Agronomy Research **11** (2), 391–404, 2013

Application of system dynamic model for the composting of petroleum contaminated soil under various policies

J. Vilgerts, L. Timma*, A. Blumberga, D. Blumberga and Dz. Slišāne

Riga Technical University, Institute of Environment and Energy Systems, Kronvalda bulvāris 1, LV-1010 Riga, Latvia;
*Correspondence: lelde.timma@rtu.lv

Abstract. In this paper the dynamic model for the composting of contaminated soils with petroleum products is presented. The main objectives of this study is to gain a deeper understanding about the dynamic relations between composting process and demand in the market and to determine how different policies will influence the model and therefore the total amount of recycled contaminated soil. The methodology applied consists of a system dynamic model, which describes the relationships between the cause and effect in complex and dynamic systems that have delays, feedbacks and non-linearities. The developed model passed both the behaviour validity and the tests of behavioural sensitivity. The validation indicated that the model is capable of generating 'the right behaviour for the right reasons'. This paper shows the results of four various policies (including reference scenario) and sensitivity analysis. The results of the research indicate that the most sensitive parameter is the volume available for composting, which is the main factor that influences the amount of recycled material.

Key words: bioremediation, composting, hazardous waste, system dynamics.

INTRODUCTION

A lot of efforts are being made in order to introduce a sustainable hazardous waste (HW) management system, nevertheless 154 kg of HW per capita were created in the European Union (EU) 27 member states in 2009. Eurostat estimates growth up to 198 kg of HW per capita in 2010 (European Commission, 2013). (European Environmental Agency, 2012) reports that waste reduction goals of the 6th European Action Program are not reached.

Within the EU the (Directive 2008/98/EC, 2008) on waste defines waste management hierarchy: firstly, waste prevention should be promoted, followed by recovery, and, as the last option, waste disposal can be considered. One of the key goals of the (Council Directive 1999/31/EC, 1999) on the landfill of waste is to gradually separate biodegradable waste from landfilling. Nevertheless, based on the (European Commission, 2013) report Bulgaria, Romania, Malta, Lithuania and Latvia has an extremely high reliance on landfilling, where over 90% of waste is still landfilled.

Not only statistical data but also scientific publications point out the growing need for a better waste management system. The growing amount of municipal solid waste in Latvia is forecasted by (Dace & Blumberga, 2012). (Sjöström & Östblom, 2010) showed no decoupling in waste generation from economic growth in Sweden also. The increasing amount of HW is reported in China (Duan et al., 2008). The intensity of HW in Latvia is studied by (Vilgerts et al., 2013[a]) to be in a corridor of + 18.4% to – 36.1% for the next 6 years. The total amount of HW in Latvia by 2020 in the optimistic scenario can decline by 27.7% or grow by 87.8% in the pessimistic scenario (Vilgerts et al., 2013[b]).

In order to comply with the waste framework policy the introduction of waste recovery methods will be needed. Bioremediation is a biological treatment method, which involves satisfying the specific conditions so the fitting microorganisms can thrive. During metabolic activities microorganisms utilise contaminants as nutrients, energy source or in co-metabolism, until the contaminants became biologically degraded (Jogdand, 2010).

One of the bioremediation strategies includes composting. For composting organic material containing hazardous chemicals a population of microorganisms is added with elevated temperatures and with addition of nutrients in order to increase their bioactivity (Thapa et al., 2012). Composting is a reliable method of recycling soils contaminated with petroleum products (Wang et al., 2011). The final product of composting can be used for road maintenance.

In recent years studies in waste management have attempted to incorporate systematic thinking in the sector (Yuan et al., 2012). As defined by (Seadon, 2010) 'The conventional waste management approach is that waste generation, collection and disposal systems are planned as independent operations. However, all three are very closely interlinked and each component can influence the other'. The dynamic relations within the waste management sector in Latvia are pointed out also in the research by (Kuplais et al., 2010). Nevertheless, application of system dynamic (SD) modelling in the waste sector has been studied only in some particular cases.

Studies done for the construction and demolition waste sector by application of SD models (Hao et al., 2007; Wang & Yuan, 2009; Yuan et al., 2011; Yuan, 2012) suggested use of SD because of the method's ability to deal with the complexity of interrelationships. Three policy scenarios for a construction and demolition waste management system have been compared within the SD model (Yuan et al., 2012) and the economic feasibility with the sensitivity analysis for the recycling centres of construction and demolition wastes (Zhao et al., 2011). The proposals for the improvement of the environmental performance of construction waste management were carried out from the simulations within the SD model (Ye et al., 2012).

The results of the SD model developed for a health care waste management system in the city of Jakarta, Indonesia (Chaerul et al., 2008) show that landfill sites in Jakarta city will be full by 2020 and a poor management system of HW can lead to the decrease in life expectancy in developing countries.

Impact assessment of the scavenging on the operation of the electrical and electronic equipment management systems was conducted with the SD model (Besiou et al., 2012). The results of the research showed that legal incorporation of scavenging with a formal recycling system would be beneficial for the economy, environment and social sustainability.

