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ORIGINAL PAPER

Identification of waste management development drivers and potential emerging waste treatment technologies

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Abstract Application and development of municipal solid waste treatment technology depends on various socio-economic and environmental factors. All those factors are work as development drivers for waste management systems. The study aims to identify key drivers from case studies of waste management development trend in Sweden. Social, economic and environmental drivers are identified and presented in this study. The study identifies personal behaviour, local waste management practice, consumption and generation of waste as the key social drivers. Resource value of waste, economic benefit from waste treatment facilities and landfill tax have been acknowledged as economic drivers for developing waste treatment technology. Moreover, global climate change, environmental movement and awareness have been working as environmental drivers for developing various waste treatment methods in Sweden. In addition, the study aims to analyse emerging waste treatment technologies based on a number of literature review and questionnaire survey. Dry composting, pyrolysis-gasification, plasma arc, and anaerobic digestion have been identified as potential emerging technologies for waste management systems in Sweden.

Keywords Municipal development drivers · Solid waste · Emerging waste technology · Waste treatment technology

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Introduction

Resource recovery from waste is one of the primary objectives of waste management systems in developed countries like Sweden. Waste-to-energy technology such as incineration has been implemented in Sweden for managing municipal solid waste for many decades. The first incineration plant for waste was built at Lövsta in Sweden in 1901 (RVF 1999). Incineration of waste is now in advance development stage in the context of technological efficiency. However, advanced waste management systems like incineration have various environmental and socio-economic problems. Due to the development of awareness on environmental pollution and various consequences of climate change, a sustainable waste management system is required and comparatively difficult to achieve for every country. Municipal solid waste (MSW) includes household waste, and wastes from commercial office, business centre and normal industrial waste which is generally managed by local municipal authority. The biological treatment of waste parallel to waste incineration is implemented widely in Sweden, playing a vital role in the countries' overall waste management strategy. Biological treatment of organic waste (35 % of all organic household waste) is mandatory and a part of Swedish national environmental objectives (SEPA 2007). Treatment of solid waste continues to be a topic on the environmental agenda (Formas 2004) and now has a place also on the political agenda (Finnveden et al. 2007). Today's consumption-driven society produces an enormous amount of waste. The large volume of waste puts a huge pressure on the waste management sector. Moreover, waste management systems include socio-economic, political, environmental and technological considerations and have many stakeholders. All these points of view are inter-related and dynamic in nature. Therefore, waste management systems create a complex cluster of different aspects, and functions of this complex cluster are also dynamic and interdependent. Global climate change and its various effects on human life drive current society toward a more sustainable society. There is very little analysis data available on the interdependent of the social, economic and environmental demands on waste management systems. This study aims to identify the important drivers of waste management systems in Sweden and tries to understand the development trends in the Swedish context. Taking into consideration of social, economic and environmental aspects, the study will also outline the emerging waste treatment technologies for Sweden. The paper will also attempt to explain interrelationship of different drivers in waste management systems in Sweden.

Materials and methods

The study was done using three research methods: literature study, questionnaire survey and analysis of the case studies of waste management systems in Sweden. A number of waste management research studies were analysed to identify the key development drivers in the waste management sectors in Sweden. Waste management development drivers are analysed within social, economic and environmental parameters. Literature studies include waste management books, research papers, peer reviewed journal publications, reports from business organizations and online resources. The questionnaire survey gathered responses from 39 selected waste management professionals from various sectors including academia, business organizations and local government bodies in Sweden. Questionnaire survey was conducted by email. Three survey questions were sent to the waste management professionals seeking their opinions on the key factors in the current Swedish waste management systems and possible future development. Box 1 shows the sample for the questionnaire survey.

