Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

A dynamic model for organic waste management in Quebec (D-MOWIQ) as a tool to review environmental, societal and economic perspectives of a waste management policy

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ARTICLE INFO

Article history:
Received 22 September 2016
Revised 26 January 2017
Accepted 8 April 2017
Available online xxxx

Keywords:
Dynamic system model
Organic waste management model
Composting
Waste management policy
Scenario
Environment
Economy
Society
Sustainability

ABSTRACT

A dynamic systems model of organic waste management for the province of Quebec, Canada, was built. Six distinct modules taking into account social, economical and environmental issues and perspectives were included. Five scenarios were designed and tested to identify the potential consequences of different governmental and demographic combinations of decisions over time. Among these scenarios, one examines Quebec's organic waste management policy (2011–2015), while the other scenarios represent business as usual or emphasize ecology, economy or social benefits in the decision-making process. Model outputs suggest that the current governmental policy should yield favorable environmental benefits, energy production and waste valorization. The projections stemming from the current policy action plan approach the benefits gained by another scenario emphasizing the environmental aspects in the decision-making process. As expected, without the current policy and action plan in place, or business as usual, little improvements are expected in waste management compared to current trends, and strictly emphasizing economic imperatives does not favor sustainable organic waste management.

1. Introduction

1.1. Historical organic waste management review

Landfilling is still the dominant waste management practice in Quebec (Recyc-Québec, 2009a), though it faces criticisms and limited public support (Dionne et al., 2006). Despite efforts to decrease greenhouse gas (GHG) emissions via biogas capture and incineration (29.5% decrease between 1990 and 2008), landfilling is still responsible for 2.7% of the province's GHG emissions (MDDEP, 2010b).

Source separated organic waste (OW) treatment options are more sustainable. Composting releases biogenic CO_2 (unaccounted for global warming potential) and only traces of other GHGs (CH_4, N_2O) (IPCC, 2006). Furthermore, it allows nutrients recycling and organic matter stabilization, promoting better soil management practices (Dupont, 2009; MAPAQ, 1990). Mechanization of OW management (i.e. mixing and shredding) started in the 1930s, but composting did not spread widely in America until the 1980s (Blum, 1992). In 1989, a 50% waste diversion goal was set for 2000 in the province of Quebec, later modified to more ambitious targets for 2010: 60% for the municipal and 65% for the industry, commerce and institution (ICI) sectors (MDDEP, 2000). However, only 12% of Quebec's organic waste had been diverted from the landfill in 2009 (Recyc-Québec, 2009a). Consequently, the aforementioned diversion objective was carried forward in a new policies and action plan (2011–2015) which also aimed to ban landfilling of cardboard (by 2013), wood (by 2014) and OW (by 2020) (MDDEP, 2011). Yet, none of these targets had been reached in 2016, and mandatory commissioning OW treatment facilities by municipalities benefiting from governmental funds has already been delayed until 2022. In comparison, Nova Scotia and Prince-Edward-Island have already banned the landfilling of organic waste by 1997 and 1999 respectively.

1.2. Legal context and current practices

The Quebec *Environment Quality Act* imposes the generation of municipal waste management plans aligned with provincial waste management policies, and empowers metropolitan or rural communities limitations or prohibition on the discharge or incineration of waste within their territory (Government of Quebec, 1972). The *Municipal Powers Act* states that every municipality is responsible

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http://dx.doi.org/10.1016/j.wasman.2017.04.021
0956-053X/© 2017 Published by Elsevier Ltd.

for waste elimination or valorization on its territory (Government of Quebec, 2005). Where OW collection services are emerging, municipalities generally collect and treat residential OW, while the institutional, commercial, and industrial sector (ICI) may take advantage of municipal services or contract private companies. Although centralized offsite organic waste treatment facilities are predominantly adopted, *in situ* alternative treatment options exist for domestic, community or ICI settings.

A composting and biomethanisation infrastructure development investment program was deployed by the provincial government (MDDEP, 2009a) to jointly support the waste management policy, the climate change action plan (MDDEP, 2008b), and the 2006–2015 energy strategy (MRNF, 2006). Part of the funding comes from royalties on fossil fuels (*Green fund*) to mitigate climate change (Government of Quebec, 2007). Investments are also accompanied by a regulation on financial security applicable to organic waste treatment facility operators to ensure that sites are correctly operated and that funds are available for site closure (Government of Quebec, 2009). Finally, further support for municipal OW treatment comes from temporary and permanent royalties on landfilling, hereafter referred to as paybacks (Government of Quebec, 2010). Despite government sponsored public hearings on recommendations for the development of a new waste management policy, a few published economic impact assessments on land-filling royalties (MDDEP, 2009b), and financial guarantees for organic waste valorization sites (MDDEP, 2009c), no other information is publicly disclosed concerning the future of OW management in Quebec.

