treatment of the resources (Figure 4.1).

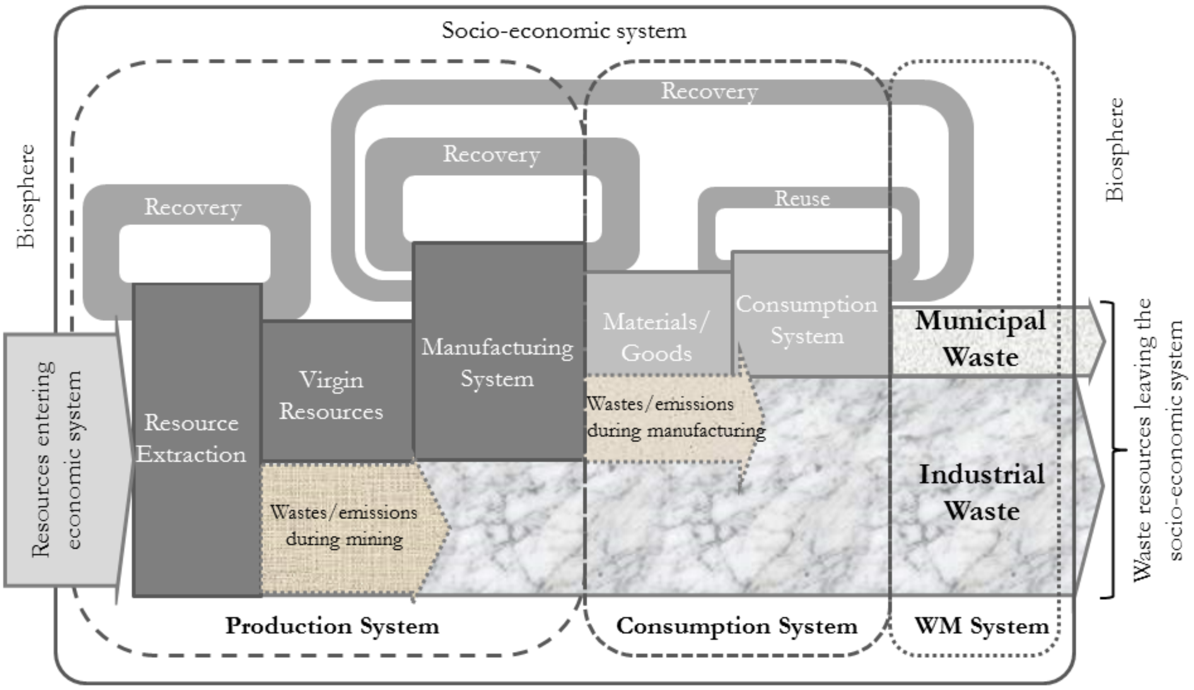


Figure 4.1 Wastes in our society –liquid, gaseous and solid emissions/wastes generation during the extraction, production, consumption and final disposal phases.

Table 4.1 indicates the amounts of wastes generated from different sources – extraction, production and consumption. Indeed, the wastes from mining and production activities are much higher in mass as compared to wastes leaving the consumption system for example in the form of discarded products. Hence, the municipal waste streams which are the most '*visible*' waste streams on the social agenda merely represent '*the tip of the iceberg*' of total waste generation.

Table 4.1 Estimated global waste generation and collection in the year 2006 (in billion tonnes). Adapted from Chalmin and Gaillochet (2009).

Waste Amount (in billion tonnes)	Generated	Collected
Mining, electricity and water industry (non-hazardous) [4]	6.4	n.d.
Manufacturing industry (non-hazardous)	1.2 to 1.67	1.2
Manufacturing industry (hazardous)	0.490	0.3
World total municipal solid waste (MSW)	1.7 to 1.9	1.24
Construction and demolition (hazardous and non-hazardous) [5]	1	n.d.

n.d. – no data available. Source: (Chalmin and Gaillochet, 2009)

4.1.2 Global WM System Status: Development Drivers and Current Situation

Wilson (2007) identifies various drivers for progress in municipal WM such as the need for (1) improved public health, (2) improved environment protection, (3) improved resource efficiency, (4) combating climate change, (5) improved institutional capacity and (6) increased public awareness and participation. Nonetheless, throughout the world, there are considerable variations in what are perceived as important drivers for WM.

Consequently, the WM system situation is highly different throughout the world. The differences can be recognised within a region as well as a country due to factors such as, *inter alia*, the socio-economic situation. In low- and middle-income countries, there is a lack of adequate financial resources, well-organised institutions and infrastructure for municipal WM operations as compared to high-income countries. Landfill is the most commonly used waste handling method globally (cf. Figure 4.2).

[4] Waste produced in a selection of countries. For more information see: CHALMIN, P. & GAILLOCHET, C. 2009. *From Waste to Resource - World Waste Survey 2009,* Paris, France, Economica Editions.

[5] Waste produced in a selection of countries. For more information see: ibid.

