TECHNIUM

Technium Vol. 2, Issue 5 pp.92-104 (2020)
ISSN: 2668-778X
www.techniumscience.com

Anaerobic digestion life cycle assessment (LCA)

Farhad Sakhaee,*
School of Engineering, Parks College of Engineering, Aviation and Technology,
Saint Louis University, USA
farhad.sakhaee@slu.edu

Nader Sakhaee
Chemistry Dept. Southern Illinois University Edwardsville, IL, USA
nsakhae@siue.edu

Abstract: Life cycle assessment (LCA) is a tool to evaluate environmental impacts based on products of a process. This research is a case study of wastewater treatment facilities of ERTC (Environmental Resources Training Center), SIUE University, based on available data for two semi-annual sludge quantities (year 2015) from sludge management report. The aim of this study is to compare set of possibilities for a wastewater treatment facility at ERTC. The simulation has been done through SimaPro model. Electricity and methane were considered and the cumulative weight of their impacts has been investigated. Total solids for two semi-annual sludge has been fed to the model in kilogram and different production (electricity and methane) configuration were investigated. The most plausible configuration based on the cumulative environmental impact proposed as best practical solution.

Keywords: Sludge disposal treatment, Anaerobic digestion, Life Cycle Assessment (LCA)

1. Introduction:

There are many ways for treating wastewater treatment sludge, amongst them anaerobic digestion is one of the most efficient and most environmental friendly process, which meets the environmental needs due to sustainability engineering criteria during different phases. [1, 2]. Sludge management had been considered as a secondary issue compared to the main wastewater treatment processes, but in last decades it became more important in terms of pollutant control in the systems due to strong growth of sludge output. Results showed combination of anaerobic digestion and agricultural land application were most environmental friendly methods with less emissions and less consumption of energy. This research is a case study of sludge disposal treatment by anaerobic digestion method at (ERTC) at SIUE. Life cycle assessment is a tool to assess the environmental impacts throughout a products life cycle from raw material to waste management phase. Figure1.Shows different phases of a life cycle assessment project. [3]

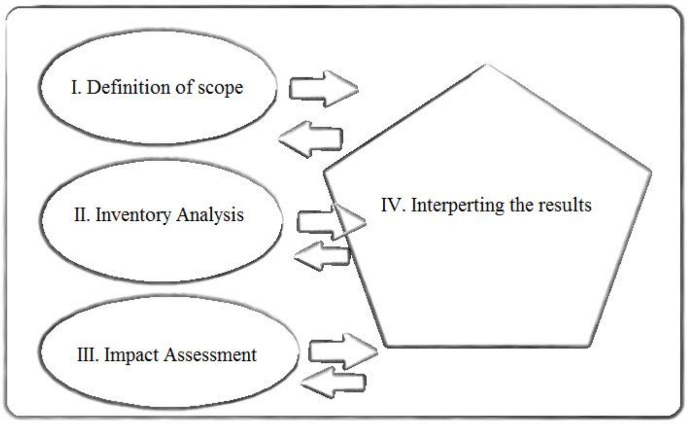


Figure 1. Life cycle assessment different phases.

Figure 2. Shows a schematic in which one kilogram of dry sludge turns into energy to produce a sustainable energy cycle.