Box 1: Questionnaire for experts' survey

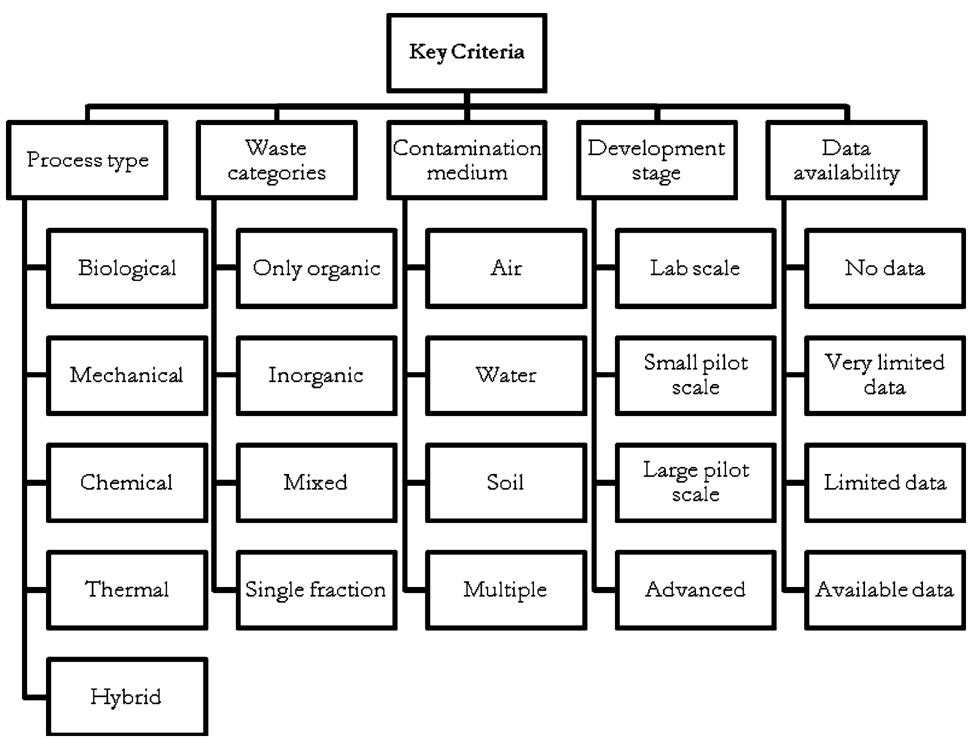
Question 1: In your opinion, what are the key factors (drivers) for developing waste treatment technologies in Sweden?

Question 2: What are the most challenging factors in sustainable waste management systems in Sweden?

Question 3: Do you recommend any emerging (new or developing) technology for Sweden which can be implemented in future for sustainable waste management systems?

The research also includes review of a case study of exiting waste management systems in Sweden. Potential emerging technologies have been identified through the research based on key criteria's process type of the technology, handling capacity of the waste category, potential contamination methods, technological development stage and data availability of the technology. Figure 1 shows the selected key criteria used for examining the potential waste treatment technologies in Sweden.

Fig. 1 Key criteria for analysing emerging technologies



The study analysed municipal solid waste treatment technology in Sweden. Potential emerging technologies in Sweden, are analysed based on following criteria,

- Process type (biological, mechanical biological, thermal, thermo-chemical, hybrid, etc.).
- Waste categories (organic, inorganic, paper, mixed MSW etc.).
- Contamination medium (air, water, soil or multiple)
- Development stage of the technology (laboratory scale, pilot scale, large pilot scale, mature and advanced)
- Data availability and reliability (very limited, limited or available)

Finally, selected potential emerging waste treatment technologies were analysed based on SWOT (SWOT: strength, weakness, opportunity and cost) analysis and the technologies evaluated by a qualitative evaluation method based on waste handling capacity, development stage and waste management problem solving capacity.

Previous studies

Several studies were analysed to understand waste management systems in Sweden including (Sundberg et al. 1994; Hartlén 1996; Björklund et al. 1999; Björklund 2000; Eriksson et al. 2002; Avfall Sverige 2008; Dahlén and Lagerkvist 2010). Global waste management development trends were analysed based on the reference studies of (Larsen and Børrild 1991; Sakai et al. 1996; Bhide and Shekdar 1998; Contreras et al. 2006; Tanaka 2007; UN-HABITAT 2008; Khetriwal et al. 2009; Miliute and Plepys 2009; UN-HABITAT 2010; Bernstad and la Cour Jansen 2011). Key findings from these studies are:

- Development of waste management systems is dependent on social, political, economic and environmental issues.
- Development of waste management systems is also dependent on geographical location, social practices and behaviour changes.
- Waste treatment technologies are developed and applied to manage waste problems depending on local waste management facilities.
- Waste management development drivers are interconnected and dynamic in nature; therefore, the actual influence of an individual driver may not be seen in dynamic waste management development trends. For example regulations can influence the development of certain waste treatment technologies.