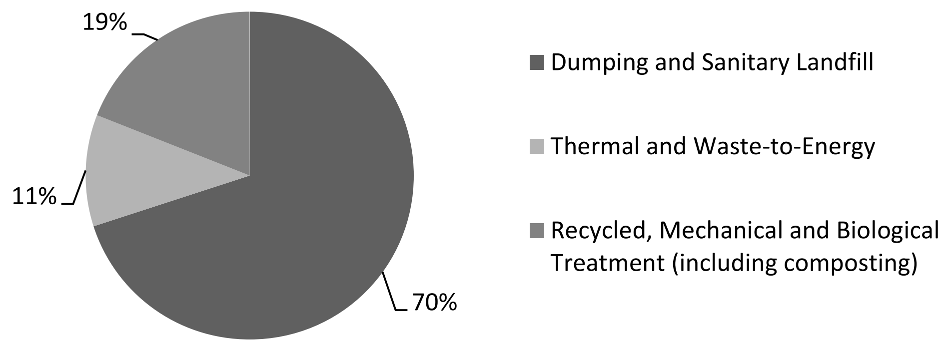


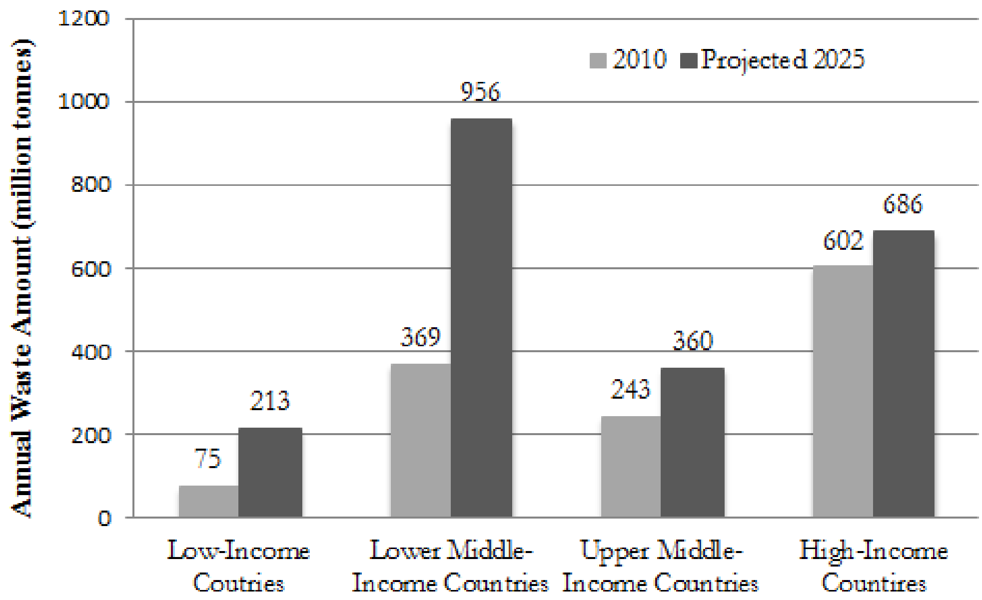
Figure 4.2 Status of global MSW management. Out of the total annual amount of waste generated worldwide in 2006 (municipal, industrial and hazardous), MSW was 1.7-1.9 billion tonnes and most of it was driven to dumpsites and sanitary landfills worldwide. Data source: Chalmin and Gaillochet (2009)

Industrial waste[6] generation and composition depend upon various factors such as the degree of industrialisation and type of industrial setup in the country. Industrial waste generation rates are largely unknown due to incomplete, heterogeneous and uncertain available data (Chalmin and Gaillochet, 2009, World Bank, 2012). Mining activities, to supply raw materials for energy generation and goods manufacturing, produce tremendous amounts of wastes, often non-hazardous (c.f. Table 4.1). However, ecological damage due to the rucksack and release of these wastes into the environment cannot be undermined.

Municipal Solid Waste (MSW) collection and treatment has been considered an important aspect of improving public health around the world. MSW generation is affected by different factors such as population, socioeconomic development index (HDI) and the income level (GNI per capita)(Wilson, 2007, Wilson et al., 2012). Generally, the greater the economic prosperity, the greater the amount of waste produced. Figure 4.3 shows the urban MSW amounts in low-, middle and high-income countries[7]. In high-income countries the MSW growth has stabilised (cf. Figure 4.3); however, waste amounts are still increasing albeit at a very low rate. Indeed, in these countries, per capita waste (kg/capita/day) generated is already very high as compared to low- and middle-income countries (Figure 4.3).

[6] In this thesis, industrial wastes refer to the combined wastes from mining and manufacturing activities.

[7] Classification of the countries is based on income levels: Low-income countries (<US$876), middle-income countries (lower-middle and upper-middle income countries are combined together for comparison purposes) (876≤US$≤10,725), High-income countries (>US$10,725).



Urban Population (millions)	343	676	1296	2080	572	619	774	912
Waste (kg/capita/day)	0.6	0.86	0.78	1.3	1.16	1.6	2.13	2.1

Figure 4.3 Estimated[8] annual MSW generation in the year 2010 and 2025 in different countries based on economic development and urban population. Classification of the countries is based on the World Bank classification based on per capita income levels. Data sources: The World Bank (2012)

Rapidly growing waste amounts (MSW and industrial) in low- and middle-income countries can be ascribed to fast economic development and increasing population and urbanisation in these countries. However, the increasing industrial waste generation rates in low- and middle-income countries can largely be ascribed to consumption in the high-income, high imports countries. For instance, Figure 4.4 shows the increasing trend in imports[9] by the 27 EU-member countries from the year 2001 to 2012. This implies that the extraction/manufacturing wastes associated with the production of these imported goods/materials have been produced outside the EU-27 states. Therefore, these nations account only for the wastes due to the use and final disposal of imported resources and outsource a significant amount of their waste generation (Bartelmus, 2003).

[8] The values for the year 2010 are the current estimated values based on the data collected and assumed for major cities in the countries and the values for the year 2025 are extrapolated with appropriate assumptions regarding economic growth and waste generation rates. For more information see: WORLD BANK 2012. WHAT A WASTE: A Global Review of Solid Waste Management. *In:* UNIT, U. D. L. G. (ed.). Washington, D.C.: The World Bank.

[9] The total imports includes total billions worth of food, drinks, tobacco; raw materials; minerals fuels, lubricants and related materials; chemicals and related materials; machinery and transport equipment; other manufactured goods; and commodities and transections not classified elsewhere in Standard International Trade Classification. However, the imports from developing world includes food, drinks, tobacco; raw materials; minerals fuels, lubricants and related materials; and manufacturing goods. For more information, please see EUROSTAT. 2013. Available: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database [Accessed 20 September 2013].

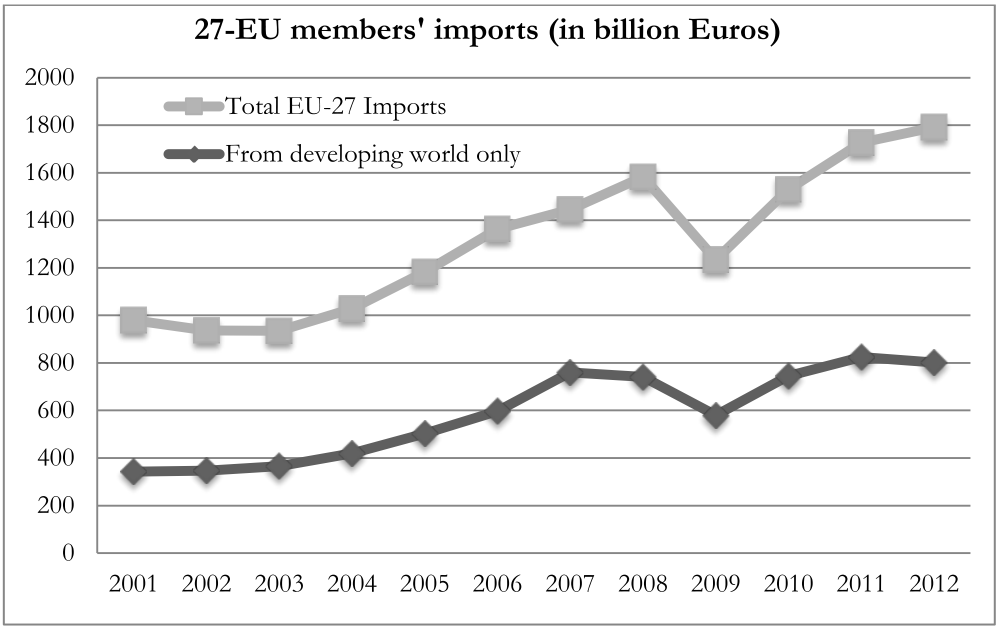


Figure 4.4 EU-27 imports and the imports from developing world only during the year 2001-2012. The values are in billions Euro worth of import (cost, insurance and freight). Data Source: Eurostat (2013)

4.1.3 Contribution to the Aim of the Thesis

The literature survey and group brainstorming sessions used to collect and analyse information on the status of current global WM, provided useful information to help answer the second research question. At first glance the study indicates that the WM problems are more serious in the developing countries, largely due to the increasing waste generation rates and relatively under-developed infrastructure in the developing countries[10] as compared to high-income countries. However, I argue that despite being well equipped with financial resources, well-organised institutions and intellectual resources, the overall seriousness of existing WM issues is with the high-income countries, due to their level of consumption. Therefore, the implementation of similar WM approaches in the developing countries may not be sufficient to solve the waste issues. In addition to this, increasing globalisation has stimulated production activities in the developing countries; therefore, the increasing waste generation in these countries is largely due to the high consumption in high-income countries. Thus, the overall global WM situation is on an unsustainable trajectory.