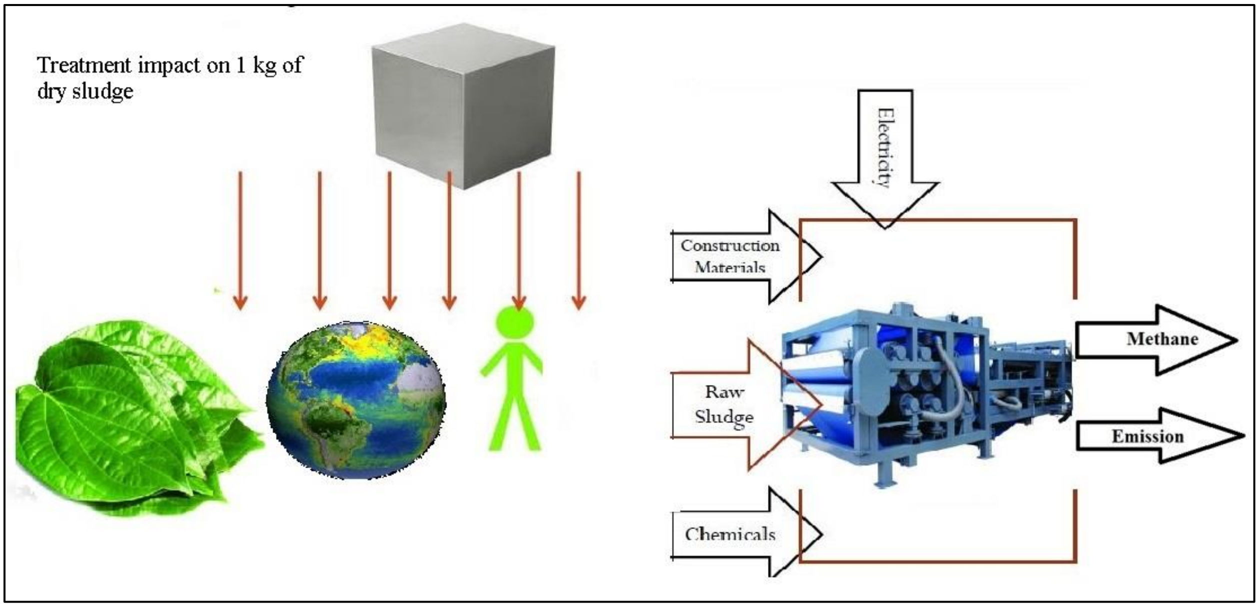
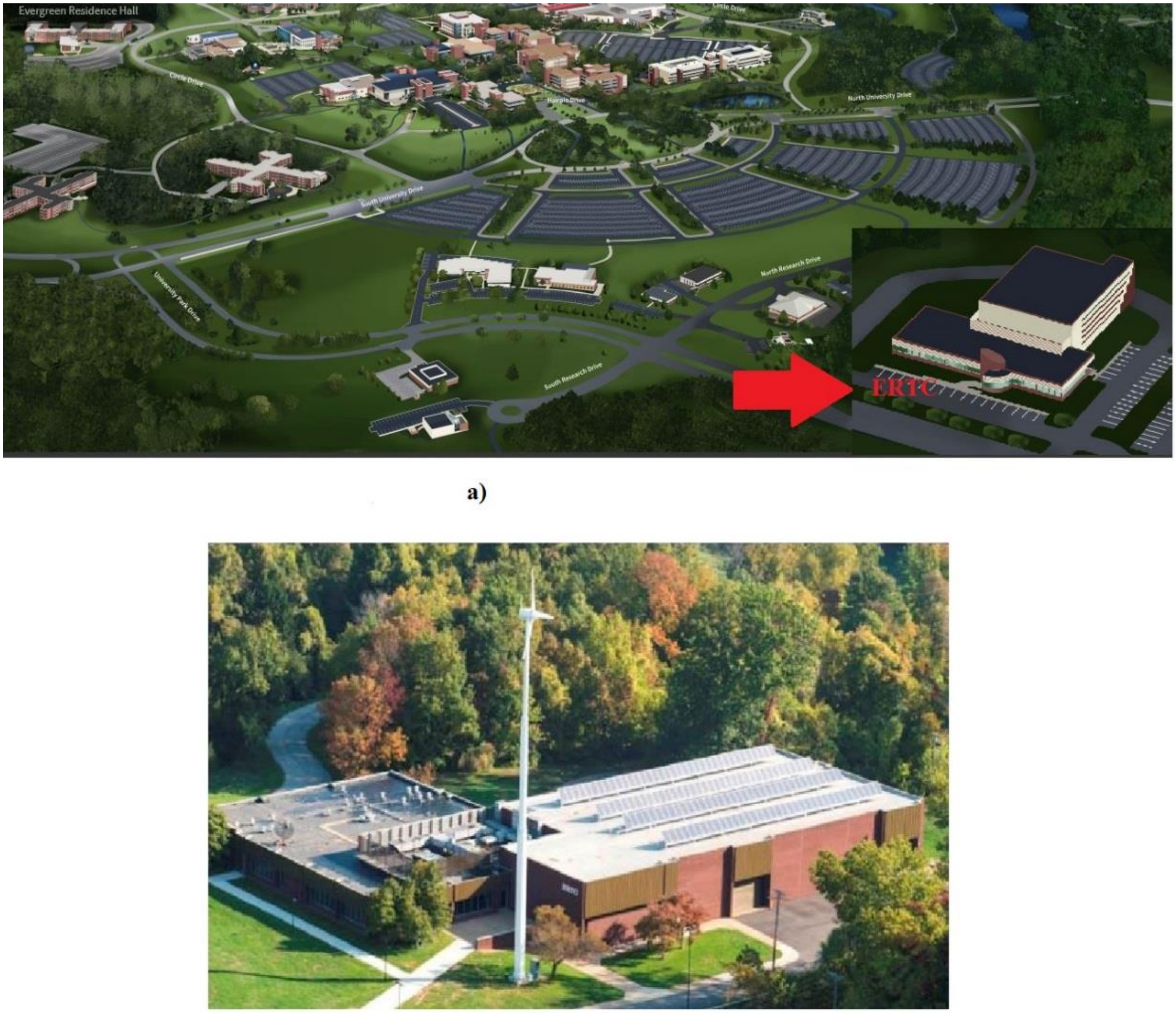


Figure 2. Schematic for sludge treatment impact and energy produ

Study area

Figure 3. Shows the physical location of ERTC in southern Illinois University of Edwardsville.



a)

b)

Figure 3. Location of Environmental Resources Training Center (ERTC) SIUE.

2. Overview and historical background

2.1. SIUE Sludge Facility

The wastewater plant was built in 1963. The water enters at the “HEADWORK”, it passes through bar racks to remove the larger solids holding them from damaging pumps or interfering with downstream process. The sludge being processed in two anaerobic digesters which consist of a primary and secondary unit that has a combined storage of 468000 gallons. The methane produced by the digesters is used as a fuel for a heat exchanger that keeps the sludge at a constant temperature of around 96 degrees Fahrenheit. Digested sludge is drawn-off from the secondary digester twice a year by a contractor who applies it to agricultural land owned by university. The sludge is injected sub-surface into the soil and utilized as a fertilizer. The Environmental Resources Training Center, sludge report on this paper based on the two-semi-annual set of data. First: Jan to June 2015, Second: July to December 2015.

