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RESEARCH ON ECONOMIC EFFECTIVENESS OF VARIOUS TECHNOLOGICAL OPTIONS FOR GREENHOUSE GAS EMISSIONS REDUCTION IN DOMESTIC SOLID WASTE TREATMENT IN HANOI

Major: Climate Change
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SUMMARY OF DOCTORAL DISSERTATION

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At ………………………………

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PREAMBLE

1. The necessity of the dissertation

In its Nationally Determined Contributions (NDC), Vietnam commits a 8% cut in greenhouse gas (GHG) voluntarily by 2030 under normal scenario and a reduction of up to 25 percent could be possible if having global organizations' support. The rate of waste emission which accounts for about 6.2% of total emissions of Vietnam, has high potentials to reduce nearly to zero. In the context of 47% of total waste is from solid waste (SW) landfilling, the research on economic efficiency (ECE) of technological solutions (TES) to reduce greenhouse gas emission (GHGE) in domestic solid waste treatment (DSWT) creates important premises contributing to implementing commited targets of Vietnam in NDC.

2. Research objectives

- Building methods of evaluation of the ECE of TES on reducing GHGE in DSWT in Vietnam.

- Identifying TES reducing GHGE in DSWT in Vietnam and calculating emission reduction factor of each TES.

- Identifying the ECE of TES reducing GHGE in DSWT for Hanoi.

3. Research subject and research scope

3.1. Research subject

Research subject of the dissertation is the ECE of TES reducing GHGE in DSWT in Vietnam.

3.2. Research Scope

- Time: Based on the life cycle of each project, the calculations of emission levels, emission potentials; ECE of each TES for Hanoi city is calculated until 2050.

- Location: The Dissertation carries out pilot evaluations in Hanoi.

- Content: DSWT methods used in Vietnam have been chosen for research and calculations. Domestic solid waste (DSW) in this dissertation do not include harmful SW.

4. Research Hypothesis

- GHG inventory methods in SW can be combined with other methods of evaluation of ECE in order to build the methods of assessment on efficiency of TES on reducing GHGE in DSW which are suitable to the conditions of Vietnam; and economic factors, environmental factors, GHGE can be estimated and play a role in evaluating the efficiency.

- DSW treatment methods implemented in Vietnam can be combined under a certain criterion to create TES reducing GHGE in DSWT but still achieve the goal of treating all components of DSW.

The treatment methods of MSW being implemented in Vietnam can combine with a certain criterion to create the reducing industrial development programs in MSW treatment. of CTRSH.

- The methods of evaluating the effectiveness of TES to reduce GHGE in DSWT which are built in the dissertation can be used to calculate and evaluate for Hanoi.

5. New contributions of the dissertation

- Theoretical contributions: Based on the methods of GHG inventory in SW and the method of cost-benefit analysis (CBA), the dissertation has applied, combined and built a methodology for evaluating ECE of TES in reducing GHGE in DSWT. In which, economic, environmental, GHGE aspects have been considered and evaluated.

- Practical contributions: The dissertation has applied the built methodology to evaluate ECE of TES on DSWT for Hanoi.

6. Scientific and practical contributions

- The Thesis has synthesized, built methodology to evaluate ECE of TES on DSWT in Vietnam. The results of this research can be used as a reference for relevant studies.

- The dissertation's research results can provide scientific bases to help policy makers develop effective management policies in the field of GHG reduction and waste management.

- The dissertation's research results can assist Hanoi city to identify TES to reducing GHG, prioritized in DSW, towards effective implementation of Action Plan for implementation of Paris Agreement on climate change of the city.

7. Structure of the dissertation

Chapter 1: Overview of research on TES and evaluations of ECE in DSW treatment.

Chapter 2: Methods of evaluation on ECE of TES reducing GHG being priotized in DSW in Vietnam.

Chapter 3: ECE of TES in reducing GHG in DSWT in Hanoi**.**

CHAPTER 1. OVERVIEW OF RESEARCH ON TECHNOLOGICAL SOLUTIONS AND EVALUATIONS OF ECONOMIC EFFICIENCY IN DOMESTIC SOLID WASTE TREATMENT

1.1. Overview of the current status of DSW in Vietnam

The quantity of DSW generated in the period from 2011 to 2015 increases an average of 12% per year and and the trend will continue to increase in the near future. The percentage of organic matter in DSW is about 54-77%, recyclable waste accounts for about 8-18%.

1.2. Overview of GHGE in treating DSW

1.2.1. Current situation of GHGE in waste

The volume of GHGE increased from 2.6 million tons of CO_{2eq} in 1994 to 20.7 million tons CO_{2eq} in 2013 and the propotion in total national GHGE increased from 2.5% to nearly 8%.

1.2.2. Technologies of GHG emission reduction on DSWT

Technologies of GHG emission reduction on DSWT include: biotransformation technologies; heat treatment technologies; volume reduction solutions, recycle and reuse; producing solid energy fuel from DSW.