The amount of the waste from the energy sector has been studied in China with SD model (Yu & Wei, 2012). Authors concluded that environmental pollution from coal will continue to increase in China even after 2030.

In the area of urban waste management studies on the application of SD for developing countries (Sudhir et al., 1997), for the transition model from landfilling (Mashayekhi, 1993), for the forecasting of the amount of generated waste, (Karavezyris et al., 2002; Dyson & Chang, 2005; Sufian & Bala, 2007), to model electricity generation from waste (Sufian & Bala, 2006), to test a link between the ecological characteristics and waste management (Cummings & Cayer, 1993), to analyse the influence of local policy initiatives on waste recycling (Ulli-Beer, 2003), on the effects of the pricing systems on the waste management (Ulli-Beer et al., 2007) and for the planning of sustainable waste (including hazardous waste) management system (Kollikkathara et al., 2010) have been investigated. The SD model for the management system for municipal solid waste disposal revealed policy instruments, which can reduce methane emissions to the level of 2001 by the year 2025 in Delhi (Talyan et al., 2007).

The management of municipal water and wastewater networks in the framework of an SD approach have seen applications in simulations of technical innovations (Kotz & Hiessl, 2005), of sustainability within the sector (Guest et al., 2010), testing the interconnections between the demand and supply side (Ahmad & Prashar, 2010) and in the frame of the utility view point (production, distribution, operation, maintenance and finance sectors) (Adeniran & Bamiro, 2010), self-sustainable water utility (Rehan et al., 2011). The evaluation of efficacy of microalgae usage in the treatment of the leachate from municipal landfills and hypersaline effluent from desalination plants conducted by (Richards & Mullins, 2013) applied SD modelling. The results showed that after a 10–day period the microalgae have removed over 95% of metals from the mixtures.

In this paper the dynamic model for the composting of contaminated soils with petroleum products is presented.

The main objectives of this study is to gain a deeper understanding about the dynamic relations between the composting process and demand in the market and to determine how different policies will influence the model and therefore the total amount of recycled contaminated soil. The methodology applied consists of a system dynamic (SD) model, which describes the relationships between the cause and effect in complex and dynamic systems that have delays, feedbacks and non-linearities.

MATERIAL AND METHODS

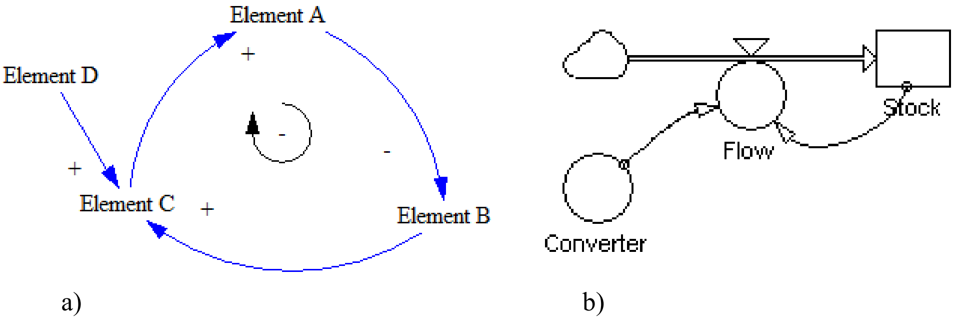
Under this paragraph the methodology of system dynamics, development of the model and assumptions, the descriptions of scenarios and validation of the model will be presented.

The methodology of system dynamics

System dynamics was first presented by (Forrester, 1958) nowadays the SD modelling is applied in a wide range of sectors: management of water resources systems (Mirchi et al., 2012), analysis of product-service systems (Lee et al., 2012), assessment of policy tools in the energy sector (Blumberga et al., 2013).

The SD technique enables to acquire the relationships between the cause and effect in complex and dynamic systems that have delays, feedbacks and non-linearities. The methodology of SD applies a computer simulation model, which is developed for the problem under review. The structure of SD model is built on diagrams of causal loop, which defines the main feedback mechanisms within the system (Forrester, 1961; Sterman, 2000). A diagram of causal loop is given in Fig. 1 a).

The diagram of causal loop consists of elements and causal links (arrows). A causal link is '+' in the case if A adds to B or an alteration in A gives an alteration in B in the same direction. A causal link is '–' in the situation when A subtracts from B or an alteration in A produces an alteration in B in the opposite direction. A diagram of causal loop allows exploring the chain effects of a cause.



a) b)

Figure 1. a) a diagram of causal loop and b) a stock–flow diagram.

In order to obtain a quantitative model a diagram of causal loop is converted to a stock–flow diagram. The stock–flow diagram consists of four main 'building blocks': a stock, flow, converter and connector, see Fig. 2 b).

A stock has two functions – it accumulates in–flows and is a source of out–flows. A flow defines a rate change for a flow of information and for physical flow from and to the stocks.

