Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Designing an agricultural vegetative waste-management system under uncertain prices of treatment-technology output products

D. Broitman [a,*], O. Raviv [b], O. Ayalon [b], I. Kan [c]

[a] *Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa, Israel*
[b] *Department of Natural Resources & Environmental Management and The Natural Resources and Environmental Research Center, University of Haifa, Haifa, Israel*
[c] *Department of Environmental Economics and Management, and the Center for Agricultural Economics Research, Robert H. Smith Faculty of Agriculture, Food and Environment, Hebrew University of Jerusalem, Rehovot, Israel*

ARTICLE INFO

Article history:
Received 20 August 2017
Revised 20 December 2017
Accepted 29 January 2018
Available online xxxx

Keywords:
Agricultural waste
Economic model
Optimization
Risk neutral
Risk averse

ABSTRACT

Setting up a sustainable agricultural vegetative waste-management system is a challenging investment task, particularly when markets for output products of waste-treatment technologies are not well established. We conduct an economic analysis of possible investments in treatment technologies of agricultural vegetative waste, while accounting for fluctuating output prices. Under a risk-neutral approach, we find the range of output-product prices within which each considered technology becomes most profitable, using average final prices as the exclusive factor. Under a risk-averse perspective, we rank the treatment technologies based on their computed certainty-equivalent profits as functions of the coefficient of variation of the technologies' output prices. We find the ranking of treatment technologies based on average prices to be robust to output-price fluctuations provided that the coefficient of variation of the output prices is below about 0.4, that is, approximately twice as high as that of well-established recycled-material markets such as glass, paper and plastic. We discuss some policy implications that arise from our analysis regarding vegetative waste management and its associated risks.

1. Introduction

Large amounts of vegetative residues are produced annually by agriculture.[1] To establish a sustainable agricultural vegetative waste-management system (VWMS), one must consider the wide range of technologies suitable for treating vegetative organic biomass in view of their long-run economic feasibility levels. This is a challenging investment decision given that the prices of the treatment technologies' output products may fluctuate with time, particularly when the markets for these products are non-existent or not well established. In this paper, we conduct an economic analysis of agricultural VWMSs while accounting for fluctuating output prices.

Setting up an agricultural waste-management system involves the introduction of new technologies into both farming and waste-management sectors. In relation to agricultural research, while the adoption of new production technologies and the farmers' related risk preferences have been intensively examined (Daberkow and McBride, 2000; Marra et al., 2003; Genius et al., 2013; Liu, 2013; Barham et al., 2015), only a few studies have analysed agricultural waste-treatment technologies (Purvis et al., 1995; Launio et al., 2014). From the perspective of the waste-management literature, analyses of agricultural vegetative residues tend to focus on a single treatment technology with different waste-input options (e.g., Brown et al., 2013; IRENA, 2014; Srivastava et al., 2014; Tidaker et al., 2014; Baruya, 2015), or on an assessment of environmental impacts associated with specific treatment facilities (e.g., Favero and Massetti, 2013; Delivand et al., 2015). Academic studies incorporating multiple treatment technologies for vegetative waste are scarce (Hadas et al., 2013; Goldfarb, 2015; Greenhot et al., 2015). To the best of our knowledge, there has never been an economic analysis of investments

Abbreviations: CE, Certainty-Equivalent; CV, Coefficient of Variation; F&V, Fruit and Vegetable; RDF, Refuse-Derived Fuel; VWMS, Vegetative Waste-Management System.

* Corresponding author.
E-mail address: danib@technion.ac.il (D. Broitman).

[1] Quantifying the *vegetative* waste produced by the agricultural sector is not a simple task. Available statistics are generally categorized as "agriculture, forestry and fishing waste". For example, almost 20 million tons of this type of waste were produced in the EU in 2014 (EUROSTAT, 2017). But, this waste category not only includes additional economic sectors, but also non-vegetative agricultural wastes (for example waste from animal farming). Calculating the amount of vegetative waste in the case study was the first step in our research, as described in Section 2.1.

https://doi.org/10.1016/j.wasman.2018.01.041
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in VWMSs that accounts for the risk associated with the uncertain output prices of different treatment technologies.

We develop an economic optimization model that defines the preferred treatment technology for different vegetative waste types. The model assesses the impact of output-product price fluctuations on the optimal technological array of the VWMS, from risk-neutral and risk-averse perspectives. Under the risk-neutral approach, the average final prices are the exclusive benchmark, and we calculate breakeven prices between the various technologies. Adopting a risk-averse perspective implies that the decision to implement a certain treatment technology is based on the rank of the certainty-equivalent (CE) prices of the technologies. The CE, in turn, depends on two additional parameters: the degree of risk aversion assigned to risky investments by a representative agent in the society, and the variance of the output price associated with each treatment technology. We adopt the Arrow–Pratt formulation (Arrow, 1963; Pratt, 1964) to compute breakeven CE prices of the technologies under different coefficient-of-variation (CV) levels of the final-product prices. In particular, we are interested in the minimal CV levels that alter the CE rank of the technologies in comparison to CV levels of well-established recycled-material markets such as glass, paper and plastic. We apply the methodology to data on agricultural vegetative waste from the Israeli agricultural sector.

