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Bhawana Pathak
R.K. Kale *Editors*

Environment and Sustainable Development

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ISBN 978-81-322-1165-5 ISBN 978-81-322-1166-2 (eBook)
DOI 10.1007/978-81-322-1166-2
Springer New Delhi Heidelberg New York Dordrecht London

Library of Congress Control Number: 2013943261

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Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

About the Book

Global society in the 21st century is facing challenges of improving the quality of air, water, soil and the environment and maintaining the ecological balance. Environmental pollution, thus, has become a major global concern. The modern growth of industrialization, urbanization, modern agricultural development and energy generation has resulted in the indiscriminate exploitation of natural resources for fulfilling human desires and needs, which has contributed in disturbing the ecological balance on which the quality of our environment depends.

Human beings, in the truest sense, are the product of their environment. The man-environment relationship indicates that pollution and deterioration of the environment have a social origin. The modern technological advancements in chemical processes/operations have generated new products, resulting in new pollutants in such abundant levels that they are above the self-cleaning capacity of the environment. One of the major issues in recent times is the threat to human lives due to the progressive deterioration of the environment from various sources. The impact of the pollutants on the environment will be significant when the accumulated pollutants load will exceed the carrying capacity of the receiving environment.

Sustainable development envisages the use of natural resources, such as forests, land, water and fisheries, in a sustainable manner without causing changes in our natural world. The Rio de Janeiro-Earth Summit, held in Brazil in 1992, focused on sustainable development to encourage respect and concern for the use of natural resources in a sustainable manner for the protection of the environment.

This book will be beneficial as a source of educational material to postgraduate research scholars, teachers and industrial personnel for maintaining the balance in the use of natural sources for sustainable development.

About the Editors

Dr. M.H. Fulekar is Professor and Dean at the School of Environment and Sustainable Development, Central University of Gujarat. He was also Professor and Head, University Department of Life Sciences, University of Mumbai. He has in his credit more than 150 research papers and articles published in national and international journals of repute. He is also author of 10 books. He has supervised nine Ph.D. students. He has done extensive research in the area of Environmental Sciences under the following research projects: UGC, CSIR, BRNS, DBT (R&D) and industrial consultancy projects.

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Professor R.K. Kale has been teaching at the School of Life Sciences, Jawaharlal Nehru University (JNU), New Delhi. He has published more than 120 research papers in national and international scientific journals. He supervised research work of 29 students leading to award of Ph.D. and also 6 students for M.Phil degree. His research areas include cancer and radiation biology. He has also greatly contributed to the area of higher education and society. He was awarded ICMR Prize for Biomedical Research – 1996, for his original contribution to radiation biology. He has extensive experience in University Administration and Planning; and served the JNU in various capacities including Dean of the School of Life Sciences. Presently, he is Vice-Chancellor of the Central University of Gujarat, Gandhinagar, India.

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Emergence of Green Technologies Towards Sustainable Growth

1

Tapan Chakrabarti

Abstract

Environmental technology (abbreviated as envirotech) or green technology (abbreviated as greentech) or clean technology (abbreviated as cleantech) is the application of the environmental science and green chemistry to conserve the natural environment and resources and to curb the negative impacts of human involvement. A growing wave of global environmentalism is forcing manufacturers to produce greener products through greener processes. Sustainable growth demands that market should take steps both to expand the number of green-oriented products they receive and to reduce heavy environmental footprint. For the technology industries at large, going green requires transformation along virtually every step of every value chain.

This chapter deals with the 4 principal requirements for sustainable development, 12 principles of green engineering, 5 major attributes of green technology and 9 Rs for waste minimisation and waste to wealth paradigm shift and addresses 'end-of-life' issues. Emphasis should be laid on ecosystem protection and reduction in the waste and greenhouse gas emission within the limits of the carrying capacity of the ecosystem. Under no circumstances, the biodiversity should be sacrificed in the name of development. Safety, health and environmental (SHE) issues must be given top priority in all developmental ventures so that sustainable development with environment and health security is ensured for all the time. Special emphasis is laid on adoption of environmental carrying capacity–based planning process. Policy and regulation based on scientific and economic tools (natural resource accounting, polluter pays, damage assessment, risk-based standards and remediation) are the key ingredients for sustainable consumption and development.

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M.H. Fulekar et al. (eds.), *Environment and Sustainable Development*,
DOI 10.1007/978-81-322-1166-2_1, © Springer India 2014

Keywords
Green technology • Energy efficiency • Hazardous material • Recycle material • Sustainable design

Preamble

A growing wave of global environmentalism is forcing manufacturers to produce greener products through greener processes. Sustainable growth demands that market should take steps both to expand the number of green-oriented products they receive and to reduce heavy environmental footprint. Sustainable development is the core of green environmental technologies. Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable growth is a subset of sustainable development. For the technology industries at large, going green requires transformation along virtually every step of every value chain.