A flow can be either positive (in–flow) or negative (out–flow). An in–flow will fill a stock and out–flow will drain a stock. A converter is used for miscellaneous calculations and transforms information from stock variables to flow variables.

A converter is used to select functions and variables therefore, a converter has a utilitarian role in the model. A connector transmits information between elements. The relationships between a stock and flow can be expressed by the Eq. 1 and Eq. 2.

$$\mathrm{Stock(t)} = \mathrm{Stock(t - d_t)} + \mathrm{(flow)d_t} \tag{1}$$

$$\mathrm{Stock} = \int \mathrm{(flow)dt} \tag{2}$$

Development of the model and assumptions

The model for the composting of petroleum contaminated soil was created within five-steps.

Firstly, the main variables, which influence the behaviour of the system, were identified and included into the model. The identified variables were associated with the interaction between them and the diagrams of casual loop were obtained. The construction of a stock-flow diagram based on the presented diagrams of causal loop followed. The developed model was validated. The sensitivity analysis of the model variables was carried out. The final step was the simulation of various scenarios and analysis of the effects on the model results.

As the raw materials for the composting of petroleum contaminated soil: sewage sludge, filling additives (wood chips or straw or turf) and bioeffect (the mixture of nitrogen and microorganisms) were used. From the experts the proportions between raw materials were obtained as 30 : 50 : 15 : 5 (petroleum contaminated soil : sewage sludge : filling additives : bioeffect).

It is assumed that petroleum contaminated soil contains a maximum 50 g of petroleum products within 1 kg of soil. The final product is used for road maintenance and it is assumed safe for sale in the domestic market and for export annually. The initial capacity of a composting field is assumed to be 4000 m^2. Other constants are given in the Appendix.

Description of the model with causal loop diagrams

The developed model has four negative feedback loops. The diagrams of casual loop for the model are given in Fig. 2.

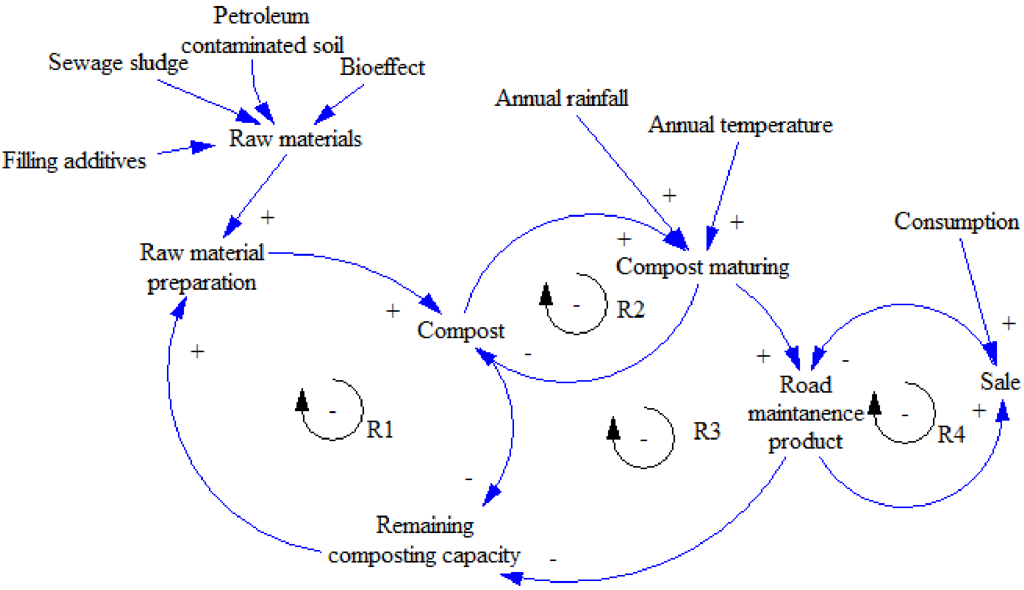


Figure 2. The diagrams of causal loop.

In the negative feedback loop R1, increase in the amount of compost would lead to a decrease in the remaining composting capacity. Since the remaining composting capacity decreases, the rate of raw (composting) material preparation will decrease as well. Consequently, because of the limited space for composting, the efforts to increase the amount of compost will further accelerate the reduction of the amount of compost available for composting.

For the loop R2 suppose the production rate of compost maturing increases due to favourable climate conditions for composting, the amount of the compost in storage therefore will decrease. Due to the decrease in the amount of compost, the production rate of compost maturing will eventually decline as well.

In the negative feedback loop R3 an alteration in any variable will eventually influence itself in a negative manner. By increasing the amount of matured compost the remaining capacity for the composting will decrease. The reduction in the remaining capacity for the compost will in turn reduce the amount of compost (see description of the loop R1), which then reduces the production rate of compost maturing (see description of the loop R2). As a result, when the production rate of matured compost decreases the amount of matured compost (final product) also reduces.

Finally, the loop R4 explains the role of the market within the model. In the case when sales increases, the amount of matured compost decreases, which in turn will decrease sales, because of the limited amount of the final product.