2.2. Historical background

Historical evidence indicates that the AD process is one of the oldest technologies. Biogas was used for heating bath water in Assyria during the 10th century BC and in Persia during the 16th century (www.biogasworks.com). AD advanced with scientific research and, in the 17th century, Jan Baptista Van Helmont established that flammable gases evolved from decaying organic matter. Also, Count Alessandro Volta in 1776 showed that there was a relationship between the amount of decaying organic matter and the amount of flammable gas produced. In 1808, Sir Humphry Davy demonstrated the production of methane production by the anaerobic digestion of cattle manure.[4] The industrialization of AD began in 1859 with the first digestion plant in Bombay, India. By 1895, AD had made inroads into England where biogas was recovered from a well-designed sewage treatment facility and fueled street lamps in Exeter. Further AD advances were due to the development of microbiology. Research led by Buswell and others in the 1930s identified anaerobic bacteria and the conditions that promote methane production.

2.3. General process description

Generally, the overall AD process can be divided into four stages: pretreatment, waste digestion, gas recovery and residue treatment. Most digestion systems require pre-treatment of waste to obtain homogeneous feedstock.[5]

3. Scope and goals of this study

The goal of this study is to evaluate the resources consumptions and their consequent environmental impacts by making a life cycle assessment for different scenarios. The system boundaries of the study are as follow: a single stage unit of anaerobic digestion has been considered as a process unit, and the effect of input, and outputs calculated during a life cycle assessment. The environmental impacts related to minor consumable materials and the construction are not considered because the impacts were negligible than those of the long operate period (more than 30 years). Thermal energy recovered from the anaerobic digestion is used to warm up the input sludge. This is actual operation conditions at most sites. A distant of one mile (two miles for two-way trip) considered as an average transport distant for agricultural landfill. The sludge is transported by tanker truck to the application site where it was injected into the subsoil. Digestate removed from the reactor would likely need to be cured before it could be considered as a marketable product or a material used to produce a blended soil conditioner. Approximately 40 to 45 percent of the tonnage delivered to an SSO plant would require curing while 30 to 35 percent of all delivered material to a mixed waste facility would require post reactor aerobic treatment.

4. Materials and method

4.1. Available data

Input data are methane biogas, electricity transportation energy, emissions to the air including (Nitrogen, Carbon dioxide, Carbon monoxide) as well as emissions to soil (Chromium, cadmium, copper, nickel, potassium, zinc, selenium, manganese and molybdenum) which are all include in Table 4. The semi-annual raw sludge is also provided for year 2015.

Table 1 and 2 Below show the raw sludge quantity for year 2015, from sludge management report.

Table 1: Quantity of raw sludge First semi-annual

Month	Gallons to Digester	%TS
Jan	54400	
Feb	78200	
May	67300	
Apr	81700	Ave=2.76
May	60950	
June	28900	
Total	371450	

Table 2: Quantity of raw sludge Second semi-annual

Month	Gallons to Digester	%TS
July	54000	
Aug	35600	
Sept	82100	
Oct	85200	Ave=3.43
Nov	79000	
Dec	85900	
Total	421800	

4.2. Functional unit definition

Functional unit defined as the base unit of assessment in the (LCA) and, here considered to be one ton of sludge in dry basis (one tDM) Dry Mass. [6-12] The reason of this selection was based on the essential feed of the digester which was feeding sludge, 1500 to 3000 gallons per day. Sludge was pumped to the digester. In table.2 percentages of total solid (%TS) is equal to 3.43, hence calculating of dry mass of sludge is: dry mass of sludge = (weight of every gallon of water) *(%TS). Other inputs and outputs must be changed to functional unit, for example electricity amount for processing one dry ton of sludge must be calculated. [13-17], all emissions to air and soil, and even transportation of the hauled sludge to the land farm must be converted to mass per dry ton of sludge. for example, the distant of land farm to the treatment is one mile for two-way trip considered 3.21869 ton.km as a distant*dry ton of sludge, for instance the potassium amount in emissions to soil is 5310 mgr./kg equal to 5310 gr/ton. Functional unit for sludge treatment considered as ton per dry mass of sludge as explained earlier. Every gallon of water weights around 8.34 lbs., and 1 ton= 2000 lbs. Table.3 was used as estimation of amount of energy produced by the methane biogas considering the capacity of digester tanks of SIUE, input energy used from methane evaluated as 167 MJ/D.TON. [5].

Table 3: Methane energy produced estimation

Methane	55-70% by vol.
Carbone dioxide	30-45% by volume.
Hydrogen sulphide	200-4000 PPm by vol.
Energy content of AD has product	20-25 MJ/Standard m^3
Energy content ofCH_4 per ton MSW	167-373 MJ/Yon MSW

4.3. Procedure

Life cycle assessment has been done based on three elements in this study which are energy, raw material and, emission. (a) Energy: the amount of electricity and methane (biogas) calculated for heating one ton of dry sludge based on functional unit, also the percentage of each resource allocated due to possible degree for recovery of biogas. (b) Raw material: the sludge category determined due to its characters and region, whether municipal or industrial sludge is feed as an input. (c) Emissions: the amount of air and soil emissions considered. Air emissions are CO_2 and CH_4, and the land emissions almost related to the soil which sludge has been injected there. The amount of nitrate, phosphate and Ammonia also determined in the soil sample of land farm.

4.4. Input Data to Simapro

This research is a case study of wastewater treatment facilities of ERTC (Environmental Resources Training Center) of SIUE University, hence all the data used belong to that organization. Data available for two semi-annual sludge quantity for year 2015, from sludge management report.

Table 4: Input Data to SimaPro

From techno sphere:
Methane, biogas: 167 MJ, Electricity: 144 kwh, Transport: truck 16B250=3.21869 tkm

---

Emissions to air:

Nitrogen total: 96900 gr, Carbon dioxide, biogenic: 1200 kg, carbon monoxide, biogenic: 50000 gr

Methane.