Environmental technology (abbreviated as envirotech) or green technology (abbreviated as greentech) or clean technology (abbreviated as cleantech) is the application of the environmental science and green chemistry to conserve the natural environment and resources and to curb the negative impacts of human involvement. The four principal requirements for sustainable development are:

- Green demand grows.
- Green requires industry collaboration.
- Taking proactive steps towards sustainability.
- Hardware and software opportunities and support.

The 12 principles of green engineering are:

- *Inherent rather than circumstantial*
  Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
- *Prevention instead of treatment*
  It is better to prevent waste than to treat or clean up waste after it is formed.
- *Design for separation*
  Separation and purification operations should be designed to minimize energy consumption and material use.
- *Maximize efficiency*
  Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
- *Output pulled versus input pushed*
  Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
- *Conserve complexity*
  Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
- *Durability rather than immortality*
  Targeted durability, not immortality, should be a design goal.
- *Meet need, minimize excess*
  Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
- *Minimize material diversity*
  Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
- *Integrate material and energy flows*
  Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
- *Design for commercial "afterlife"*
  Products, processes, and systems should be designed for performance in a commercial "afterlife."
- *Renewable rather than depleting*
  Material and energy inputs should be renewable rather than depleting.

The 12 principles of green chemistry are:

- *Prevention*
  It is better to prevent waste than to treat or clean up waste after it has been created.
- *Atom economy*
  Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
- *Less hazardous chemical syntheses*
  Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- *Designing safer chemicals*
  Chemical products should be designed to effect their desired function while minimizing their toxicity.
- *Safer solvents and auxiliaries*
  The use of auxiliary substances (e.g., solvents, separation agents) should be made unnecessary wherever possible and innocuous when used.
- *Design for energy efficiency*
  Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
- *Use of renewable feedstocks*
  A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
- *Reduce derivatives*
  Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
- *Catalysis*
  Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- *Design for degradation*
  Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
- *Real-time analysis for pollution prevention*
  Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
- *Inherently safer chemistry for accident prevention*
  Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Attributes of Green Technology

The five major attributes of green technology are:

- Sustainability
  Meeting the needs of society in ways that can continue indefinitely into the future without damaging or depleting natural resources. In short, meeting present needs without compromising the ability of future generations to meet their own needs.
- “Cradle-to-cradle” design
  Ending the “cradle-to-grave” cycle of manufactured products, by creating products that can be fully reclaimed or reused
- Source reduction
  Reducing waste and pollution by changing patterns of production and consumption
- Waste reduction plans focus on 9Rs:
  (i) Restore
  (ii) Reduce
  (iii) Renew
  (iv) Recover
  (v) Recycle
  (vi) Reuse
  (vii) Rethink
  (viii) Replenish
  (ix) Replace
- Innovation
  Developing alternatives to technologies – whether fossil fuel or chemical intensive agriculture – that have been demonstrated to damage health and the environment
- Viability
  Creating a center of economic activity around technologies and products that benefit the en-

vironment, speeding their implementation and creating new careers that truly protect the planet

The green design and manufacturing calls for

- Pursuance of energy efficiency
- Avoidance of using and manufacturing hazardous materials
- Use of recycled materials
- Use of recyclable materials
- Designing to last
- Waste to wealth
- Packaging to meet the global packaging standards
- Addressing "end-of-life" issues

Pursuance of Energy Efficiency

The improvement in the standard of living and ever-expanding population result is high consumption of nonrenewable resources. It is estimated that 20 % of population is consuming 80 % of nonrenewable resources. To manage with limited resources, new technology is currently being researched and manufactured to reduce the consumption of nonrenewable energy. Energy consumption is divided into four classifications: the residential, commercial, industrial, and transportation sectors of the economy. Of these four categories, industry consumes the most amount of energy. By 2050, oil production throughout the world will be only half of what it is today, and, therefore, alternate sources of energy need to be discovered and implemented soon. In fact, the production of renewable energy is one of the keys to energy conservation.