Until demand will be present in the model, in other words, sales will trigger the negative feedback loop R4, the feedback relations within the loop R3 will ensure that the decrease in the amount of the matured compost would be counteracted by an increase in the raw materials preparation rate (the loop R1) and the increase in the production rate of compost maturing (the loop R2) which in total leads to the increase of the amount of matured compost. In the case when demand is zero, the production of the matured compost stops.

Formulation of the model through stock-flow diagrams

Stock-flow diagrams are a more detailed description of causal loop diagrams. The model consists of three stocks: the compost, road maintenance product (matured compost) stocks and the total amount of recycled soil; see Fig. 3.

The in–flow for the compost stock is made up from the flow of raw material preparation. The compost stock is limited by the total composting capacity. The out–flow from the compost stock leads to the flow of compost maturing. The direct variables affecting the flow of compost maturing are environmental conditions and the compost stock. For the stock of road maintenance product (matured compost) there is the in–flow of compost maturing and the out–flow of sales. The stock representing the total amount of recycled soil is linearly proportional to the amount of petroleum contaminated soil used for the composting. Detailed equations for the model are given in the Appendix. For the simulation software Powersim 8 was used.

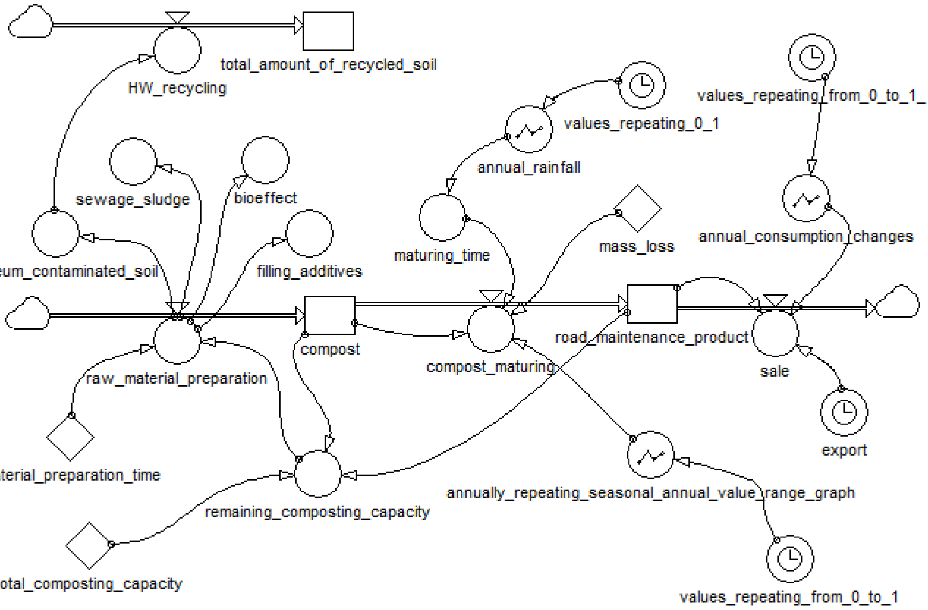


Figure 3. SD model for petroleum contaminated soil composting.

Scenarios description

The total amount of recycled hazardous material (petroleum contaminated soil), is estimated in the SD model. The simulation is done for the time period of 5 years.

For the reference scenario the initially defined values within the model are used, see Appendix. The composting capacity was set to 4,000 m^3, the mass loss of matured compost to 20%, minimal temperature for compost maturing 10 °C. 1,000 m^3 of compost are initially located in the stocks of the compost and road maintenance product. Export of the final product is set to be 4,000 m^3 $year^{-1}$. The sales in the domestic market are defined by the function of annual consumption changes, for a detailed description see Appendix.

Three additional policy scenarios were developed: scenario A, scenario B and scenario C. Scenario A – it is economically viable to use more area for composting therefore the total composting capacity is increased up to 6,000 m^3. Scenario B – due to public awareness the demand for the road maintenance product, which is produced from recycled materials increases by 50% (both in domestic market and abroad). Scenario C: scenario A and scenario B are combined.

Validation of the model

Data availability and quality are always the main concerns for modelling studies. There are no models that completely represent the studied systems. Validation of system dynamics models enables us to understand whether the model is acceptable for its intended use (Forrester, 1961). It also enables us to build confidence in the model based on observations and data from a real system (Barlas, 1996; Sterman, 2000). The validation tests include structural validation tests. Saysel and Barlas, (2001) states that the most powerful and practical structural validation tests combines both tests under extreme conditions and tests of behaviour sensitivity. It should also be kept in mind that the main purpose of the SD model is to capture the broad dynamic behaviour patterns of the real system, and not provide ‘point’ predictions.

The test under extreme conditions involves the assignment of extreme values to the model and comparison of the model outputs under extreme condition to the real systems outputs under the same conditions. The total composting capacity is one of the most sensitive parameters in the model, therefore it has been chosen for the behaviour validity tests. The results of the behaviour validity tests are given in Fig. 4.