Emissions to soil:

Chromium: 143.8 gr, cadmium: 0.79 gr, copper: 1170 gr, nickel: 24.8 gr, potassium: 5310 gr, zinc: 928 gr, selenium: 5.94 gr, Manganese: 433 gr, Molybdenum: 28.5 gr.

---

5. Results

SimaPro model has been used in this study to evaluate the environmental impact of this process based on life cycle assessment. [18-21]. Figures 4 and 5 show the energy path attributed to each semi-annual process. By applying the unit function to the result of tables 1 and 2 the amount of sludge is calculated in the top box of figures 4 and 5.

From table 1: Dry Mass of Sludge = (weight of every gallon of water) *(%TS)

$= (371450) * (2.57/100) *8.34/2 = 4.28*10^4$ kg Sludge.

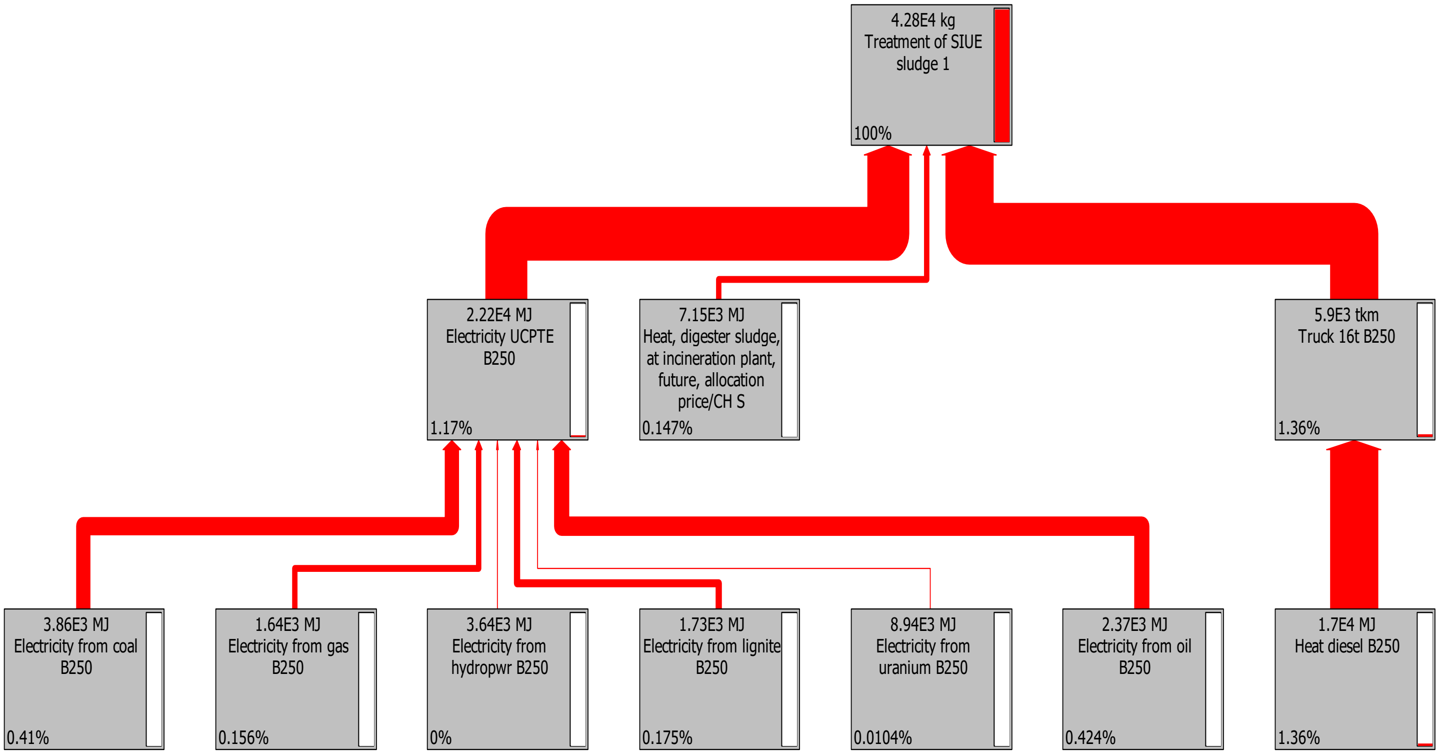


Figure 4. Life cycle assessment results for first semi-annual raw sludge (2015), Environmental Resources Training Center (ERTC) SIUE.

From table 2: Dry Mass of Sludge = (weight of every gallon of water) *(%TS)

= (421800) * (3.43/100) *8.34/2 = 6.03*10^4 kg Sludge.