There are several ways of conserving energy: the first being efficient energy use, which refers to using existing forms of energy and making it last longer. A good example of this is a car that has a higher mileage per liter of petrol/diesel/gas. Adoption of green architecture is another way of energy conservation. In transportation sector, automobiles can have more advanced tires, which decrease the friction between the road and the car; changes in motor oil formulas, which decreases the internal friction in the engine; and also breakthroughs in the aerodynamics of the vehicles. Car companies are developing new hybrid car models with better fuel efficiency and a heavier reliance on electric energy, which considerably reduces the oil consumed as fuel for a vehicle. In fact, electric cars reduce greenhouse gases emissions, decrease in air pollution, and lessen the dependence on oil. LED light bulbs supply light for televisions, computers, phones, lamps, flashlights, headlights, and other systems. Furthermore, devices are incorporating more effective power save modes. An Energy Star efficient washing machine reduces the amount of electricity and water used per wash cycle, greatly reducing the energy cost. Another vanguard of future green technology is an advancement of electrical infrastructure known as Smart Grid. Currently, the power distribution system is wasteful in its transportation of electricity to the general consumer. The term Smart Grid refers to a proposed technology where a network of information-based equipment cooperates with the already established power distribution infrastructure. With meters strategically placed to track the patterns of electrical flow, the information could be used by both the utility companies and the ultimate consumer. Utility companies could adjust the flow and distribution to be more efficient with the knowledge of where the electricity is being used. In addition, sources of other electrical energy such as solar and wind energy could be incorporated into the distribution system easily and put to use effectively. With more data to analyze, companies can find the optimal positioning for new towers and power lines that will fulfill the highest need or yield the largest profit.

There are several applications for green technology in industry. Cogeneration is a relatively new method of harnessing the heat dissipated off plants that are generating electricity.

Avoidance of Using and Manufacturing Hazardous Materials

From the use of nonrenewable resources for fuel and feedstock (e.g., gas and soil), through the release of pollutants from factories during production, to the disposal of final products that contain hazardous waste, each stage of the life cycle of a product produced by the chemical industry ("cradle to grave") can have negative impacts on man and his environment (OECD 2001). The reaction system in a process transforms the feeds from lower-value materials to higher-value products. Green chemistry is the design of chemical products and chemical processes that reduce or eliminate the use and/or generation of hazardous substances. This involves the definition of the feed materials, reaction pathways, products, and reactor conditions to minimize the impact of the reaction system on the environment, including the workers. The various aspects considered are:

- Use of nonhazardous, renewable feed materials
- Development of molecules that are not toxic, bioaccumulative, and persistent in the environment, yet still retain the desired functionality for which the product molecule was designed
- Development of reaction systems that use nonhazardous, environmentally friendly materials, media, and conditions (temperature, pressure, and energy requirements) to manufacture the desired molecules

As any material added to, or made in, a process will ultimately be emitted to the environment, the hazardous nature of the feedstock to a chemical process must be taken into consideration. If a toxic material is required, then only small amounts, at a time, should be used in the process of manufactured.

Green chemistry research is, therefore, focused on reducing the inherent toxicity of feedstock materials through structural modification or replacement and on the in situ manufacturing of toxic feedstock from nontoxic feed materials. The ideal would be to develop molecules that are not toxic, do not pass through a toxic state during metabolism, are not persistent, are not bioaccumulative, and have the desired efficacy for which the product is designed. Some examples include direct reaction of carbon dioxide with amines, instead of with phosgene, to produce isocyanates and urethanes. Use of polysaccharides from biological/agricultural wastes to make new polymeric substances and development of a process for the in situ manufacture of methyl isocyanate in a small reactor, rather than purchasing and storing larger quantities of the material as a feedstock, are some of the other examples to check the hazardous impact of the process.

In contrast to feedstock and molecule development, green chemistry's focus is on the reactor system which encompasses catalyst and solvents.

Catalysis can lead to the design and implementation of environmentally benign processes by developing reaction pathways that attain 100 % selectivity towards the desired product. Catalysis can also reduce the amount of energy required to transform feed materials into products, that is, allowing reactions to proceed rapidly at lower pressures and temperatures. The ability to run a system closer to ambient conditions is one of the basic principles of inherently safer processing.

The tragic release of methyl isocyanate (MIC) at Bhopal led to the development of a catalytic route for in situ manufacture of MIC. Within 6 months after the incident, an online small, catalytic pipeline reactor could be developed that produced MIC, resulting in only a few pounds being inventoried in the process at any one time.

Elimination of solvents not only eliminates waste generation, but it also reduces the cost of manufacture. A supercritical fluid, such as carbon dioxide, is an example of a very desirable solvent substitute. Studies showed that free-radical halogenations (bromination) in supercritical fluids were equal to, or superior to, those conducted in conventional solvents. Methyl methacrylate polymers could be produced in supercritical fluids, thus eliminating the need for halogenated organic solvents.