1.2.3. Policies on GHGE reduction in waste in Vietnam

The legislation on GHGE reduction in waste has been fully developed. GHGE reduction has been concerned and included in climate change adaptation policies in Vietnam. However, it is needed to be improved.

1.2.4. Overview of research on calculation of GHGE in DSW

Currently, there are two main approaches for calculating GHG emissions levels from DSW: (1) based on CH_4 emission and (2) based on source emissions. Most of research on GHGE and GHGE reduction potentials are instructed by IPCC.

1.3. Overview of research on ECE of TES reducing GHGE in DSWT

1.3.1. Methods of evaluation on ECE

Common methods of evaluation on ECE include: Non-parametric Tests or Data Envelopment Analysis (DEA); prarameter evaluation or Stochastic Frontier Analysis (SFA); Cost Minimization Anlysis (CMA); Cost-Benefit Analysis (CBA); Cost Utility Analysis (CUA).

1.3.2. Overview of domestic research

Research in Vietnam often focus on building local baselines emission, forecast emission volume and orient solutions to reduce GHG from waste such as the project "Enhancing cooperation and research capacity on NAMAs in MRV manner in SW"; the program "Transforming SW to resources in cities of Vietnam"; the project "Research, evaluate the potential of environmentally dual benefits on climate change adaptation activities in Vietnam"; INDC technical report... So far, there has been no research to calculate the cost, benefits associated with reduction potentail of TES reducing GHG in DSWT.

1.3.3. Overview of international research

Although there have been a lot of research in the world on quantifying costs, benefits and reduction potentials in waste in general and DSWT in particular, due to data uncertainty, this problem has been a challenge. Joe Pickin has done research on economic valuation methods for environmental impact assessment, uptream externalities and other important factors that is inconsistent in CBA, in analyzing CTR recycling technology CTR. Molinos-Senante has used the definition of shadow price to quantify environmental benefits from wastewater treatment technologies; Rieder de Oliveira Neto has analyzed the economics and techniques of waste heat energy recovery systems to increase efficiency of electricity production, using CEPCI model ...

Overall results of the research have shown that CBA is a internationally and nationally commonly used method in evaluating costs, benefits, ECE. Now in the world and Vietnam, the models and methods often focus on evaluating one matter/factor on sustainable development of SWT methods.

CHAPTER 2. METHODOLOGY TO EVALUATE ECONOMIC EFFICIENCY OF TECHNOLOGICAL METHODS TO REDUCE GREENHOUSE GAS EMISSION IN DOMESTIC SOLID WASTE TREATMENT IN VIETNAM

2.1. Calculating assumptions

The dissertation has used some assumptions to do the calculations: (1) Base year is 2017; (2) The components of the DSW have not changed; (3) DSW is totally collected and classified; (4) the quantity of DSW increases annually under 2 scenarios: 10% per year, and 3.27% per year; (5) After closing, a landfill continues 30 years of GHGE; (6) Average inflation is 6%; (7) Social discount rate is 5%; (8) Vietnam's economic growth rate is 6%, metropolitan population growth rate is 2.6%, average GDP is 3.31%; (9) annual operating cost based on the survey year or project suggestions; initial investment cost is repaid in the first year; (10) analysis period is the life cycle of the project; (11) Exchange rates: USD/VND is 22,735, EURO/VND is 25,915; (12) Prices of carbon credit on Swiss market is used to transfer value to Vietnam; (13) After closing of a landfill, the impact on environment is propotionate with level of GHGE; (14) products of projects on DSWT are sold up.

2.2. Methods of evaluation of potential of GHGE reduction in DSW

2.2.1. Calculation of GHGE of DSWT methods

2.2.1.1. GHGE from landfilling

$$CH_{4\ emissions} = \left(\sum_x CH_4 gen_{x,t} - R_t \right) \times (1 - OX_t) \quad (Gg/year) \qquad (2.1)$$

In which: CH_4 emissions are CH_4 emission volume in year t (ton); CH_4 gen is the CH_4 volume formed in year t (ton); t is calculating year; x is the type of DSW; R_t is recovery rate CH_4 in year t (ton); OX_t is the oxidation coefficient due to surface coating in year t.

2.2.1.2. GHGE from landfilling in which gas is recovered for electricity generation

$$CH_4 = \left[CH_{4\ (landfilling)} \times (1\text{-}R)\right] - \frac{(CE \times 10^{-3})}{27} \quad (\mathit{Gg/year}) \qquad (2.3)$$

In which: $CH_{4\ (landfilling)}$ is level of GHGE in normal landfilling; CE is the GHG quantity if fossil fuel is used to produce the same amount of electricity which is produced from landfill gas; R is recovery rate of landfill gas.

2.2.1.3. GHGE from biological treatment methods

$$CH_{4\ (emissions)} = \sum_{i=1}^{n} (M_i \times EF_i) \times 10^{-3} - R \quad \mathit{(Gg/year)} \qquad (2.4)$$

$$N_2O_{\ (emissions)} = \sum_{i=1}^{n} (M_i \times EF_i) \times 10^{-3} \quad \mathit{(Gg/year)} \qquad (2.5)$$

In which: M_i is organic waste which are treated by biological method i; EF_i is emission rate with i method; R is the total amount of CH_4 being recoverd in inventory year.