Under the extreme conditions, the outputs from the model (the total amount of recycled soil and road maintenance product) followed the changes in the total composting capacity. The tests of behaviour validity showed a realistic response of the model under the tested conditions.

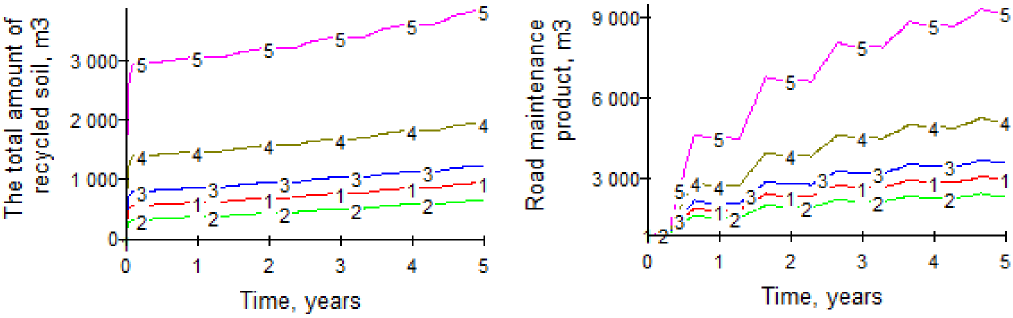


Figure 4. The behaviour validity tests. On the left – the total amount of recycled soil and on the right – the road maintenance product (line 1: the reference scenario = initial composting capacity 4,000 m^2, line 2: 20% decrease, line 3: 20% increase, line 4: 70% increase, line 5: 200% increase in the initial composting capacity).

Sensitivity of the model can be seen when various simulated runs are compared. For the 2nd (line 2) and 3rd run (line 3) the increase in the total amount of recycled soil and road maintenance product is not as high as in the 5th run (line 5) when extreme increase is simulated.

The developed model passed both the behaviour validity and the tests of behavioural sensitivity. The validation indicated that the model is capable of generating ‘the right behaviour for the right reasons’.

RESULTS AND DISCUSSION

The results of sensitivity analysis and four policy scenarios (reference scenario, scenario A, scenario B and scenario C) are discussed in this section to ascertain the impacts of various mechanisms on HW (petroleum contaminated soil) utilisation by composting.

Sensitivity analysis

The impacts of the variations in the values of five input parameters on the total amount of recycled HW (contaminated soil) are given in Fig. 4.

The results of the sensitivity analysis show that the model is most responsive to the changes in the amount of composting capacity. The second most influential factor is the flow rate of products' export and sales in the domestic market. Both above mentioned parameters influence the amount of remaining capacity available for composting, since the increase in consumption triggers the negative feedback loop R4 and R3, see Fig. 2 and the increase in the total amount of composting capacity available is directly linked to the remaining composting capacity, see Fig. 3 and Appendix.

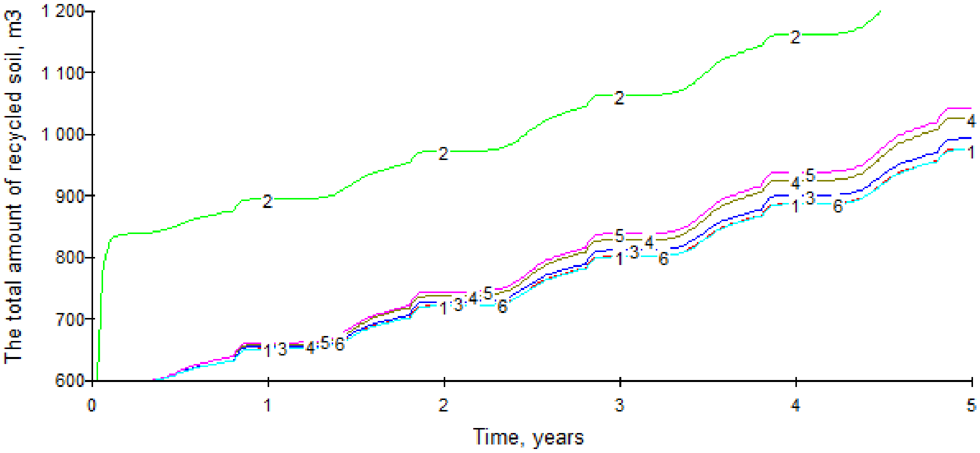


Figure 5. The results of sensitivity analysis (line 1: reference scenario, line 2: 20% increase in the total composting capacity, line 3: 20% increase in export, line 4: 20% in domestic consumption, line 5: 20% increase in sales (both domestic market and export), line 6: 20% increase in time needed for material preparation).

Policy scenarios

The results obtained by simulations of four policy scenarios are shown in Fig.6.

The total amount of recycled hazardous material (contaminated soil) in the reference scenario reaches 977.73 m^3 at the end of 5th year. The largest amount of recycled soil is obtained in scenario C, where the amount of recycled soil is 83.3% higher than in the reference scenario. The second best result was given by scenario A – the amount of recycled soil increased by 74.1% in comparison to the reference scenario.