4.2 Challenges to Current Resource Management in Our Society

This subsection gives an overview of current resource flow dynamics and challenges to current resource management in our society (Paper 1, 2 and 3).

4.2.1 Inextricable Link between Resource Consumption, Economic Growth and Waste Generation

The role of socio-economic factors cannot be ignored when considering levels of consumption and disposal of resources. Complex consumer behaviour is shaped by social norms, cultural traditions, advertisements and habits; and business models relying heavily on selling goods are

[10] Here, developing countries refer to the low- and middle-income countries.

important drivers for resource consumption (Oksana and Kate, 2013). Increasing amounts of waste throughout world economies show an inextricable link between economic growth and resource consumption (Paper 1 and 2). This could be explained by the consumption rebound effect and the engine of economic growth (Figure 4.5). The reinforcing feedback loops of the cycle of innovation and 'creative destruction', and the consumption rebound effect feeding the engine of economic growth stimulates material consumption (Paper 2). The innovation refers to incremental gains in efficiency through product design which lead to a 'rebound effect' (Polimeni et al., 2008); and creative destruction refers to planned obsolescence and perceived obsolescence (Leonard, 2010, Guiltinan, 2009, Chapman, 2009). From a long-term perspective, product design requires developing innovative solutions to real world problems such as resource scarcity and pollution.

The micro-level gains through incremental improvements in material and energy efficiencies at product-level gives rise to macro-level losses such as negative externalities and economic inequalities (see Figure 4.5). The negative externalities due to wastes/pollution and economic inequalities lead to adverse environmental and social impacts spanning local to global scales (illustrated in Paper 2). From a long-term sustainability perspective, this presents a vital challenge to current resource management.

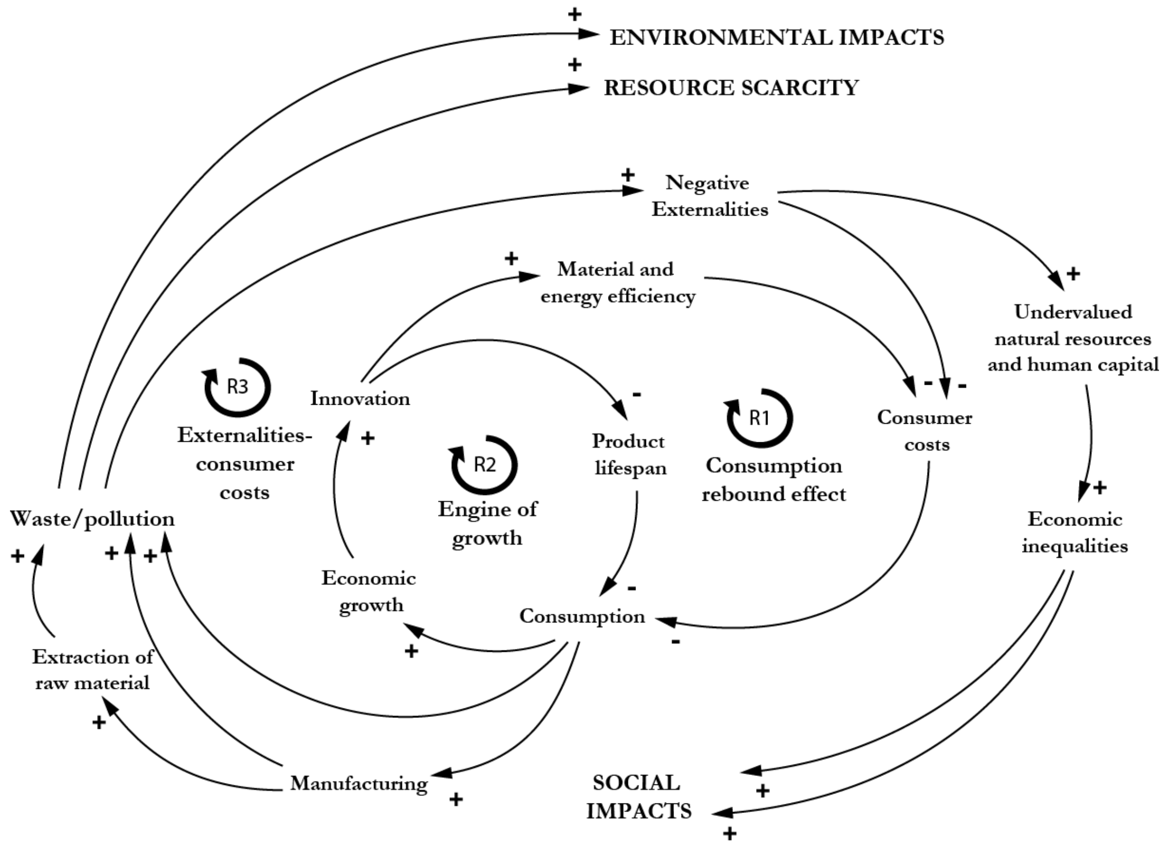


Figure 4.5 Illustration of reinforcing feedback loops: Engine of Growth (R2), the Consumption Rebound Effect (R1), and Externalities-Consumer Costs (R3). Here innovation refers to both incremental gains in efficiency as well as creative destruction (Paper 2).

4.2.2 Lack of a Systems-Oriented Approach

Several approaches have been suggested to improve resource management and achieve the optimal environmental, economic and social goals. At the organisational level, these approaches include technological improvements, design for environment and cleaner production. Inter-organisational synergies to minimise energy requirements and use industrial wastes as inputs include initiatives such as eco-industrial parks and industrial symbiosis. However, the driving factors behind most of these approaches have been to obtain financial gains (Tudor et al., 2007) rather than a systems oriented solution to the waste problems. Similarly, efforts such as cleaner production and design for environment focus only on a particular product or system. With respect to the issue of the resource scarcity, it should encompass a wide brief, rather than being focused primarily on a particular waste stream, product or system.