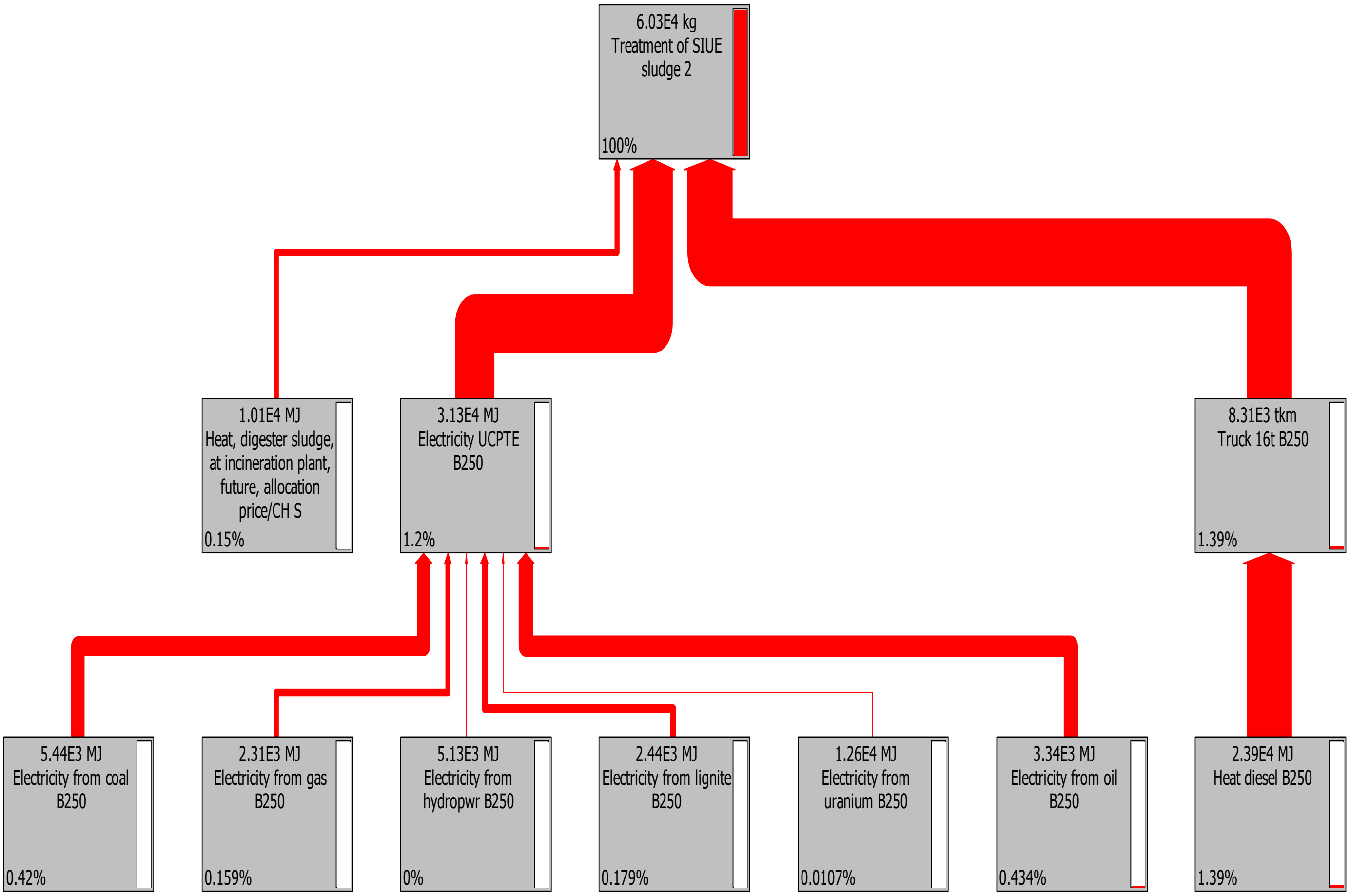


Figure 5. Life cycle assessment results for second semi-annual raw sludge (2015), Environmental Resources Training Center (ERTC) SIUE.

Different scenarios for energy configuration has been studied based on life cycle assessment and the results presented throughout figures 6 to 8. These scenarios include a comparison between six set of combinations of electricity and methane configurations and best solution considered as the most sustainable and practical approach based on minimum negative environmental effect. (Table.5)