Waste management scenario in Sweden

Sweden is one of the European Union (EU) member countries; therefore, waste management systems in Sweden are influenced by socio-economic and political decisions made and applied other EU countries. The EU commission acts as the leading driver for waste management regulations and systems within EU countries. In addition, Sweden is also prominent in adopting and applying environmental rules and regulations in the waste management sector. From the early 1960s, landfill was widely used to dispose of waste in Sweden (Miliute and Plepys 2009). This later led to several environmental problems due to lack of advanced pollution control facilities and efficient waste management systems. As a result, an environmental protection act was espoused in the late 1960s. Later in 1970s, resource value of waste was acknowledged and recycling of cans was introduced in the 1980s and a new production design of beverage containers (SJV 2005) was gaining importance at that time. In the mid-1990s Sweden introduced better waste management systems following the EU packaging directive (94/62/EC) (EU Directive 1994) and later in 2000 extended producer responsibility was introduced. These regulations and innovative packaging systems have increased the recycling rate of beverage cans. Some of these recyclable cans have economic value for example, by returning the PET bottle, one can get money back. Therefore, this economic value of waste bottles is favourable to the collection systems. Incineration is the foremost waste treatment technology in Sweden. Air emissions primarily SOx, NOx and dioxin were the leading polluters in the twentieth century in Sweden. Due to the development of public environmental awareness in global climate change which also leads to the urgency of developing EU waste incineration directive (2000/76/EC) for standard emissions into the atmosphere, seeking for an efficient and sustainable waste management systems is important. Later, the landfill directive (2001:512) was introduced banning certain categories of waste from landfill. Those wastes are managed by other waste treatment technologies such as biological treatment, combustible waste by Incineration and so on. Avfall Sverige is the waste management organization which works as a part of local authority and mainly responsible for sustainable waste management systems in Sweden. According to the Avfall Sverige, Swedish waste management goal is to maximize environmental and social benefits by prioritizing a waste hierarchy. The most important treatment methods applied for waste are: material recycling, biological treatment, waste-to-energy and landfill (Avfall Sverige 2010). In 2009, household waste volumes (4,731,660 tons, or

511.2 kg per person) decreased by close to 5 % compared to the year before. 98.6 % of the household waste is recycled, only 1.4 % goes to landfill. The waste quantity that goes to landfill has decreased by 50 % compared to 2008 (Avfall Sverige 2010).

Results and discussion

Key drivers in waste management systems in Sweden

Waste management systems are dependent on socio-economic issues such as population growth and Gross Domestic Product (GDP) (EEA 2008; Mazzanti and Zoboli 2008). Both GDP and population number have relationship with consumption and the generation of waste. Collection of waste or management of waste is influenced by some other drivers like local practice and recycling. Miliute and Plepys (2009) identified two types (market driven and policy driven) of drivers for household waste recycling systems. Waste was seen as valueless with 'no economic value' (Ludwing et al. 2003) before oil crisis in 1970s; however, the view has been changed after the great global energy crisis. Now, waste has been treated as resources and source of energy. Another holistic study on waste management development drivers has been done by Wilson (2007). Six waste management development drivers are categorized by Wilson in his study; those are (1) public health, (2) environmental protection, (3) resource value of waste closing the loop, (4) institutional development, (5) responsible issues and (6) public awareness over the time. The study includes environmental issues with the social drivers. Waste treatment development drivers are categorized in three different broad sectors in this study such as social, economic and environmental. A summary of waste management development drivers is presented below in three sustainability categories such as social, economic and environmental.