Over the next 20 years, middle-class consumers in the developing countries likely to rise by 3 billion which will put a strain on natural resources. Therefore, despite gains in material and energy efficiencies, the global demand for resources will continue to increase in the coming decades. Resource scarcity has been an important driver to accelerate technological innovation through, for example, improved material and energy efficiencies. However, the forthcoming challenges are not technological in nature. It is becoming increasingly evident that the technological developments alone have not been proven successful in providing a sustainable solution to resource management issues. Thus, in future, there is a need to approach these issues from a broader perspective.

In the midst of resource scarcity and environmental degradation, new societal-material relations such as extended producer responsibility (EPR) and product stewardship have emerged. These concepts aim to move materially intensive economies from a linear consumption model to a circular one. However, these concepts do not take into consideration wider system attributes such as the dimension of property and the role of the consumers acting at the meso-scale of households and neighbourhoods (Lane and Watson, 2012).

4.2.3 Lack of Recognition of Various Scales and Levels

Resource management encompasses numerous aspects - technical, economic, environmental and social - actors, and complex driving mechanisms. Current resource management efforts have failed to recognise this broad set of variables; many factors responsible for practical implementation and performance of various innovations for resource management have not been fully addressed yet (Paper 3). Consequently, often, policy interventions face failures during their implementation stages due to, for example, economic reasons or competition with existing approaches. Hence, policy decisions fail to achieve intended goals.

For instance, the EPR concept has been introduced to strengthen product development processes, in particular design for environment, in companies and to achieve much needed resource recovery (Walls, 2006). However, EPR systems do not fully internalise external costs of WM and therefore, reduce the incentives for waste prevention and green product design (Dubois, 2012). Studies have shown that EPR is unlikely to drive eco-design at least in the short-run where; (1) product prices are inelastic and the effects of the EPR equal for all producers

(Gottberg et al., 2006, Walls, 2006); and (2) in cases where, such innovations harm companies economically, "*green technology loses and profitability wins"* (Vesilind et al., 2007).

Further, the concept of EPR seems to blame companies for some environmental problems such as pollution and at the same time fails to recognise the role of consumers who demand products with certain features which may cause these environmental problems (Wiesmeth and Häckl, 2011). Successful implementation and performance of such policy decisions requires consideration of various important variables for example, economic incentives for companies and values and preferences of consumers.

Thus, there is a need to understand various factors that shape consumption – socio-economic, technological innovation and business models (Oksana and Kate, 2013). This demands a careful observation of economic principles and technological innovations during the design phase of incentive-compatible EPR policies (Wiesmeth and Häckl, 2011). Effective implementation of the central idea of EPR through the transition of global waste regimes still focus on safe disposal, aiming towards sustainable resource management throughout the product's lifecycle chain (Wilts et al., 2011).

Another important challenge is to spread awareness among citizens on how individual-level consumption and disposal behaviour gives rise to global-level environmental pressures and impacts. Studies have shown a strong concern among people for a clean environment and the belief that learning, information and awareness campaigns are important drivers to behavioral change (Mbeng et al., 2009). However, this does not necessarily translate into an increased participation in recycling or reuse initiatives. In high-income countries, people consider the disposal of waste as a significant environmental concern, but it is not an issue at the forefront of their minds; consequently, there is often a poor public participation in WM (MORI, 2002). Therefore, apart from studying consumers' awareness and behaviour towards environmental issues, there is a need to explore the root causes for the mismatch between consumers' attitudes and behaviour. This is particularly important in the area of policy making and environmental education.

4.2.4 Increasing Complexity of Product Composition and Variety in the Production and Consumption Systems

Waste materials discarded to the WM systems have increased tremendously in numbers and variety and are likely to increase further. This has led to increasing challenges for WM systems to handle this increasing waste complexity (UNEP, 2011). Even the countries with a relatively developed infrastructure for WM face challenges to manage wastes sustainably due to, for example, (1) products which are not suitable for recycling and (2) unsatisfactory waste sorting.

Another important issue to consider is the extensive transformation of the resources in the production and consumption systems. The resources undergo several transformations from 'cradle to grave' (illustrated in fig. 4.6). These transformations result in changes in the physical, chemical and biological properties of the materials, which reduce the potential utility of these resources (Gößling-Reisemann, 2011). The production and consumption systems dilute such resources to a critically low level; this makes the choice of WM options highly restricted due to economic, technological and environmental constraints.

A vital challenge for the current resource management paradigm is to understand the resource consumption as a loss of potential utility and equally a range of possible uses of these resources in the future (Gößling-Reisemann, 2011). Therefore, there is a need to study the resource quality, from a thermodynamics perspective, along with the resource quantity throughout the resource supply chain.