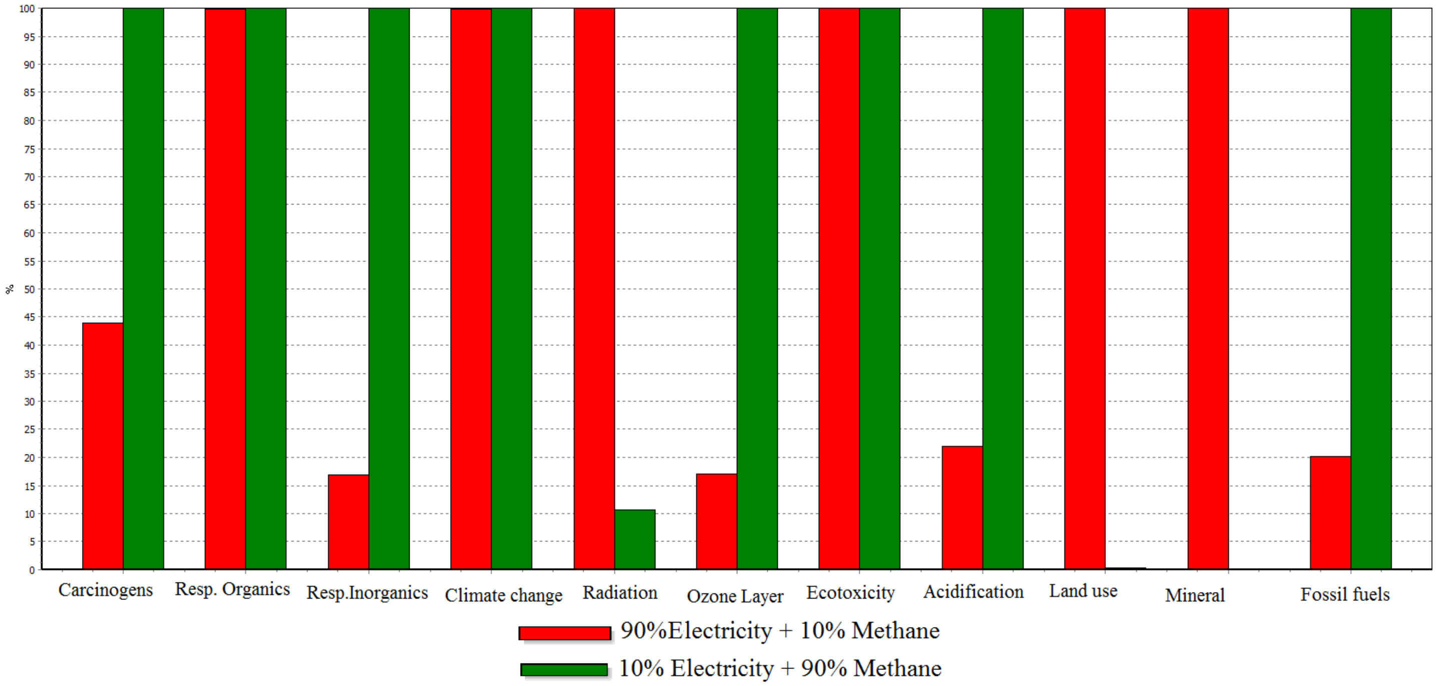


Figure 6. Comparison of 90% Electricity+10% Methane vs. 90% Methane +10% Electricity

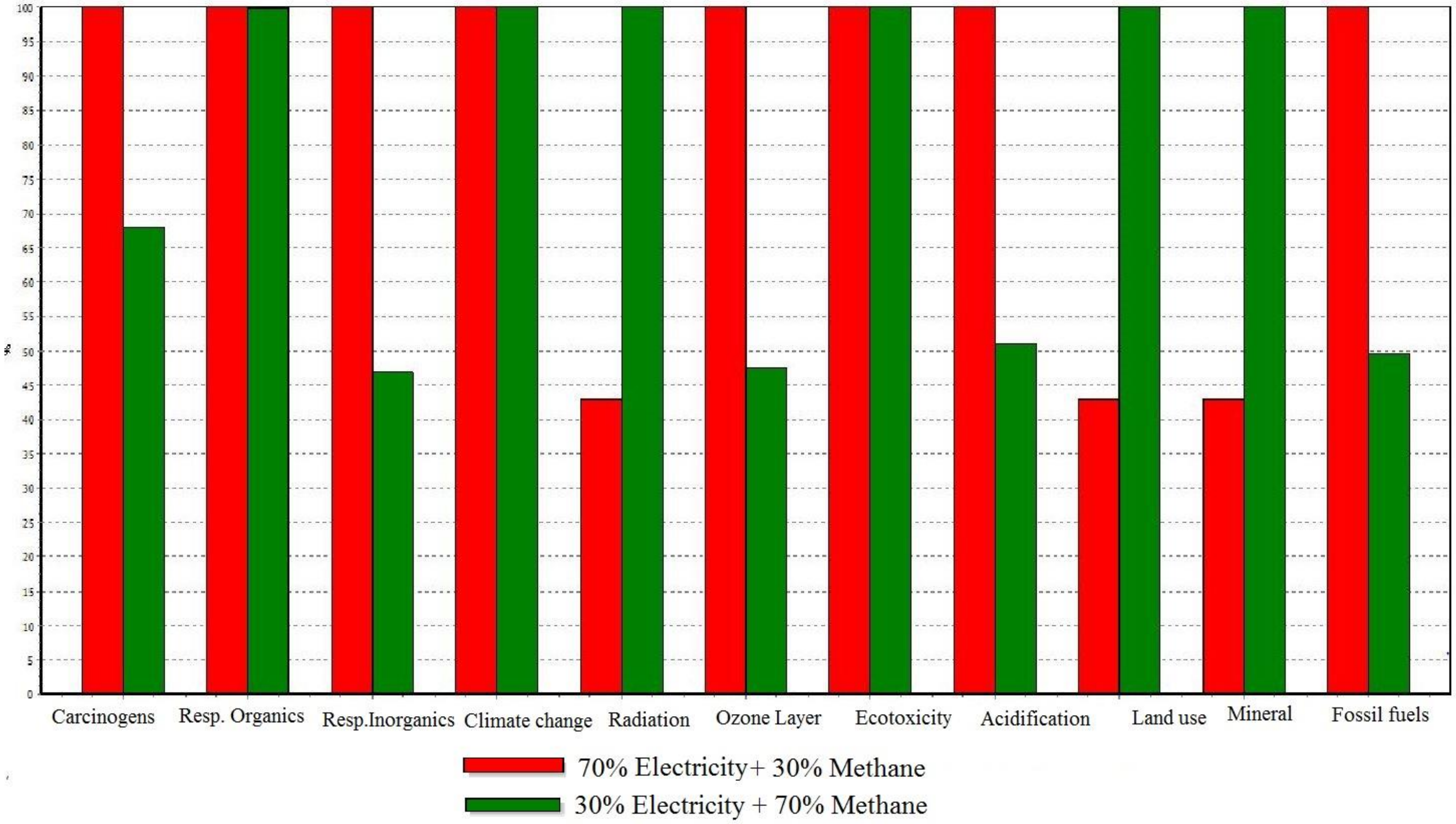


Figure 7. Comparison of 70% Electricity+30% Methane vs. 70% Methane +30% Electricity