Use of Recycled Materials

Recycling is processing used materials (waste) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution

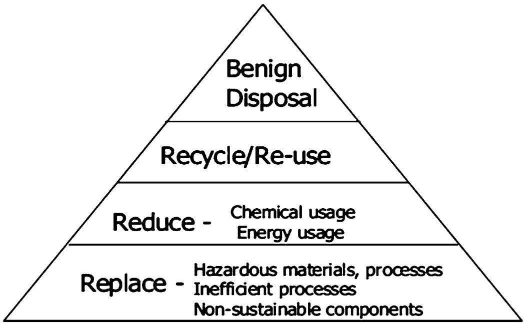

Fig. 1.1 Green chemistry priorities (Smith 2003)

(from landfilling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production (Wikipedia). Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, Recycle" waste hierarchy. The recycling sector in India has been in operation since the 1960s, and while only a fraction of the total plastic waste is being recycled in most Western countries, around 75 % of the plastic wastes are recycled in India (Haque et al. 1997; Haque 1998). Ragpickers mainly carry out the recycling process in India, and they play a vital role in the economy of solid waste recycling process (Agarwal et al. 2005).

Recycling, being one of the green chemistry priorities, is shown in Fig. 1.1.

In the strictest sense, recycling of a material would produce a fresh supply of the same material – for example, used office paper would be converted into new office paper, or used foamed polystyrene into new polystyrene. Paper is a natural resource that can be recycled up to about five times. This substantially reduces the impact on the environment. By using recycled paper, unnecessary use of virgin materials can be avoided. Today the quality of paper containing recycled fiber (e.g., 51 % recycled fiber) has improved and is comparable with virgin paper. Similarly, one can think of recycling plastics, glass, metals, and wood derived from municipal solid wastes. However, this is often difficult or too expensive (compared with producing the same product from raw materials or other sources), so "recycling" of many products or materials involves their reuse in producing different materials (e.g., paperboard) instead. There are some ISO standards relating to recycling such as ISO 15270:2008 for plastics waste and ISO 14001:2004 for environmental management control of recycling practice.

However, this is often difficult or too expensive for other materials (compared with producing the same product from raw materials or other sources). Therefore, "recycling" of many products or materials involves their reuse in producing different materials (e.g., paperboard) instead.

The two leading innovative mechanisms of waste disposal being adopted in India include composting (aerobic composting and vermicomposting) and waste to energy (WTE) (incineration, pelletization, biomethanation). WTE projects for disposal of MSW are a relatively new concept in India. Although these have been tried and tested in developed countries with positive results, these are yet to get off the ground in India largely because of the fact that financial viability and sustainability is still being tested.

Municipal solid waste (MSW) generally includes degradable (paper, textiles, food waste, straw, and yard waste), partially degradable (wood, disposable napkins, and sludge), and nondegradable materials (leather, plastics, rubbers, metals, glass, ash from fuel burning like coal, briquettes or woods, dust, and electronic waste). Composition-wise MSW has around 50 % of organic/biodegradable materials, around 10 % of the recyclables, and around 40 % of inert materials. Generally, MSW is managed as collection from streets and disposal at landfills. Aerobic composting is practiced by some of municipalities in the country. Most of the municipalities opt for uncontrolled landfilling. Anaerobic decomposition of MSW in landfills generates about 60 % methane (CH_4) and 40 % carbon dioxide (CO_2) together with other trace gases.

The major barriers to the recycling of hazardous waste are economic in nature. Although the technology may be available to recycle or recover chemicals from hazardous wastes, costs for disposal are lower than to recycle; investment risk is high, and payback is low for recycling facilities. Further, the volume of available waste material and market for recycled materials are small.

Use of Recyclable Materials

Recyclable materials encompass raw or processed material that can be recovered from a waste stream for reuse and include many kinds of glass, paper, metal, plastic, textiles, and electronics. Although similar in effect, the composting or other reuse of biodegradable waste – such as food or garden waste – is not typically considered recycling. Materials to be recycled are either brought to a collection center or picked up from the curbside, then sorted, cleaned, and reprocessed into new materials bound for manufacturing.

Designing to Last

Waste minimization and resource maximization for manufactured products can most easily be done at the design stage. Reducing the number of components used in a product or making the product easier to take apart can make it easier to be repaired or recycled at the end of its useful life.

In some cases, it may be best not to minimize the volume of raw materials used to make a product but instead reduce the volume or toxicity of the waste created at the end of a product's life or the environmental impact of the product's use.