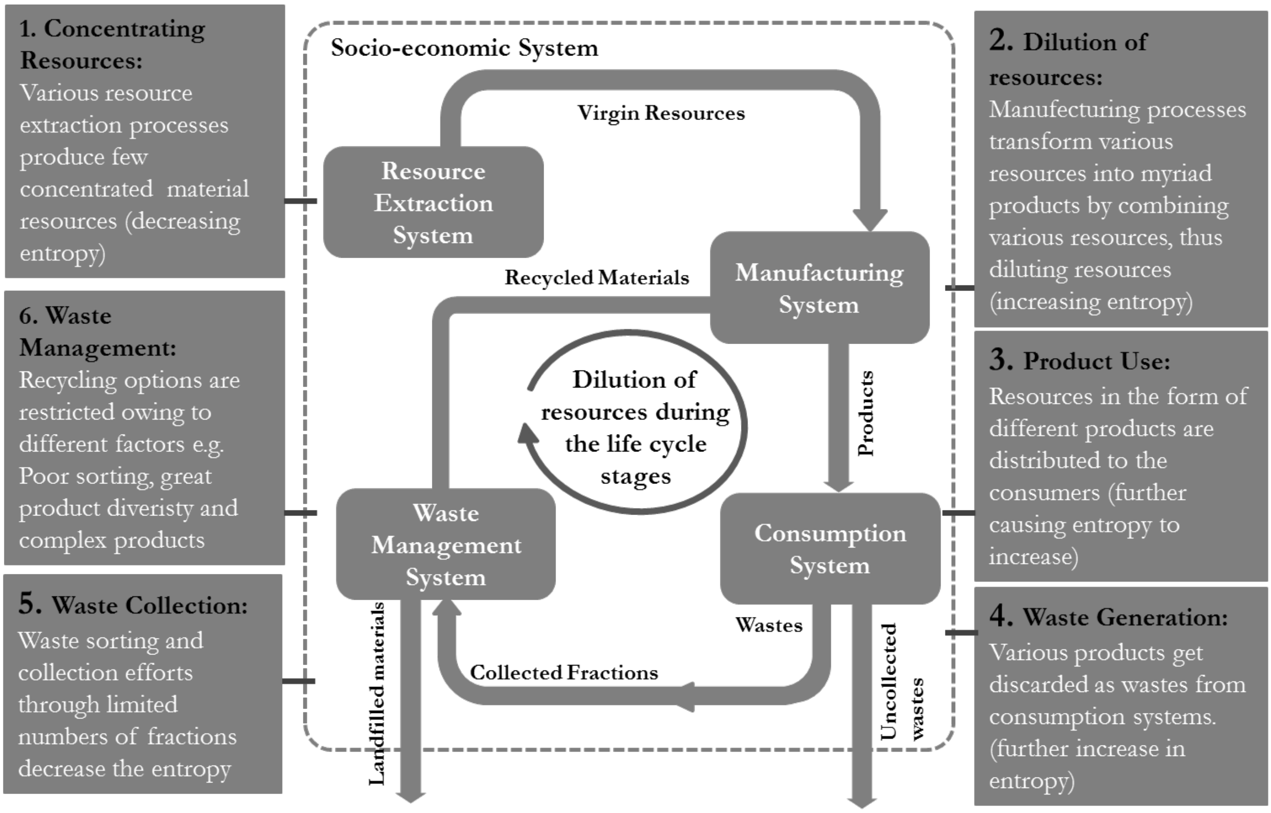


Figure 4.6 Illustration of dilution of resources through different lifecycle stages (Paper 1).

4.2.5 Contribution to the Aim of the Thesis

The findings from this research question provided an overview of various challenges to global resource management. The literature survey and group brainstorming sessions helped identify various sustainability issues related to the current product design paradigm and the limitations of current waste/resource management practices. Causal loop diagrams have been developed to illustrate different sustainability issues related to current product design practices. Based on the findings, I argue that current resource management efforts have failed to recognise a broad set of variables, which influence the practical implementation and performance of various innovations in the area of resource management.

Furthermore, the group brainstorming sessions provided a theoretical background for the relevant systems and transformations needed to address different challenges as discussed in this subsection. This has facilitated the development of a broader systems approach to waste/resource management and a sustainability-driven systems-oriented design framework.

4.3 A Broader Systems Approach to Waste/Resource Management

A broader systems approach to resource management has been proposed, based on an assumed necessary transition from a linear to a circular model of resource consumption. The approach adopts a viewpoint from a sustainability science (Kates et al., 2001) research heuristic which suggests recognising broad system level interactions. The approach suggests identifying various actors, sub-systems and casual mechanisms in the broader system of design, production, consumption and WM with information on economic, technological, political, and environmental aspects (as illustrated in Figure 4.7). This allows a holistic view of the unified system of resource metabolism in the society. The main objectives of the approach can be summarised as follows:

1. Reduction of residues/wastes/emissions throughout the system of production and consumption and WM.
2. Maintaining resource quality throughout the life-cycle of the resource.
3. A world-wide shared vision among businesses and society.

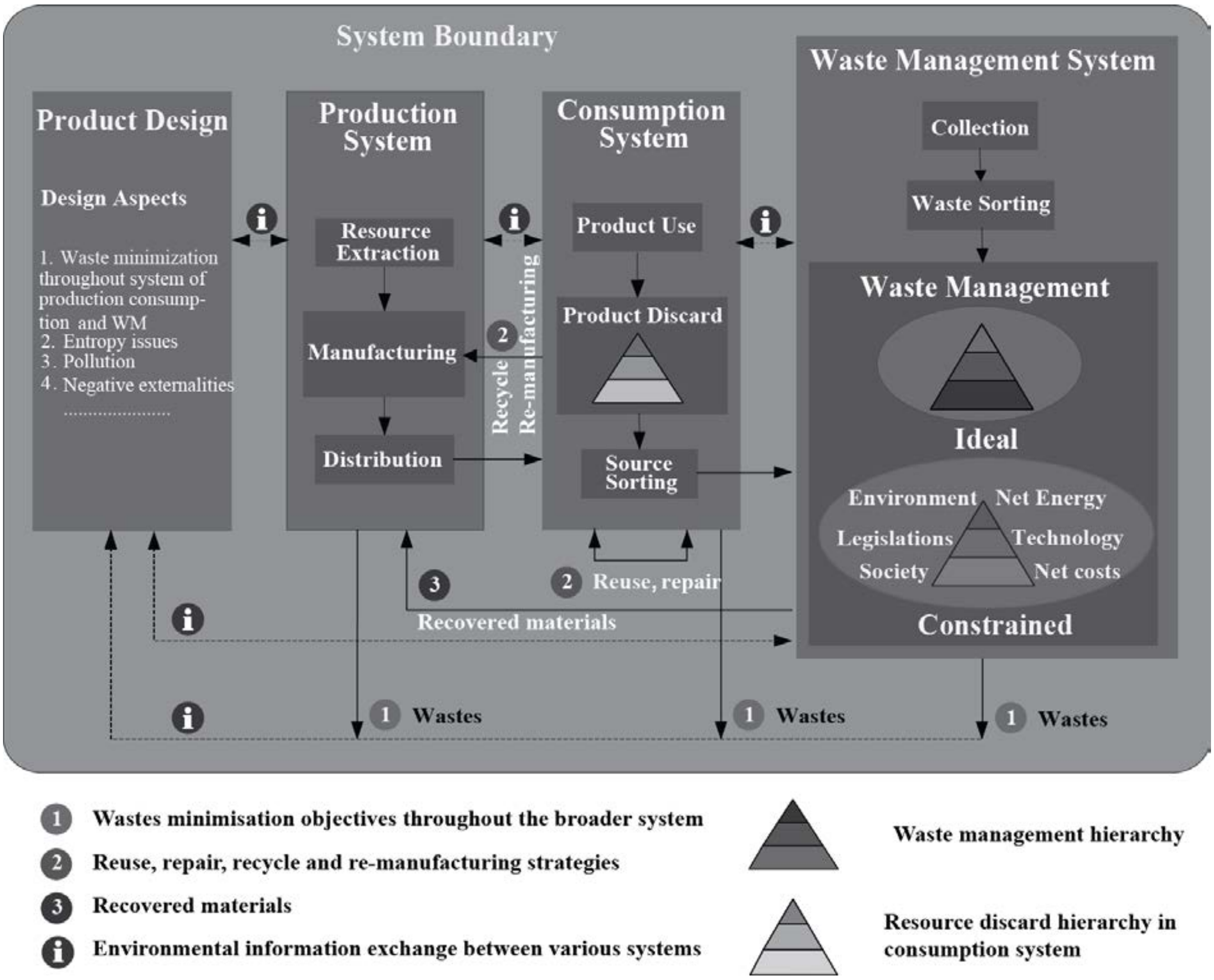


Figure 4.7 System interactions, processes and information flow in a broader design, production, consumption and WM system. The resource discard hierarchy in the consumption system refers to the hierarchical decisions of repair, reuse, re-manufacturing and disposal of products/resources, whereas, the WM hierarchy refers to waste treatment options in the WM system. The product design system incorporates environmental aspects throughout the lifecycle chain of a product along with other design aspects (Paper 3).