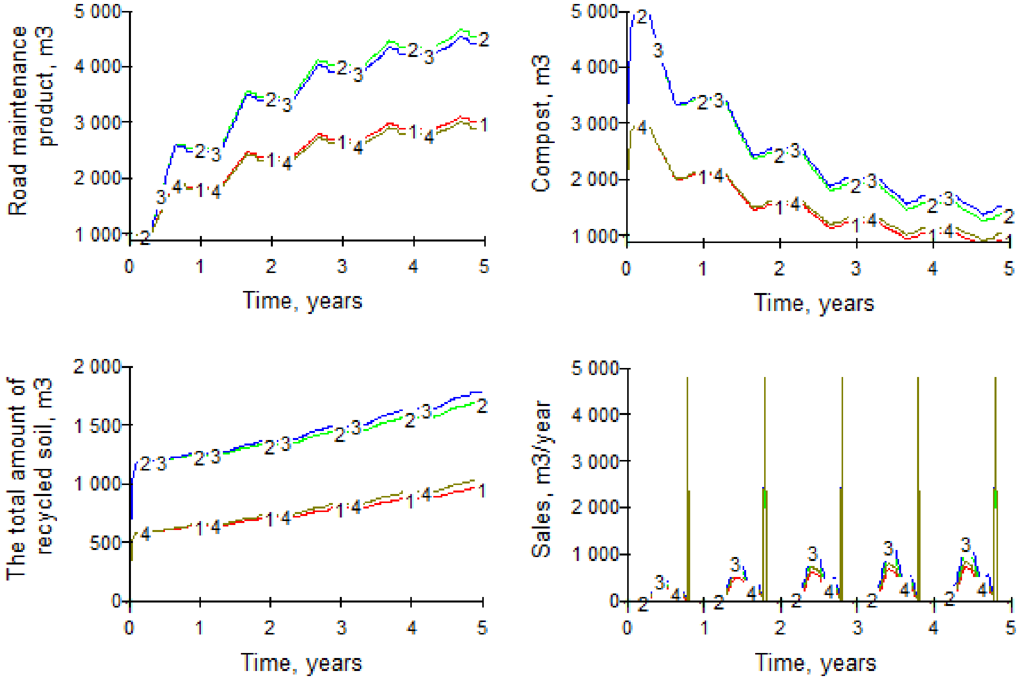


Figure 6. The results for policy scenarios (line 1: reference scenario, line 2: scenario A, line 3: scenario C, line 4: scenario B).

As can be seen in Fig. 6, in the first two years there is a rapid increase in the amount of road maintenance product followed by a slower growth in the following three years. In this case limited availability of raw materials for composting would pose an additional problem in the early stage of operation.

Another limiting factor in the model is the total capacity of the composting utility; therefore it is essential to take into account the sales rate, which in the end defines the remaining capacity for composting of new raw materials. The highest impact is associated with the changes in the remaining composting capacity. The explanation for the high sensitivity of the parameter is associated with relatively high absolute value of the remaining capacity in comparison with other variables in the model. For the case when the available space for the composting capacity will be decreased the influence of the remaining parameters will gain importance. The main difference between the results of scenarios can be seen in the rate at which the hazardous waste is recycled, in this case – petroleum contaminated soil. The findings of this research point out the dynamic relations within the model and the relationships between a cause and effect that have delays, feedbacks and has a nonlinear nature.

CONCLUSIONS

Application of system dynamic modelling in the waste sector has been studied only within a few particular cases: electrical and electronic equipment, energy sector, construction and demolition waste, health care waste, municipal solid waste, municipal water and wastewater sectors. This study concentrates on the application of SD modelling for composting. Composting is a safe way of recycling petroleum contaminated soil. The end products of composting can be used in road maintenance.

A model comprising of four feedback loops is developed based on the principles of system dynamics. To ensure the validity of the model structural validation tests were carried out. The developed model passed both the behaviour validity and tests of behavioural sensitivity. The validation indicated that the model is capable of generating 'the right behaviour for the right reasons'.

The results of sensitivity analysis and policy simulation tests indicate that the composting capacity has the greatest impact on the amount of recycled soil and end product (road maintenance material).

This paper shows the results of four different policies (including reference scenario). However, based on the model, similar scenarios comprising other policies could also be simulated and discussed.

Future studies could be directed at the investigation of different bioeffects and their influence on the amount of time in which compost matures.