Social drivers

Social indicators identified as potential drivers for technological development of the waste sector in Sweden, are population, the volume of waste generation, people behaviour, local waste management practices and the process of urbanization. Population and the volume of waste generation are vital for designing waste management systems. In recent studies, human behaviour and behavioural change have been identified as key drivers in waste management systems. Socio-political drivers such as local and international rules and regulations are also important in the development of waste treatment technology. Regulations have been acting as a supporting tool for promoting, developing or restricting a system. Landfill was conventional waste management

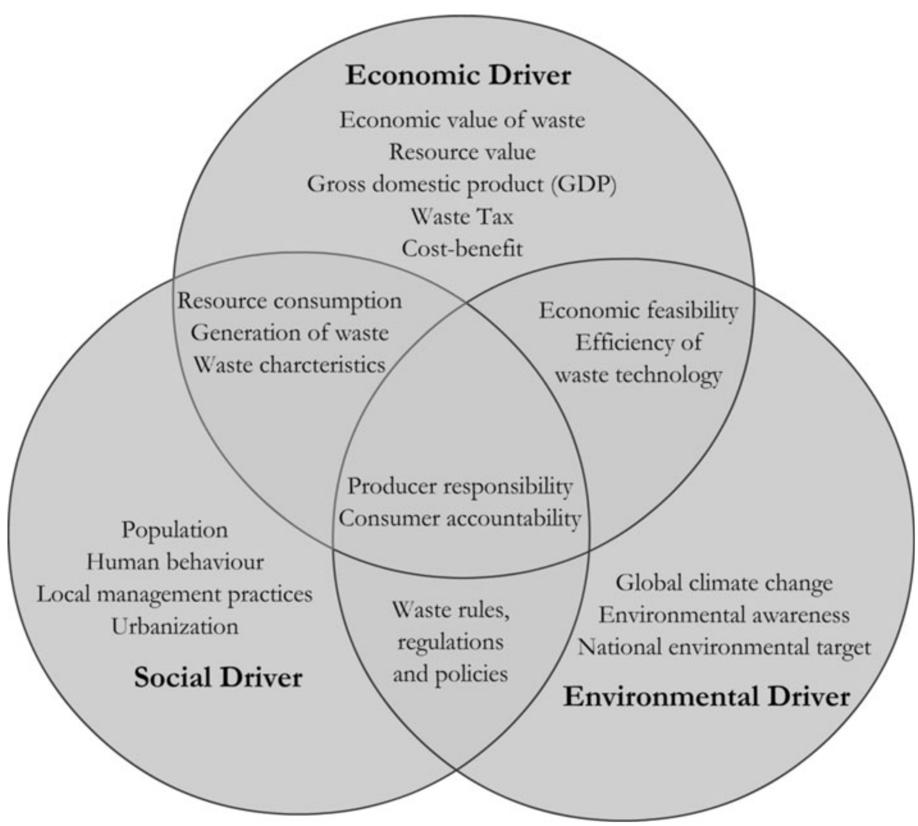


Fig. 2 Drivers in sustainable waste treatment technology development in Sweden

Table 1 Key milestones in waste generation and management in Sweden (1900–2009)