The recovery operations of the 'discarded' resources from the consumption systems take place within economic, environmental and thermodynamic constraints such as net energy and costs. Often, the resources reach a state of negative economic value due to the costs associated with its removal and treatment. To minimise the waste discarded to the WM system, the inner cycles of reuse, repair and remanufacturing should be strengthened. This could be achieved by improving the reverse logistic (Pokharel and Mutha, 2009) of discarded resources from the consumption system to the production systems. This would foster 'on-site' recycling and reuse of resources (El-Haggar, 2007) and hence preserve the resource quality throughout the value chain.

4.3.1 Sustainability-Driven Systems-Oriented Design Framework

The product design phase decides most of the environmental characteristics of a particular product system. With this in mind, a conceptual framework - Sustainability-Driven Systems-Oriented Design - was proposed to work within broader system boundaries in the design process (Figure 4.8). This framework aims at addressing possible effects that micro-level gains could have on macro-level losses; and how the issues regarding maintaining the resource quality throughout the production and consumption systems can be addressed during the product design phase. It further aims to offer a system-level perspective to the design process in order to identify undesirable consequences of design choices and define appropriate countermeasures.

The framework suggests incorporating sustainability aspects into the design process (Sevaldson et al., 2010) by combining Systems-Oriented Design with additional sustainability aspects through GIGA-mapping technique. The GIGA-mapping[11] is a generative diagramming technique used to generate a holistic picture of the landscape wherein the design project is embedded. GIGA-mapping can interlink a multitude of information ranging from economic, technological, political, environmental, cultural, user centric perspectives to issues of sustainability. Therefore, it considers much more information than might initially thought to be relevant. At a later stage in the design process, one '*shrinks*' the system boundary in an informed manner to ensure factors that might be crucial to the design project are included.

[11] GIGA-mapping is super extensive mapping across multiple layers and scales, investigating relationships between seemingly separated categories and so implementing boundary critique to the conception and framing of systems. More information on http://www.systemsorienteddesign.net/index.php/giga-mapping/giga-mapping-information

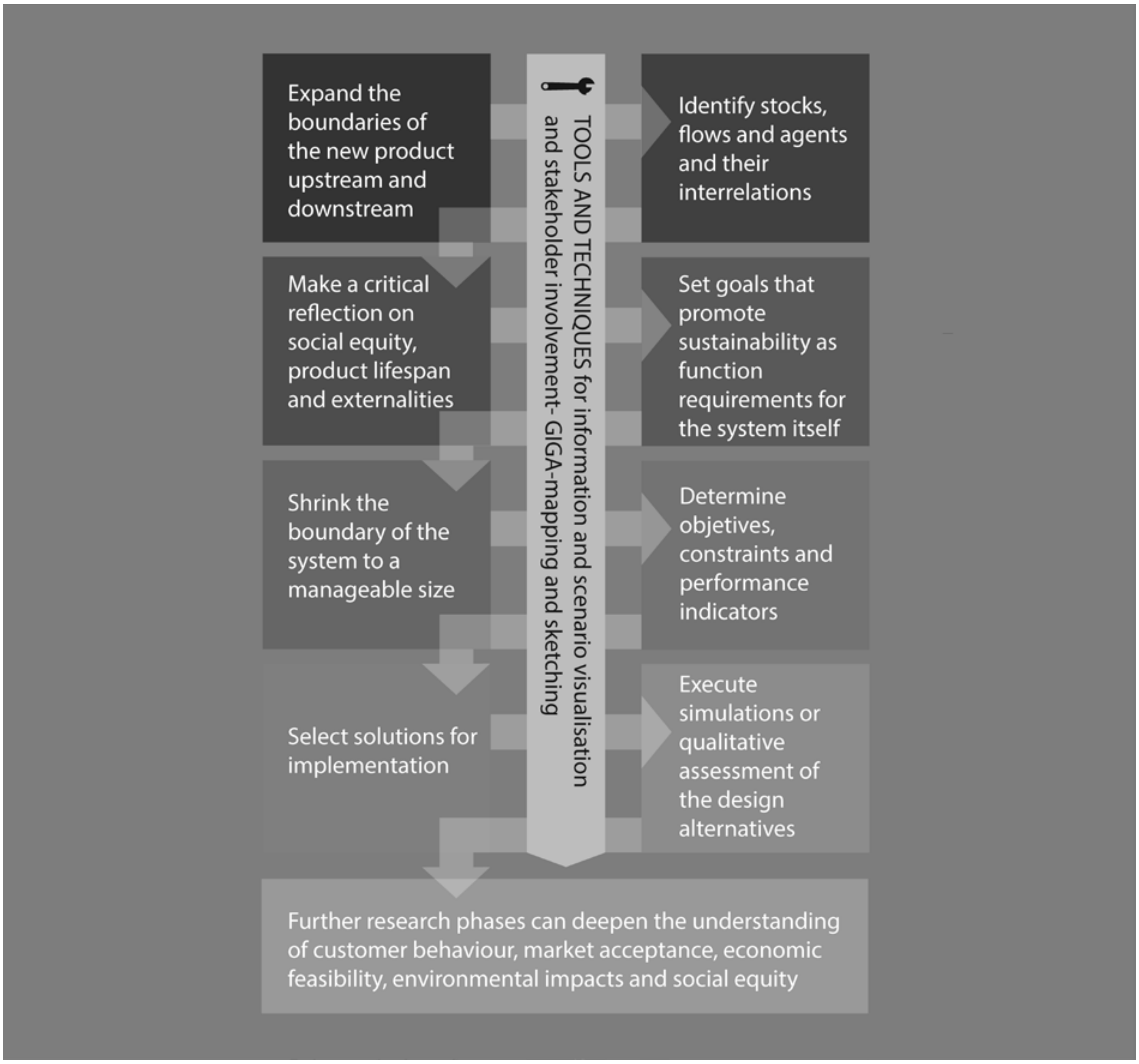


Figure 4.8 Framework for Sustainability-Driven Systems-Oriented Design (Paper 2).

4.3.2 Contribution to the Aim of the Thesis

The literature survey followed by group brainstorming sessions on various concepts - systems thinking, sustainability science and life cycle thinking - applied to resource management, assisted in the development of a broader systems approach to waste/resource management and the Framework for Sustainability-Driven Systems-Oriented Design as discussed in this subsection. Application of these concepts to waste management suggested the inclusion of upstream activities of production and consumption to address important aspects of waste issues. The conceptual framework to facilitate the inclusion of potentially unintended consequences during the process of product design was developed.