Waste to Wealth

Globally, the estimated quantity of annual wastes generation during 2010 is about 20 billion tons of which about 12 billion tons is industrial wastes and 4 billion tons is municipal solid wastes (MSW). Currently, out of 1 billion tons of waste produced annually in India, about 350 million tons is organic wastes arising from agricultural sources and about 390 million tons is inorganic waste from industrial and mining sectors. The rest of them are from different sources such as municipal, medical and biomedical/hospital, radioactive, hazardous, and electrical and electronic waste. The sources for the nonhazardous inorganic wastes are coal combustion residues, overburden wastes from coal colliery, mine tailing, and wastes from aluminum, iron, copper, and zinc primary and secondary extraction processes. The major sources for agricultural waste are as follows: bagasse; biomass yield (except grain and edible yield) of crops, vegetables, and cereals; groundnut shell; wooden mill waste; coconut husk; and cotton stalk and residues from natural fiber extraction processes. The sources for the hazardous wastes are electroplating, metal extraction, galvanizing, refinery, petrochemical, pharmaceutical, leather, ship-breaking, paint, and coating industries.

Recycling is one of those activities which has taken off in India very well. However, environmentally sound technologies (ESTs) must be adopted to carry on with green recycling operations (Haque et al. 2000).

Packaging to Meet the Global Packaging Standards

Global packaging industry is growing swiftly and ready to meet the tomorrow's trends although the global recession of 2009 has also affected the sales of the packaging products and packaging films. During recession, a decline in the global packaging sales has been observed which is about 2.6 % in 2009. But the global packaging industry has regained its original growth in 2010 and expected to reach $739.9 billion by 2014. The global market for packaging machinery is projected to reach US$52.9 billion by the year 2018, the annual growth rate being 3.1 %. With such a high growth rate, the global packaging industry has become an integral part of product marketing, merchandising, food chain, and logistics. Seventy percent of the sales is estimated in the consumer market and rest of the 30 % in industrial market. In consumer market, the food industry is the biggest industry using the packaging films and material. After this comes the beverage industry.

Environmental concerns have led to governments throughout the world taking steps to deal with the issue of packaging waste and recycling.

Packaging directives from the European Commission, for example, have led to the imposition of challenging targets for recycling, and national governments are also examining new ways to discourage packaging waste. Landfill is a major political issue, with landfill taxes and ban on landfill of organic material being introduced by governments – in some cases before the necessary infrastructure is in place to provide alternatives to disposal.

In the light of climate change and environmental concerns, major retailers and brand owners have started to put pressure on suppliers, demanding carbon footprints and sustainable business practices. Also consumers have begun to desire all things natural, unaffected by "unnatural" processes, hence the suspicion of GM foods, etc. The packaging industry has taken steps to address the environmental question, but this has been more of a function of cooperation with government rather than a broader perspective. A broad collaboration throughout the value chain will be required in the future to address sustainability, avoiding suboptimization.

Addressing "End-of-Life" Issues

All products have a life cycle that covers a sequence of interrelated stages from the acquisition of raw materials until their end of life, when the product's functionality no longer satisfies the requirements of the original owner (2). At the end of life, the product can be disposed of or its life cycle extended over time (2,4) (Fig. 1.1). There are five basic end-of-life strategies. In accordance with their potential economic and environmental efficiency, the strategies can be ranked as follows:

- Reuse
- Servicing
- Remanufacturing
- Recycling
- Disposal

Manufacturers can reduce the life-cycle environmental impacts of their products through their influence on product design, material choices, manufacturing processes, product delivery, and product system support.

From an economic perspective, extended producer responsibility (EPR) is a referential strategy to promote the integration of the environmental costs associated with product life cycles into the market prices of the products. This economic approach to EPR focuses on the role of producers and consequently of corporate organizations. The minimization and prevention of wastes, the increased use of recycled materials in production, and the internalization of environmental costs in product prices are fundamental while implementing an EPR program in companies.

Although all strategies follow the extended producer responsibility principle, in practice several logistic differences arise due to particular interpretations of the concept. In general, it was observed that a direct comparison is rather difficult since the strategies consider different legal frameworks, they cover different types and numbers of products, and the resultant mass flows and related operational costs are highly context-dependent variables. Therefore, it is not possible to indicate which strategy presents the highest overall efficiency. The study concludes that a little contribution is feasible if the advantages and weaknesses of the models depicted and discussed here are considered in further regulatory decisions.

Sustainable Design Principles

The main attributes of sustainable design principles are:

- Low-impact raw materials
  Nontoxic, sustainably produced or recycled materials which require little energy to process.
- Energy efficiency
  Manufacturing processes and products which require less energy.
- Quality and durability
  Longer-lasting and better-functioning products to be used to avoid frequent replacement.
- Design for reuse and recycling
  Reusable and recyclable products, processes, and systems to be adopted.
- Design impact measures