APPENDIX

Total amount of recycled soil (t) = total amount of recycled soil (t – dt) + HW recycling × dt
INIT total amount of recycled soil = 0
HW recycling = petroleum contaminates soil
Compost (t) = compost (t – dt) + raw material preparation × dt
INIT compost = 1,000
Raw material preparation = remaining composting capacity / material preparation time
Remaining composting capacity = total composting capacity – compost – road maintenance product
INIT total composting capacity = 4,000
INIT material preparation time = 0.4 / 12
Petroleum contaminated soil = raw material preparation × 0.3
Sewage sludge = raw material preparation × 0.5
Bioeffect = raw material preparation × 0.05
Filling additives = raw material preparation × 0.15
Road maintenance product (t) = road maintenance product (t – dt) + compost maturing × dt
INIT road maintenance product = 1,000
Compost maturing = IF (annually repeating seasonal annual value range graph > 10, THEN compost / mass loss / maturing time, ELSE 0)
INIT mass loss = 5
Maturing time = annual rainfall / 79 – 0.2
Annual rainfall = GRAPH (values repeating 0 1, 0, 1, [33, 25, 31, 39, 43, 61, 79, 79, 76, 60, 61, 49 'Min:0; Max:80'])
Road maintenance product (t) = road maintenance product (t – dt) – sale × dt
Sale = road maintenance product × annual consumption changes + export
Annual consumption changes = GRAPH (Values repeating from 0 to 1, 0, 0.1, [0, 0, 0.02, 0.09, 0.26, 0.22, 0.08, 0.11, 0, 0, 0 'Min:0; Max:1'])
Export = PULSE (4000 × TIMESTEP, 0.8, 1)

REFERENCES

Adeniran, E.A., & Bamiro, O.A. 2010. A system dynamics strategic planning model for a municipal water supply scheme. *proceeding of 28th international conference of the system dynamics society*. Seoul (Korea), 1–14.

Ahmad, S. & Prashar, D. 2010. Evaluating municipal water conservation policies using a dynamic simulation model. *Water resources management* **24**, 3371–3395.

Barlas, Y. 1996. Formal aspects of model validity and validation in System Dynamics, *System Dynamics Review* **12**, 183–210.

Besiou, M., Georgiadis, P. & Wassenhove, L.N.V. 2012. Official recycling and scavengers: symbiotic or conflicting? *European journal of operational research* **218**, 563–576.

Blumberga, A., Blumberga, D., Bazbauers, G., Zogla, G., Laicane, I. 2013. Sustainable development modelling for energy sector. *Under the final review for publication in the journal of cleaner production*, 13 pp.

Chaerul, M., Tanaka, M. & Shekdar A.V. 2008. A system dynamics approach for hospital waste management. *Waste management* **28**, 442–449.

Council Directive 1999/31/EC on the landfill of waste 1999. *Official journal of the European communitie*s, 19 pp.

Cummings, L.E. & Cayer, N.J. 1993. Environmental policy indicators: a systems model. *Environmental management* **17**, 655–667.

Dace, E. & Blumberga, D. 2012. An assessment of the potential of refuse-derived fuel in Latvia. *Management of environmental quality* **23(5)**. 503–516.

Directive 2008/98/EC on waste and repealing certain Directives. 2008. *Official journal of the European Union,* 28 pp.

Duan, H., Huang, Q., Wang, Q., Zhou, B., Li, J. 2008. Hazardous waste generation and management in China: A review. *Journal of hazardous materials* **158**, 221–227.

Dyson, B. & Chang, N.B. 2005. Forecasting municipal solid waste generation in a fast growing urban region with system dynamics modelling, *Waste management* **25**, 669–679.

European Commission, 2013. *Report from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions on the implementation of the EU waste legislation COM (2013) 6 final,* 17 pp.

European Environmental Agency, 2012. *Material resources and waste, the European environment, state and outlook 2010,* 50 pp.

Forrester, J.W. 1958. *Industrial dynamics: a major breakthrough for decision makers*, Harvard business review **36 (4)**, 37–66.

Forrester, J.W. 1961. *Industrial dynamics.* Pegasus Communications, Waltham, USA, 646 pp.

Guest, J.S., Skerlos, S.J., Daigger, G.T., Corbett, J.R.E., Love, N.G. 2010. *The use of qualitative system dynamics to identifies sustainability characteristics of decentralized wastewater management alternatives,* Water science and technology **61**, 1637–1644.

Hao, J.L., Hills, M.J. & Huang, T. 2007. *A simulation model using system dynamic method for construction and demolition waste management in Hong Kong*, Journal of construction innovations **7**. 7–21.

Jogdand, S.N. 2010. *Environmental biotechnology industrial pollution management*, Mumbai, Global Media, 115 pp.

Karavezyris, V., Timpe, K.P. & Marzi, R. 2002. Application of system dynamics and fuzzy logic to forecasting of municipal solid waste, *Mathematics and computers in simulation* **60**, 149–158.

Kollikkathara, N., Feng, H. & Yu, D. 2010. A system dynamic modeling approach for evaluating municipal solid waste generation, landfill capacity and related cost management issues, *Waste management* **30**, 2194–2203.

Kotz, C. & Hiessl, H. 2005. Analysis of system innovation in urban water infrastructure systems: an agent-based modelling approach, *Water science and technology water supply* **5**, 135–144.

Kuplais, G., Blumberga, D. & Dace, E. 2010. System analysis for integration of landfill energy production in regional energy supply, *WIT Transactions on ecology and the environment* **140**, 21–30.