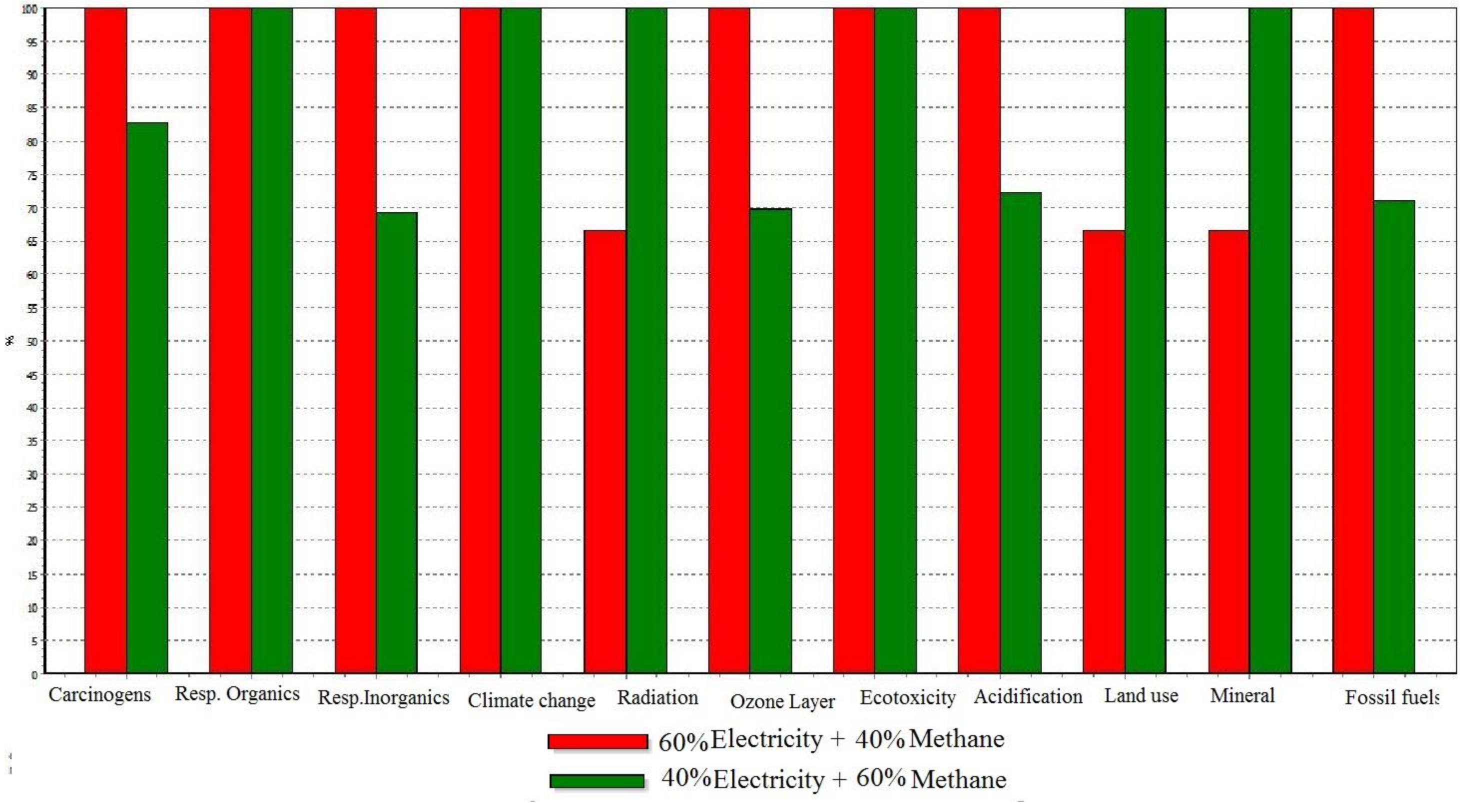


Figure 8. Comparison of 60% Electricity+40% Methane vs. 60% Methane +40% Electricity

6. Conclusion

To evaluate the impact of most dominant parameters we should apply sensitivity analysis, by changing the amount of energy resources or amount of entered sludge or outcome biogas we can investigate the change and their environmental impact due to LCA assessment.

Due to literature reviews biogas of methane considered as an essential parameter, hence three different scenarios defined:

First: 90% Methane+10% Electricity vs. 10% Methane+90% Electricity

Second: 70 Methane+30% Electricity vs. 30% Methane+70% Electricity

Third: 60% Methane+40% Electricity vs. 40% Methane+60% Electricity

Due to the result based on Table 5. first and last columns came with the minimum negative environmental impacts (720, 811 respectively) but because they are both located in one side of the extreme energy production either electricity or methane they might need higher technology and may not be applicable for most of anaerobic facilities. Considering the rest four configurations, combination of 70% Methane +30% Electricity has the minimum negative impact (860) in comparison to the rest hence considered as the most pragmatic solution.

Table 5: Energy Production vs. Environmental Impacts.

Elements	**Energy Production**					
	90% Elec	70% Elec	60% Elec	40% Elec	30% Elec	10% Elec
Carcinogens	44	100	100	82	67	100
Resp.Organics	100	100	100	100	100	100
Resp. Inorganics	17	100	100	69	46	100
Climate Change	100	100	100	100	100	100
Radiation	100	44	67	100	100	11
Ozone Layer	17	100	100	70	47	100
Ecotoxicity	100	100	100	100	100	100
Acidification	22	100	100	72	51	100
Land use	100	42	66	100	100	0
Mineral	100	43	67	100	100	0
Fossil Fuels	20	100	100	70	49	100
Sum	720	929	**1000**	963	**860**	**811**