4.4 Essential Changes Needed for a Transition Towards a More Sustainable Resource Management

This subsection discusses essential changes needed in order to address the barriers and limitations to a systems-oriented management of physical resources including design, production, consumption and waste management.

4.4.1 Need to Recognise Diverse System-Level Perspectives

The objectives of a sustainable production and consumption system cannot be realised without cooperation/participation among all actors from businesses to society. Therefore, this transition should not only be limited to manufacturing companies, recycling firms or municipalities, but should include all parts of society. The business solutions should focus on creating shared values to meet the dual aims of enhancing competitiveness of businesses while simultaneously advancing economic and social conditions. This would also help in addressing several socio-political issues related to resource management.

Furthermore, the connectedness of the current human activity system requires this cooperation to happen at all the levels - local, regional, national and global levels. In today's globalised economic operations, production, consumption and WM centres are often situated in different countries. Since the impacts from these activities can be more visible and severe in the country of, for instance, resource extraction this could make other countries in the supply chain less responsive to the issue. Therefore, it can limit the institutions understanding of the problem. Thus, an international awareness of the problem is required to address issues at all levels. Sustainable resource management objectives cannot be achieved without a global approach to the problem. This demands efforts also at regional and global levels, which may require major changes outside the core system, for example, changes in product design.

Due to a wide range of institutions in the broader system, it becomes necessary to explicitly mention the levels at which various causal interactions occur in order to explore institutional reach and their roles in addressing the problem. Figure 4.9 illustrates a hierarchical understanding of the resource flow system with the end-of-life WM system lowest in the hierarchy of the system. This helps to recognise the critical areas to intervene in the system and further to understand how larger-scale decision making works, or fails to work, with individual actions on a particular level.

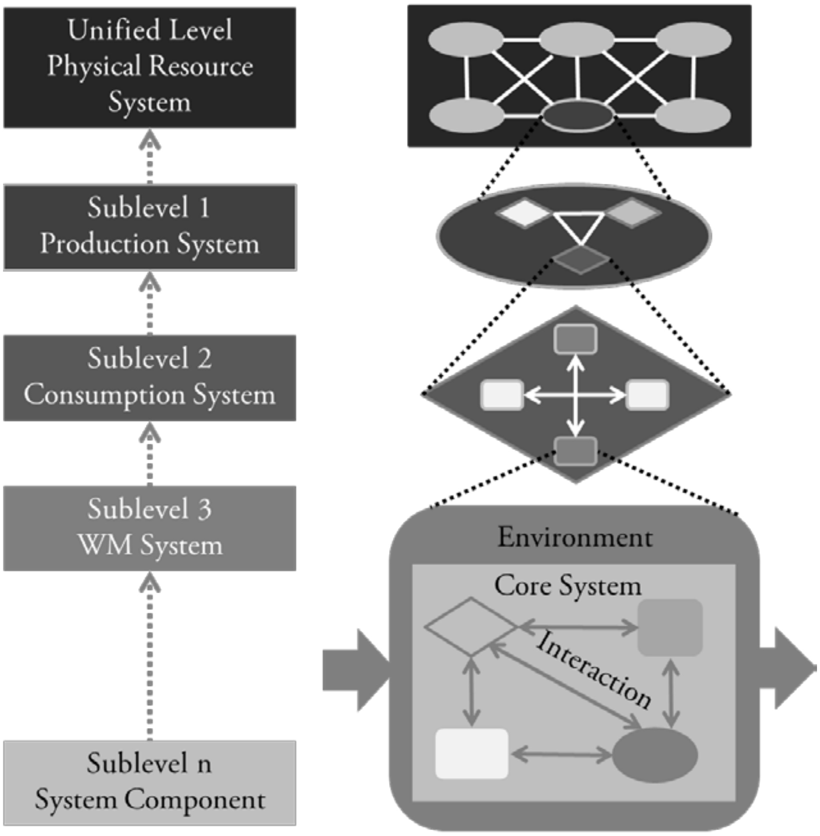


Figure 4.9 Schematic illustrations of thinking in a hierarchy of resource systems, sub-system component at sublevel n can be actors such as consumers who participate in waste sorting (Paper 3).

The approach suggests the DPSIR framework to identify various causal linear chains at each system level to understand different driving mechanisms at that particular level. This will serve as a heuristic device to facilitate engagement, communication and understanding between different stakeholders with different agendas in the system. This can help in summarising the complex interactions into an overall simpler picture at a particular level. The DPSIR scheme can act as a comprehensive representation of focused areas, allowing decision makers to step-wise trace fundamental problem drivers through actual impacts at the landscape level, and explore where appropriate responses can be directed (Ness et al., 2010).

Historically, resource management issues have been approached in a sectorial and compartmentalised way, aiming at fulfilling short-term goals by implementing 'end-of-pipe' solutions. Little attention has been paid to address the main causes of the problem. In the broader system, ideally, various responses for resource management should be directed to a range of areas as illustrated in Figure 4.10. The long-term solutions to the problem should aim at addressing the main drivers of the problem. However, the problem areas requiring urgent action should be dealt with by employing *quick fixes* to problem impacts and states, for instance, improving landfill technologies in the countries where open dumping is the main waste treatment method.

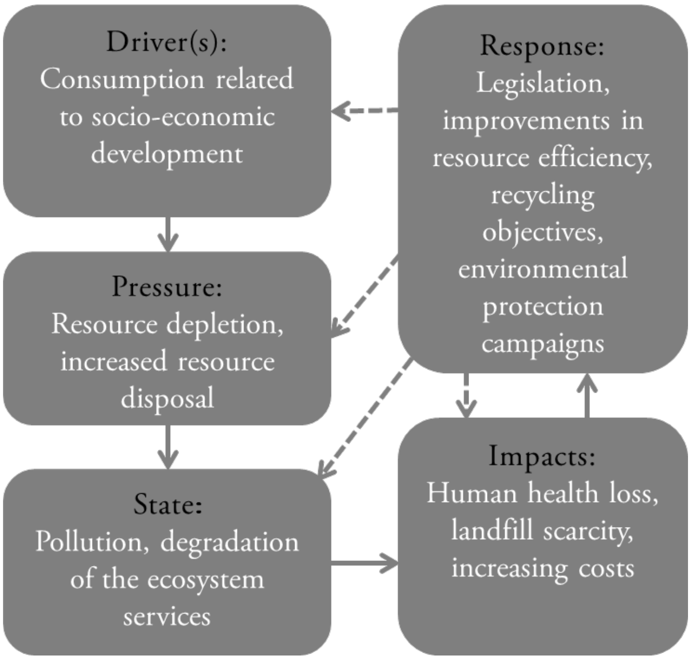


Figure 4.10 The DPSIR framework for a broader systems approach to resource management where a variety of responses are directed to the different DPSI phases. Adapted from European Environmental Agency (1999)

The proposed approach requires a high degree of cooperation amongst a broad range of actors in the system. In order to engage various actors in the system towards this goal, a rationale based on their mutual interests must be established. Guiding broad system level interventions requires clearly defined systems' objectives such as waste minimisation, resource use efficiency and resource quality, as well as the roles and responsibilities of various actors and institutions. Various critical system dynamics (systems interactions, processes, stocks, stakeholders) should then be identified and strengthened.