Years	Milestone	Reference
2009	Incorporating EU Battery Directive to the Swedish legislation	(El-Kretsen 2009)
2006	EU Battery Directive (2006/66/EC)	(EU 2009)
2005	Ban on organic waste to landfill	(Avfall Sverige 2008)
2005	Ordinance (2005:209) on producer responsibility for e-products	(SCS 2005a)
2005	Regulation (2005:220) on the return system for bottles and cans	(SCS 2005b)
2003	Regulation on incineration of waste (2002:1060)	(Eionet 2007)
2002	EU RoHS and WEEE directive (Directive 2002/95–96/EC)	(EU 2002)
2002	Ban on putting combustible waste to landfill	(Avfall Sverige 2008)
2001	The Landfill Ordinance (2001:512)	(Eionet 2007)
2000	EU End-of Life Vehicles (ELV)/Tyres (2000/53/EC)	(EU 2000)
2000	EU Waste Incineration Directive, 2000/76/EC	(EU Directive 2000)
2000	Introduction of landfill tax	(Avfall Sverige 2008)
1998	The Swedish Environmental Code (16 Env. Objectives)	(Regeringen 2000)
1997	Regulation for batteries (1997:645)	(SFS 1997a)
1997	Packaging (1997:185), Producer responsibility for packaging	(SFS 1997b)
1994	EU Packaging Directive 94/62/EC	(EU Directive 1994)
1991	The Act (1991:336) on certain beverage containers (PET)	(SFS 1991)
1982	The Act (1982:349) on recycling of Al drinking containers	(SJV 2005)
1969	Miljöskyddslag (1969:387)-Environmental Protection Act	(EU Directive 1988)
1960 s	Landfill started for MSW disposal	(Miliute and Plepys 2009)
1951	Tetra Pak founded	(Tetra Pak 2009)
1927	Volvo founded	(Volvo 2009)
1901	The first waste incineration plant in Sweden in Lövsta	(RVF 1999)

systems in Sweden until mid-1990s. However, later regulations were imposed to restrict the disposal of certain waste such as food waste and combustible waste into landfill in Sweden.

Economic drivers

A number of research studies show the relation of economic growth and waste management systems (EEA 2008; Mazzanti and Zoboli 2008). After shifting the perception of 'no economic value' of waste into the perception of waste as a resource; waste-to-energy technologies has been developed due to economic drivers. Economic benefits from waste management systems and resource recover from waste encourage technological development, incineration, anaerobic digestion for instance. Waste management systems require a huge amount of investment and labour to run the systems effectively. Therefore, economic benefits is always an issue while designing waste treatment technologies. Landfill tax and waste management treatment cost are also as key economic drivers for Sweden. On one hand, landfill tax has been restricted certain waste streams such as combustible waste and food waste dispose to landfill site in Sweden; energy has been recovered by incineration and anaerobic digestion treatment technologies from those diverted waste streams on the other hand.

Environmental drivers

Environmental drivers such as climate change and environmental awareness have been appeared after the 1990s when sustainability became an important factor for global sustainable development. Now in most of the development and urbanization processes socio-economic and environmental sustainability are the key criteria. Pollution from incineration of waste has been controlled and improved in Sweden due to the influences of environmental drivers. Local climate condition in Sweden is considered as important criteria for the development of incineration because of its facility for recovering energy and heat. As a 'end of pipe' solution, landfill and incineration without energy recovery facilities were predominantly applied in early the 1960s. Later in the global oil crisis of the 1970s and environmental awareness in the 1990s commercialization of the waste treatment technology has been started in Sweden. Development and implementation of anaerobic digestion of organic food in Sweden has reduced environmental pollution and recovered bio-fertilizer compared