Lee, S., Geum, Y., Lee, H., Park, Y. 2012. Dynamic and multidimensional measurement of product-service system (PSS) sustainability: A triple bottom line (TBL)-based system dynamics approach, *Journal of cleaner production* **32**, 173–182.

Mashayekhi, A.N. 1993. State solid waste system: a dynamic analysis, *Transition in the New York: System Dynamics Review* **9**, 23–47.

Mirchi, A., Madani, K., Watkins, Jr.D., Ahmad, S. 2012. Synthesis of system dynamics tools for holistic conceptualization of water resources problems, *Water resources management* **26**, 2421–2442.

Rehan, R., Knight, M.A., Haas, C.T., Unger, A.J.A. 2011. Application of system dynamics for developing financially self-sustaining management policies for water and wastewater systems, *Water research* **45**, 4737–4750.

Richards, R.G. & Mullins, B.J. 2013. Using microalgae for combined lipid production and heavy metal removal from leachate, *Ecological modelling* **249**, 59–67.

Saysel, A.K. & Barlas, Y. 2001. A dynamic model of salinization on irrigated lands, *Ecological modelling* **139**, 177–199.

Seadon, J.K. 2010. Sustainable waste management systems, *Journal of cleaner production*, **18**, 1630–1651.

Sjöström, M. & Östblom, G. 2010. Decoupling waste generation from economic growth - A CGE anaysis of the Swedish case, *Ecological economics* **69**, 1545–1552.

Sterman, J.D. 2000. *Business dynamics: systems thinking and modelling for a complex world*, Irwin/McGrw-Hill, Boston 982 pp.

Sudhir, V., Srinivasan, G. & Muraleedharan, V.R. 1997. Planning for sustainable solid waste management in urban India, *System dynamics review* **13**, 223–246.

Sufian, M.A. & Bala, B.K. 2006. Modelling of electrical energy recovery from urban solid waste system: The case of Dhaka city, *Renewable energy* **31**, 1573–1580.

Sufian, M.A. & Bala, B.K. 2007. Modelling of urban solid waste management system: the case of Dhaka city, *Waste management* **27**, 858–868.

Talyan, V., Dahiya, R.P., Anand, S., Sreekrishnan, T.R. 2007. Quantification of methane emission from municipal solid waste disposal in Delhi, *Resources, conservation and recycling* **50**, 240–259.

Thapa, B., Kumar, A.K.C. & Ghimire, A. 2012. A review on bioremediation of petroleum hydrocarbon contaminants in soil, *Kathmandu University journal of science, engineering and technology* **8**, 164–170.

Ulli-Beer, S. 2003. Dynamic interactions between citizen choice and preferences and public policy initiatives – a system dynamics model of recycling dynamics in a typical Swiss locality, *Proceedings of the 2003 International Conference of the System Dynamics Society*

Ulli-Beer, S., Andersen, D.F. & Richardson, G.P. 2007.Financing a competitive recycling initiative in Switzerland, *Ecological economics* **62**, 727–739.

Vilgerts, J., Timma, L. & Blumberga, D. 2013[a]. A methodology for forecasting hazardous waste flows, *accepted for the publications in the proceeding of the 7th International conference on the impact of environmental factors on health Environmental Health Risk 2013,* 10 pp.

Vilgerts, J., Timma, L. & Blumberga, D. 2013[b]. A forecast model for projecting the amount of hazardous waste, *accepted for publication in the proceedings of International conference on waste management 2013*, 4 pp.

Wang, J.Y. & Yuan, H.P. 2009. Construction waste management model based on system dynamics, *Systems engineering* **29**, 173–180.

Wang, Z., Xu, Y., Zhao, J., Li, F., Gao, D., Xing, B. 2011. Remediation of petroleum contaminated soils through composting and rhizosphere degradation, *Journal of hazardous materials* **190**, 677–685.

Ye, G., Yuan, H., Shen, L., Wang, H. 2012. Simulating effects of management measures on the improvement of the environmental performance of construction waste management, *Resources, conservation and recycling* **62**, 56–63.

Yu, S. & Wei, Y. 2012. Prediction of China's coal production-environmental pollution based on a hybrid genetic algorithm-system dynamics model, *Energy policy* **42**, 521–529.

Yuan, H., Chini, A.R., Lu, Y., Shen, L. 2012. A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste, *Waste management* **32**, 521–531.

Yuan, H. 2012. A model for evaluating the social performance of construction waste management, *Waste management* **32**, 1218–1228.

Yuan, H.P., Shen, L.Y., Hao, J.J.L., Lu, W.S. 2011. A model for cost–benefit analysis of construction and demolition waste management throughout the waste chain, *Resources, conservation and recycling* **55**, 604–612.

Zhao, W., Ren, H. & Rotter, V.S. 2011. A system dynamics model for evaluating the alternative of type in construction and demolition waste recycling center – The case of Chongqing, China, *Resources, conservation and recycling* **55**, 933–944.