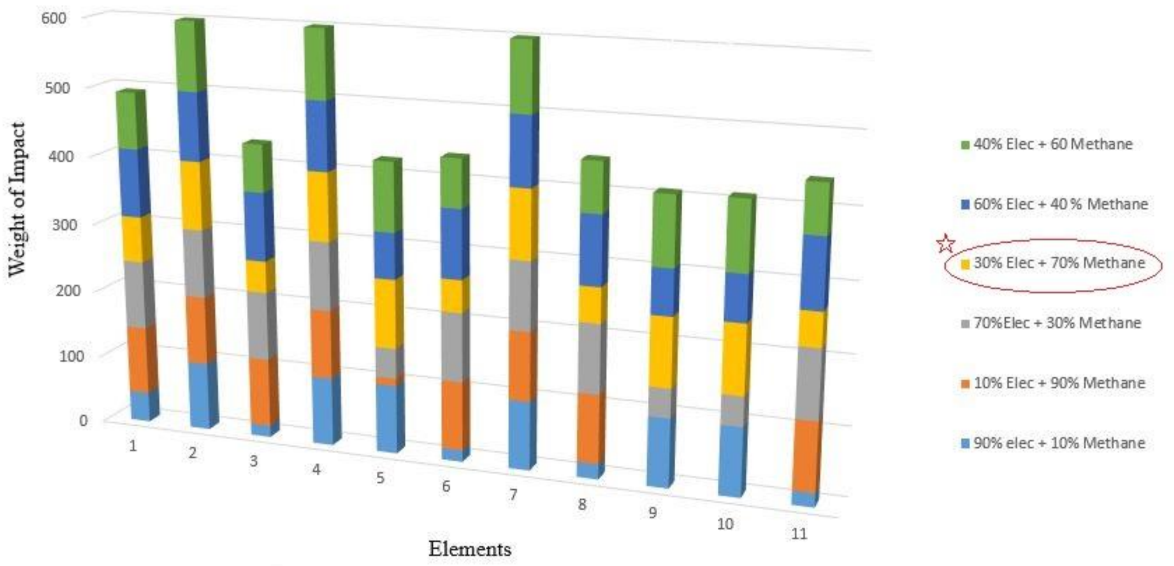


Figure 9. Best proposed solution based on LCA analysis

References

[1]. Batstone, D.J., et al., The IWA anaerobic digestion model no 1 (ADM1). Water Science and technology, 2002. **45**(10): p. 65-73.

[2]. Lettinga, G., Anaerobic digestion and wastewater treatment systems. Antonie van leeuwenhoek, 1995. **67**(1): p. 3-28.

[3]. Finnveden, G., et al., Recent developments in life cycle assessment. Journal of environmental management, 2009. **91**(1): p. 1-21.

[4]. Lusk, P., Anaerobic digestion and opportunities for international technology transfer, in Making a business from biomass in energy, environment, chemicals, fibers and materials: V. 2. Proceedings. 1997.

[5]. Verma, S., Anaerobic digestion of biodegradable organics in municipal solid wastes. 2002, Columbia University.

[6]. Weidema, B., et al., The product, functional unit and reference flows in LCA. Environmental News, 2004. **70**: p. 1-46.

[7]. Matheys, J., et al., Influence of functional unit on the life cycle assessment of traction batteries. The International Journal of Life Cycle Assessment, 2007. **12**(3): p. 191.

[8]. Alsema, E.A., Environmental life cycle assessment of solar home systems. 2000: Department of Science Technology and Society, Utrecht University Utrecht ….

[9]. Ciroth, A., G. Fleischer, and J. Steinbach, Uncertainty calculation in life cycle assessments. The International Journal of Life Cycle Assessment, 2004. **9**(4): p. 216.

[10]. Cooper, J.S., Specifying functional units and reference flows for comparable alternatives. The International Journal of Life Cycle Assessment, 2003. **8**(6): p. 337.

[11]. Hischier, R. and I. Reichart, Multifunctional electronic media-traditional media. The International Journal of Life Cycle Assessment, 2003. **8**(4): p. 201-208.

[12]. Klüppel, H.-J., ISO 14041: Environmental management--life cycle assessment--goal and scope definition--inventory analysis. The International Journal of Life Cycle Assessment, 1998. **3**(6): p. 301.

[13]. Suh, Y.-J. and P. Rousseaux, An LCA of alternative wastewater sludge treatment scenarios. Resources, Conservation and Recycling, 2002. **35**(3): p. 191-200.

[14]. Gorree, M., et al., Environmental life cycle assessment of linoleum. The International Journal of Life Cycle Assessment, 2000. **5**(4): p. 238-238.

[15]. Guinee, J., J. De Bruijn, and R. Van Duin, An Operational guide to the ISO-Standards, CML. Leiden University, Leiden, The Netherlands, 2000.

[16]. Jiménez-González, C., et al., Cradle-to-gate life cycle inventory and assessment of pharmaceutical compounds. The International Journal of Life Cycle Assessment, 2004. **9**(2): p. 114-121.

[17]. Pennington, D.W., et al., Life cycle assessment Part 2: Current impact assessment practice. Environment international, 2004. **30**(5): p. 721-739.

[18]. Ciroth, A., J. Franze, and G. Berlin, Life cycle costing in SimaPro. GreenDelta TC, august, 2009.

[19]. Grzesik, K. and K. Guca, Screening study of life cycle assessment (LCA) of the electric kettle with SimaPro Software. Geomatics and Environmental Engineering, 2011. **5**(3): p. 57-68.

[20]. Hunkeler, D., K. Lichtenvort, and G. Rebitzer, Environmental life cycle costing. 2008: Crc press.

[21]. Klöpffer, W. and I. Renner, Life-cycle based sustainability assessment of products, in Environmental management accounting for cleaner production. 2008, Springer. p. 91-102.