Table 2 The key features of emerging waste management technologies

Processes type	Key features	Waste type	Contamination Medium (Emission)	Development stage	Data availability	References
Dry composting	The concept of dry composting is experiment by Smedlund Miljösystem AB cooperation with Avfall Sverige. Organic waste or food wastes are preserves in dry mechanism, and then reduce weight and volume by about 75 %. Then dried material can be extracted biogas via anaerobic digestion. Among different composting such as in-vessel/tunnel composting, vermin-composting and windrow composting, dry composting could be potential technology.	Organic waste, garden waste, biodegradable waste	Multiple (air, water and soil)	Mature technology	Limited emission data	(Demirci et al. 2005; Prabha et al. 2007; Avfall Sverige 2009; Walker et al. 2009)
Sanitary landfill	Sanitary Landfill is the biological waste treatment technology with control landfill facility. In sanitary landfill, artificial liner is used for preventing leachate pollution and well as air emission. Landfill gas contents primarily of methane and carbon dioxide are generated from the degradation of waste. Sanitary landfill has leachate and landfill gas collection and treatment systems.	MSW	Multiple (air, water)	Large pilot scale	Available	(Tchobanoglous and Kreith 2002; Ludwing et al. 2003; FCM 2004)
Anaerobic digestion (AD)	Anaerobic digestion is a biological conversion of waste. Anaerobic digestion occurs in three different stages like (a) Hydrolysis: Liquefaction, (b) Acidification: Acid formation and (c) Methanization: Methane formation.	Organic waste, food waste	Multiple (air, water)	Large pilot scale	Available	(Alternative Resources 2006; MWIN-RCA 2006; Visvanathan 2006)
Gasification	Gasification is a thermal waste treatment technology. Gasification can be fermentation, briquetting, fluidized bed or thermal cracking. Gasification is done in a controlled environment with limited access of air in 400-600 °C. Thermo-chemical biomass gasification can be possible for both wet and dry biomass for the production of synthesis gas, hydrogen- and methane-rich gas.	MSW	Multiple (air/water)	Pilot scale	Limited	(LEE 2001; Wilén et al. 2004; Kruse 2008)
Pyrolysis thermal processes	Pyrolysis is a thermal process of MSW treatment technology. Unsorted MSW can be treated by pyrolysis process at 600–650 °C in absence of oxygen. However, it not possible to make such non air environment. Waste converted to the syngas and char from the process and combustion can be done sequentially.	MSW	Air	Pilot scale	Limited	(Finnveden et al. 2000; Halton 2007)
Plasma arc	The system basically uses a plasma reactor which houses one or more. Plasma arc torches which generate, by application of high voltage between two electrodes, a high voltage discharge and consequently an extremely high temperature environment (between 5,000 and 14,000 °C) approximating the temperature of the Sun. The gas output after scrubbing comprise mainly of CO and H2. The liquefied produce is mainly methanol.	MSW	Air	Lab scale	Very limited	(GOI 2001; Circeo 2009)
Bio-chemical conversion, anaerobic process	In MBT shredding followed by trammel separation, material recovery and biological (drying) treatment, and subsequent fuel preparation. pre-digestion stage of heating to 70 °C for one hour followed by mesophilic digestion at 35 °C, or a thermophilic digestion process, operating the whole digester at 57 °C. pyrolysis operating temperatures in excess of 430 °C	MSW	Multiple	Pilot scale	Limited	(Greater London Authority 2003)
Pyrolysis-Gasification	Pyrolysis-gasification is a hybrid waste treatment technology. There would be a net reduction in the emission of the sulphur di-oxide and particulates from the pyrolysis/gasification processes, however, the emission of oxides of nitrogen, VOCs and dioxins might be similar with the other thermal waste treatment technology.	MSW	Air	Pilot level	Limited	(DEFRA 2004; Malkow 2004; Alternative Resources 2007; Cherubini et al. 2008)
Plasma arc-gasification	Reactor temperatures range from approximately 800 °F for a cracking technology to as high as 8,000 °F for a plasma gasification technology. the organic fraction of the MSW is converted to a gas typically composed of hydrogen, carbon monoxide and carbon dioxide gases	MSW	Air	Pilot scale	Limited	(Alternative Resources 2006; Circeo 2009)

Table 2 continued

Processes type	Key features	Waste type	Contamination Medium (Emission)	Development stage	Data availability	References
Bioreactor technology	Waste is processed for maximizing the landfill gas preparation. Anoxic stage followed by the oxidation phase, methane formation, nitrogen concentrations increase along with carbon dioxide concentration originating from methane oxidation. MBT is combination of mechanical with biological processes, aiming, mainly at the stabilization of the biologically degradable components. anaerobic or aerobic processes then can continue to generate biogas from landfill	Organic waste	Multiple	Pilot scale	Limited	(Ludwing 2003)
Hydrolysis	Oxynol hydrolysis is not yet in commercial operation for MSW. Integrated and piloted existing technologies, and advanced a project for MSW-to-ethanol processing plant, complex and integrated chemical processes. The four major processes are: (1) waste preparation; (2) acid hydrolysis; (3) fermentation, and (4) distillation.	MSW, Sewage sludge	Water	Lab Scale	Very limited	(Biffa 2003; Alternative Resources 2006)
Conversion of solid wastes to protein	Laboratory investigations conducted at Louisana State University, USA showed that under aerobic conditions, it is possible to convert the insoluble cellulose contained in municipal waste by cellulytic bacteria. The bacteria are then harvested from the media for use as protein. The single cell protein produced has a crude protein content of 50–60 %	Cellulosic waste	No data	Lab scale	Very limited	(GOI 2001)
Hydro-pulping	The method has been developed to hydro pulp the waste and recovers paper fibre from refuse. The method is being used in a full scale plant of 150 tpd capacity operating at Franklin, Ohio, USA. The method is suitable for processing of paper waste	Paper waste	Multiple	Pilot scale	Very limited	(GOI 2001)