1.3. Current challenges for the implementation of the policy

Composting expansion in Quebec is currently limited by (1) the low cost of landfilling, (2) the high infrastructure and maintenance costs of certain technologies, and (3) public acceptance, mainly related to concerns about odor emissions (Taillefer, 2010). Quebec addressed these three issues through the implementation of royalties and stricter regulations for landfilling (Government of Quebec, 2010). In parallel, the development of composting and biomethanisation practices was promoted through massive investment programs associated with financial guarantees (MDDEP, 2009a). According to a survey, 95% of people would engage themselves in a separate OW collection program if it was made available (Commission des transports et de l'environnement, 2008).

In such a context, it is difficult for decision makers to build sound policies and evaluate their efficiency. By evaluating the consequences on the socio-ecological system of various scenarios, modeling is a useful tool for policy-making aiming to maximize ecological benefits and social acceptability, while minimizing the associated public expenses. Existing organic waste management (OWM) models are static, providing case specific insights about the ecological and economic impacts of different treatment technologies (Björklund et al., 1999; EPIC/CSR, 2004). Life Cycle Analysis based decision support tools generally do not involve a temporal scale or geographical resolution (Kijak and Moy, 2004). Social, environmental and economic impacts have only rarely been considered together in a Life Cycle Inventory decision support tool (Kijak and Moy, 2004).

System dynamics is defined as "the investigation of the information-feedback characteristics of (managed) systems and the use of models for the design of improved organizational forma and guiding policy"(Forrester, 1961). System dynamics is increasingly applied to help understand sustainability planning and cost-benefit resources management problems. More specifically, in waste management, dynamic systems models have been used to guide decision-making at a regional scale or for specific projects (Yuan et al., 2012). However, modeling the feedback loops of individual behaviours (e.g. education) and showing long-term trends of different OWM scenarios have never been attempted. Incorporating the system dynamics approach could promote the creation of informative and realistic organic waste management models.

1.4. Objectives

The aim of this study is to create a functional dynamic systems model of OWM at the provincial scale. The secondary objectives are (1) to illustrate the dynamic interconnections existing in OWM and their key role in developing and successfully implementing government policies; and (2) to examine the long term trends of five scenarios, including Quebec's new waste management policy, from an economic, social and environmental perspective.

2. Methodology: Model development, structure and processes

2.1. Model architecture

The Dynamic Model of Organic Waste Management in Quebec (D-MOWIQ) was constructed using the software STELLA (High Performance Systems, 2001). A description of the basic modeling components (i.e. *stock*, *flow*, *converter* and *connectors*), as well as the basic steps in model developments (*system description*, *model formulation*, *model validation* and *policy analysis*) is described in Yuan et al. (2012). The simulations are conducted at the scale of the province of Quebec, Canada. Simulations run from 1990 (coinciding with the first reliable OWM estimates) until 2050 (thirty years after the proposed ban of OW landfilling), with an annual time step. D-MOWIQ consists of six distinct modules further described in Sections 2.2–2.7. Four are static ((1) population, (2) technology, (3) environment and (4) economy). The two last modules make the model dynamic, by incorporating feedback loops. The (5) governmental decision module integrates information from the population, economy and environment modules to "decide" whether to invest in education or technological infrastructures programs. The (6) social and institutional decision module integrates information from the economy and environment modules. It includes individual, commercial, institutional and societal decision equations, to define whether individuals and ICI choose or not to participate in source-separation of OW or on-site composting. Municipalities, private parties and ICI leaders can choose which technology would be used to treat OW. A full map of the model and each subsection is shown in Supplementary materials (Figs. S1–S9).

2.2. Population module

The population module (Fig. S2) uses total annual Quebec population and annual active population (Institut de la statistique du Québec, 2009, 2010c, 2011a). Various parameters (detailed below) are normalized per capita, and demographic projections support their extrapolations to 2050. The total population is separated into different dwelling types (single family homes, six apartments or less buildings and multiple lodgment buildings) (Institut de la statistique du Québec, 2010a; Statistics Canada, 2006). The annual OW produced by the residential (Recyc-Québec, 2009b), commercial (Recyc-Québec, 2009c) and institutional (Recyc-Québec, 2009d) sectors, both in urban and rural populations (Statistics Canada, 2009), is derived from waste generation ratio (%) multiplied by the total population. A similar approach was used for the annual amounts of residual waste landfilled (Recyc-Québec, 2006a, 2009a) and municipal waste generated (Recyc-Québec, 2009b). The education level of the population was also modeled