The paper is structured as follows: in Section 2 we describe the methodology; Section 3 presents the results and discusses their implications; Section 4 provides concluding remarks and possible extensions of the research.

2. Methodology

Our methodology is based on an optimization model of a VWMS for the agricultural sector at the regional or national levels, aimed at optimally assigning waste types to treatment technologies.

2.1. Vegetative wastes and treatment technologies

Farmers cultivate crops and produce vegetative wastes as by-products; the vegetative waste can be disposed of by different waste-treatment technologies. We view the agricultural sector only as a supplier of a fixed amount of waste inputs to the VWMS. We consider three types of agricultural vegetative waste: "foliage" waste, comprised of green leaves, non-woody shrubs and field-crop biomass, "woody" waste, including branch and trunk residues from orchard and forest trees, and "fruit and vegetable" (F&V) residues. Table 1 reports the available amounts of these vegetative wastes in Israel.

Currently there is no waste management system in Israel able to treat the almost million and a half tons of vegetative wastes produced annually. Governmental policy assessments (Hadas et al., 2013; Goldfarb, 2015; Greenhot et al., 2015) claim that a large share of the waste is either burned or abandoned in the farm field, and therefore constitute a potential environmental and health threat. The lack of clear regulations regarding the treatment of vegetative wastes in Israel is a regulatory risk that only few entrepreneurs are willing to take; therefore only small-scale pilot projects are currently operating in the country, testing the viability of specific technologies.

In our analysis, we consider well-known technologies suitable for treatment of vegetative wastes.

Treatment technologies vary with respect to inputs, outputs, costs, and the prices of the generated output products. We briefly describe the treatment technologies considered in this study:

- Torrefaction – an anaerobic thermo-chemical process that produces charcoal (Bar-Ziv, 2012; Medic, 2012) for cooking (mainly in restaurants and on outdoor grills) or as biomass for electricity generation. This technology uses only woody residuals as input.
- Pyrolysis (slow) – a process of anaerobic thermo-chemical digestion of woody materials in a temperature range of 300–700 °C. Its input is generally based on foliage and woody waste, and the final products are heat and biochar. Biochar can be applied as a bio sorbent of environmental contaminants in contaminated soils or liquids. Biochar may also be used as a soil amendment for agricultural land, resulting in improved soil moisture, better nutrient absorption and pest management (Ahmad et al., 2014; Graber et al., 2014; Mohan et al., 2014), as well as for hydroponic crops and gardening.
- Animal-feed mixing – a process in which vegetative residuals are added to cattle and sheep food. Cattle and sheep diets may include between 10 and 50% agricultural residues in addition to silage. The specific vegetative wastes used by this technology are foliage and F&V residues (Yosef et al., 2015).
- RDF – a physical process of chopping and pressing biomass into briquettes or pellets with homogeneous calorific value, which are used for energy generation in industrial processes. This technology uses woody residuals or foliage as input (Srivastava et al., 2014).
- Composting – an aerobic process using microorganisms to produce a soil amendment. The vegetative wastes used by this technology are foliage and F&V residuals (Raviv et al., 2005).
- Anaerobic digestion – a thermophilic process using microorganisms for biomass digestion, and foliage and F&V residuals as input (Scano et al., 2014).

To date, there are few constrains or regulations on the implementation of the considered technologies, particularly regarding air pollution, but there are no clear directives regarding soil pollution which may be an issue of concern if biochar or compost are used in the field. Table 2 specifies the types of vegetative waste suitable for treatment by each of the treatment technologies.

Table 3 reports values and data sources of treatment costs, output-product prices and profits of the treatment technologies. The values are based on online open sources and interviews with entrepreneurs and investors operating pilot projects for testing the previously described technologies (torrefaction[2], pyrolysis[3], animal-feed[4], RDF[5], composting[6] and anaerobic digestion[7]). The scarcity of data on treatment costs and output-product prices neither allows us to account for potential economies of scale, nor for price responses to changes in the production of the recycled products. The prices of the recycled products are at the factory gate, representing the benefits accrue to the user. That is, the prices do not account for potential externalities associated with the products production and use; for example, climate benefits of biochar productions through carbon sequestration and ecological damages. All values are expressed in terms of average per ton of input waste.

2.2. Risk-neutral approach

Under the assumption of risk neutrality, the average market prices of the outputs generated by the various treatment technolo-

[2] Bar-Ziv, 2012.

[3] Pyreg (http://www.pyreg.de/machinery-en.html) and Peham-Ha'aretz (http://www.permacultureisrael.org/).

[4] Local facilities owners (Greenboim and Halevi), Ambar (http://www.mmambar.co.il/) and Shaham (http://shaham.moag.gov.il/Unit/animal/Pages/default.aspx).

[5] Redivivus (http://www.redivivus.co.il/).

[6] M. Raviv and Y. Laor at Neve-Yaar Research Center (http://www.agri.gov.il/en/units/regionalcenters/9.aspx) and from the investor I. Akiva.

[7] Eco-Energy Golan (https://www.youtube.com/watch?v = dI5ahgAEfY8).

Please cite this article in press as: Broitman, D., et al. Designing an agricultural vegetative waste-management system under uncertain prices of treatment-technology output products. Waste Management (2018), https://doi.org/10.1016/j.wasman.2018.01.041