to landfill. Due to climate change and environmental pollution restriction on landfill in Sweden is becoming a reality. In 2009, Sweden only landfill 5 % of the total waste volume (CEWEP 2011). Some of the drivers are mutually inclusive to more than one category. For instant, waste characteristics (organic, combustible or recyclable) is one of the important factors for selecting waste treatment technology which can be considered as the socio-economic driver. Economical and technological efficiency and rules and regulations are also mutually inclusive with more that one driver. However, a simplified diagram of key waste treatment development drivers is presented in Fig. 2 and the diagram shows different drivers and their relationship in waste management systems.

Table 1 shows the key milestones in municipal solid waste management in Sweden. The Table shows the development of waste regulations and other important factors for waste generation and reduction in Sweden.

Potential emerging waste treatment technologies in Sweden

The term 'emerging' technology used in this section refers to developing technology or a technology which will be developed in near future. An emerging technology may be cutting edge technology but not necessarily a new technology; it might be retrofitting of old technology. In this study emerging technologies are considered those technologies which have not been commercialized in Sweden yet. Therefore, traditional waste treatment technologies like incineration, landfill and composting have not been considered in the emerging technology list in Table 2). Every technology is required to be environmentally sustainable in current global climatic condition. Research and development of waste treatment technology has been conducted for more sustainable and efficient technologies. Even for very primitive technology such as landfill, sanitary landfill with less environmental impact and more resource recovery efficiency have been developed. Thermal waste treatment technologies have now been considered as the most efficient waste treatment options due to heat and energy recovery facilities. However, for long term sustainability, thermal waste treatments such as incineration have many limitations in the context of resource preservation and reuse. Biological treatment technologies are also important and have been widely implemented due to the fact that they generate least environmental pollution. However; only organic waste can be managed by biological treatment like anaerobic digestion. Individual technologies which can manage specific waste fraction are getting priority because of efficient waste management and resources recovery options. Therefore, individual technologies are required for the treatment of individual waste fraction like paper, glass, plastics,