4.4.2. Required Changes in the Broad System

Dematerialising the global economies requires fundamental structural, procedural and attitudinal changes (Steinberger et al., 2010, Checkland, 2000). Structural changes refer to changes in organisational groupings, reporting structures or the structure of functional responsibility, changes in those parts of the real world which in the short-term do not change (Checkland, 2000). Procedural changes are the changes to dynamic elements such as the process of reporting and informing and all the activities being carried out within static structures. Attitudinal changes, apart from individual and collective behaviours, also include changes in influence and changes in expectations from various roles (Checkland, 2000).

From a systems perspective, the types of changes described above can be targeted to have improvements in the existing system structures as well as innovations in the proposed broader system. The need to develop innovative business models for circular economy is highlighted. Several concepts for circular economy such as cradle to cradle; performance economy and industrial ecology can be helpful in guiding interventions in the broader system. The cradle to cradle concept (McDonough and Braungart, 2002) considers all the materials in the industrial and commercial processes to be of two types – biological nutrients and technical nutrients, with their optimum reuse, re-manufacturing, recycling and final treatment with least environmental impacts. The performance economy (Stahel, 2010) focuses on enhancing socio-economic performance by creating more jobs (by replacing energy by man power), economic competitiveness, resource savings (by selling service rather than products) and waste prevention. Industrial ecology adopts a systemic view to design industrial processes aiming to create closed-loop material flows. These concepts can be employed in addressing resource management challenges at various spatial levels in the broader system. For instance, the industrial ecology concept can be applied to optimise material flows in a regional industrial system. The cradle to cradle and performance economy concepts can be used to redefine the current business models based on material consumption. Life cycle thinking and systems thinking can be utilised to identify the changes required in the existing systems; and to develop new systems such as product-service systems and new product-ownership models.

Nonetheless, the choice of structural changes could vary for low- and middle-income and high-income countries. There is a need to foresee if the implementation of similar solutions in the low- and middle-income countries would solve upcoming issues. There are great opportunities for product-service systems, repair and reuse in these countries. The existing institutional structures in the high-income countries should be assigned with new functional responsibilities in order to successfully implement these changes. The envisaged changes should be systemically desirable and culturally feasible.

This requires a better understanding of the whole system of production and consumption. This necessitates the establishment of improved life cycle based databases reflecting the current status of the system in order to engage various actors in a debate for change. Therefore, before initiating any interventions, there is a need to improve the current database on resource use and wastes produced and their environmental, social and economic impacts and how these aspects are interlinked in a broader system.

The international databases fail to provide a real picture of the current situation due to unavailability of real data. For example, data availability of industrial waste is scarce, especially, in low- and middle-income countries (Chalmin and Gaillochet, 2009). Furthermore, different variables/terminologies are used for data collection/estimation for international databases, such as The World Bank and Eurostat. This reduces the utilisation of available international databases when the comparisons have to be made at certain levels. For instance, the classification of wastes is different in various countries; therefore, even if the waste generation data is available, it can't be used for any analysis purposes. Therefore, further research is needed to guide the current data collection methods. This calls for a new structured approach to data collection with shared terminologies globally. The database must be developed at all levels – municipal, local, regional, national and global – and for all resource flows in the human activity system. This could be achieved through a mutual understanding of the need for such a database for resource management in the future.

Finally, the proposed approach emphasises the need for clearly defined systems' objectives which further requires shared worldviews on the dynamic link between social, economic, ecological and technical subsystems. This appears to be an unachievable objective due to the existing demographic, institutional, operational and economic differences at all levels. However, there are examples of successful global system-level interventions such as the Montreal Protocol, where different communities have shown a great level of cooperation to achieve a shared goal to prevent ozone depletion (United Nations Environment Program, 2007).

4.4.3 Contribution to the Aim of the Thesis

The research question regarding a broader systems approach to waste/resource management and barriers and limitations to such an approach resulted in interesting discussions that contributed to the main aim of the thesis. I argue that the aim of dematerialising world economies is not possible without recognising and engaging global interactions towards a common aligned goal. The DPSIR framework was suggested to engage various actors in the system towards this goal. In particular, the need for improved databases was emphasised as a perquisite for such a broad system-level change.

4.5. Limitations and Future Work

The main aim of this thesis was to discuss the resource management issues at a global level. The thesis encompasses a broad range of aspects and discusses various issues at a very general level; however, the thesis lacks detail in some areas as has been noted by the author. The thesis does not provide in-depth analysis of several of the aspects discussed. However, to present an overview scenario of the current status of global resource management, it was necessary to limit the inclusion of more detailed analysis. Key ideas have not been implemented and verified on an actual case. The vital task of implementing the proposed approach is beyond the scope of this work. This outstanding task can guide future research work in this area. The SSM employed to carry out this broad task can be scaled down to investigate specific issues. In-depth case studies could be used to gain more qualitative as well quantitative information for a particular product life-cycle chain. The impacts of gradually broadening the system boundaries can be useful to further validate research findings.

5. Conclusions

The main purpose of this thesis was to study the global waste management system as part of a larger design, production, and consumption system. The study has been carried out by using soft systems methodology. Corresponding to the objectives of the thesis, the main conclusions are listed below:

1. *What is the status of the current waste management system in a global perspective?*

   The study indicated that currently the most serious WM issues fall within the high-income countries, primarily due to their level of consumption; and increasing globalisation has stimulated production activities in the developing countries. This leads to the conclusion that the current global WM system is on an unsustainable trajectory.

2. *What are the sustainability challenges to the current global resource management system?*

   In a long-term sustainability perspective, current resource management efforts do not recognise various institutional, social and political factors. The current product design paradigm needs to consider a set of broad system-level interactions. The increasing complexity of product composition and variety in the production and consumption system is a vital challenge to the current resource management system.

3. *How could a broader systems approach be employed to address the challenges to the current resource management system?*

   The thesis proposed a broader systems approach to resource management and a conceptual framework for Sustainability-Driven Systems-Oriented Design was proposed to address sustainability challenges facing current resource management.

4. *How could the barriers and limitations to a systems-oriented management of physical resources including, design, production, consumption and waste management be addressed?*

   The concept of systems thinking has been utilised to illustrate the need to recognise the multitude of perspectives, cross-scale dynamics and actors' interactions in a broader system to address the barriers and limitations to a systems-oriented management of physical resources in society. As a first step towards a long-term physical resource management system, a need to broaden the system boundary to design, production, consumption and WM was emphasised. In particular, the need for improved statistics on resource use and wastes has been highlighted for better management of natural resources.

6. References

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