Table 3 SWOT analysis of the emerging waste treatment technologies

Methods	Strength	Weakness	Opportunity	Threats
Dry composting	Biological process in a confined or open area. Possibility to get nutrient-rich organic fertilizer and soil conditioner from the waste. Dried waste can be preserved for future	Only biodegradable waste can be managed by this process. Emission control from the system is difficult	Opportunity of resource recovery and making bio-fertilizer. Biogas can be generated from the dry waste	Potential threat to water and soil contamination if poor management. Emissions to the atmosphere are a great threat for environmental degradation
Sanitary landfill	A natural decomposition process that can handle different types of waste with larger volume. Waste can be managed in a controlled environment	Huge land area is needed and emission control is difficult and costly. A long time is required to reclaim the landfill land restoration	Opportunity to recover biogas from the landfill. Opportunity to manage waste more environmental friendly way if sanitary landfill fully functional	Potential environmental threat due to air, water and soil contamination because of a weak liner and poor management system
Anaerobic digestion (AD)	Biochemical process with energy recovery facilities. Final residue can be used as fertilizer	Only organic waste can be managed with AD. Higher investment cost is required	Opportunity to retrieve biogas/fuel and manure from the AD facilities	Potential threat of emissions to the environment
Gasification	Almost all types of waste fractions can be treated with gasification process. Low final residue is generated from the processes	High investment cost and still developing technology for MSW	Energy and heat can be recovered from the gasification of MSW	Environmental impact through emissions to the atmosphere
Pyrolysis	Different waste categories can be treated by Pyrolysis process with lower volume of final residue	Higher investment cost and technology not yet matured enough for MSW	Opportunity of resource and energy recovery	Potential environmental threat from emissions
Plasma arc	Almost all types of waste categories can be treated with lower disposable residue	New technology for MSW management and high investment cost	Opportunity of higher energy and heat recovery option	Threat of environmental impact from the emissions
Bio-chemical conversion of MSW	Integrated waste treatment process with mechanical biological treatment	Limited waste treatment capacity; organic waste can be treated by this technology	Energy and resource recovery are possible	Potential environmental threat from emissions to the atmosphere and water
Pyrolysis-gasification	Hybrid thermal process with large volume of different waste treatment capabilities	Emerging technology with higher investment cost	Opportunity of energy and resource recovery	Potential environmental threat from air and water emissions
RDF	High resource value. Regular MSW can be managed by this technology	Desire moisture content is required for getting higher energy potentials	Energy recovery options	Threat of environmental pollution
Bio-reactor	Landfill with MBT facilities. Higher waste volume can be managed by this process compare to traditional landfill	Pre-processing of waste is required	Higher volume of biogas can be recovered from the bio-reactor	Environmental threats due to emissions from the technology
Hydrolysis process	Chemical processes of food/fruit waste to ethanol production	Very new technology with limited problem solving capacity	Opportunity of ethanol production	Water contamination
Solid wastes to protein	Conversion of waste to nutrient	Experimental stage with lower problem solving potentials	Opportunity for having nutrient recovery from waste	No such threats have been identified
Hydro-pulping	Resource recovery and reuse in paper and pulp industry	Only paper waste can be managed by this process	Resource recovery	Threat of environmental pollution from chemical s that used

cans, organic waste, woods metals, e-waste and many other types of waste streams. Table 2 shows the key features of the emerging technologies for Sweden. Emerging technologies are analysed based on the development stage of the technology and waste management problem solving capacity. A qualitative analysis of the emerging technology has also been done and presented in Table 3. Based on SWOT analysis, technologies have been analysed in the context of potential strength, weakness, opportunity and threats. Different technologies have variety of waste streams handling capacity; however, most of the thermal waste treatment technologies can treat all type of waste fractions. Biodegradable waste fractions are handled by biological waste treatment technology. Therefore, some technologies require higher sorting efficiency for better performance and others can manage in lower sorting systems. Dry composting and anaerobic digestion have been identified as potential emerging technologies for Sweden to manage organic waste. Dry composting is mainly used to reduce the volume and weight and preparing organic or kitchen waste for the extended energy recovery from the biological processes. Pyrolysis-gasification of waste has been identified as a potential emerging waste-to-energy technology in Sweden. Plasma-arc and plasma-gasification have also been identified and analysed as potential emerging technologies in the waste sector.

Conclusion

Waste management systems are involved with different multi-disciplinary factors; therefore, trends in the development of waste treatment technologies have been led by various social, economic and environmental drivers in Sweden. Identifying development drivers is important to understand, plan for design new system in the waste management sector. Society is very dynamic in nature; understanding the inter-relationship of different drivers are important for predicting and understanding the emerging waste treatment technologies. Dry composting, pyrolysis-gasification, plasma arc and anaerobic digestion have been identified as potential emerging waste treatment technologies in Sweden. However, the development of waste technologies also involves other externalities like shifting personal and social viewpoints on waste such as 'waste' to 'resource'. Currently, a number of studies have been conducted by different researchers on the 'zero waste' (Zaman and Lehmann 2011) concept. Therefore, waste avoidance and reduction technology is considered to be the prime challenge rather than the development of new waste treatment technology.

Extended producer responsibility as well as consumer accountability are gaining importance since both are the key drivers for the development of sustainable waste management systems. Therefore, further studies could be done to explore possibilities of consumer accountability in consumption and generation of waste and in product stewardship and sustainable development.

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