2.2.1.4. GHGE from semi-aerobic landfilling method

$$CH_4 = \left[\left(W \times DOC \times DOC_f \times MCF \times F \times \frac{16}{12}\right) - R\right] \times (1\text{-}OX) \times H \ (\mathit{Gg/year}) \qquad (2.6)$$

In which: H is the reduction factor of GHGE in the semi-aerobic burial method; The remaining parameters are similar to that of Formula 2.1.

2.2.1.5. GHGE from SW burning method

$$CO_2=MSW\times\sum_{j=1}^{n}\left(WF_j\times dm_j\times CF_j\times FCF_j\times OF_j\right)\times\frac{44}{12}\quad \textit{(Gg/year)} \qquad (2.7)$$

$$CH_4=\sum_{i=1}^{n}(IW_i\times EF_i)\times 10^{-6}\quad \textit{(Gg/year)} \qquad (2.8)$$

$$N_2O=\sum_{i=1}^{n}(IW_i\times EF_i)\times 10^{-6}\quad \textit{(Gg/year)} \qquad (2.9)$$

In which: MSW is the total amount being burned according to moisturous amount; WF_j is the culling rate j in total amount of DSW; dm_j is proportion of dry materials in waste j; FCF_j is C fossil proportion of waste j; OF_j is the oxidation coefficient; 44/12 is transfer coefficient from C to CO_2; IW_i is the amount of waste i being burnt; EF_i is emission coefficient CH_4, N_2O of waste i.

2.2.1.6. GHGE from RDF

$$E_{RDF}=Q_{RDF}\times EF_{RDF} - Q_{RDF}\times\frac{T_{RDF}}{T_{coal}}\times EF_{coal}\quad \text{(Gg}\textit{/year)} \qquad (2.10)$$

In which: E_{RDF} is GHGE of RDF; EF_{RDF} is the coefficient when buring RDF; Q_{RDF} is total amoutn of RDF; T_{RDF} is the calorific value of RDF; T_{coal} is calorific value of antracite coal; EF_{coal} is the emission coefficient of coal while being burnt.

2.2.2. Methods of calculating the GHGE reduction potential of alternative daily-life SW treatment methods

$$ER= BE-PE\quad \textit{(ton of } CO_{2eq}\textit{)} \qquad (2.11)$$

$$ERR=\frac{BE-PE}{W}\quad \textit{(ton of } CO_{2eq}\textit{/ton of waste)} \qquad (2.12)$$

In which: ER is the potential to reduce GHGE in DSWT to be considered; BE is the emissions of the baseline scenario; PE is the emission amount of the method under consideration; ERR is the reduction factor of GHGE in the alternative methods; W is the amount of DSW processed.

2.3. Evaluation methods of each methods on DSWT

2.3.1. Costs and Benefits

- Costs consist of: Fixed costs (C_1); operating costs (C_2); environmental costs for neighbourhood (C_3); GHGE costs (C_4)

- Benefits consist of: Benefits from DSWT (B_1); benefits from selling products from DSWT process (B_2); benefits from reducing GHGE when using products from DSWT process replacing traditional products (B_3).

2.3.2. Cost and benefit couting methods in DSWT

- Identifying fixed cost (C_1): Including construction cost, purchasing, one time paid before the project comes into operation.

- Identifying operating cost (C_2): Including costs to ensure the operations of the project which is annually paid.

- Identifying environmental costs (C_3):

+ *Defense cost method*:

$$C_3 = \frac{\sum WTP_i}{n} \times P \quad \textit{(VND)} \qquad (2.13)$$

In which: WTPi is the willingness to pay of the interviewee i; n is the number of people interviewed; P is the total population of the neighborhood with negative external environmental impacts from the SW treatment project.

+ *Health costs method*:

$$C_3 = \sum c_i \times q_i + \frac{I}{365} \times d_i \quad \textit{(VND)} \qquad (2.14)$$

In which: c_i, q_i and d_i are the average costs for a case of illness, the number of illnesses and the average number of sick days for each disease; I is GDP/person/year of the area around the SW treatment project.

2.3.2.4. Identifying GHG emission costs (C_4)

GHGE has negative consequences for society so it is considered an expense and is estimated by the market price method.

$$C_4 = Q_{CO_2} \times P_{CO_2} \quad \textit{(VND)} \qquad (2.15)$$

In which: Q_{CO_2} is the total volume of GHGE of DSWT methods; P_{CO_2} the exchange rate on the carbon credit market.

2.3.2.5. Identifying benefits from DSWT (B_1)

SW treatment fee can be considered as the fee that people are willing to pay in exchange for a better living environment when waste is collected and treated.

$$B_1 = P_W \times Q \quad \textit{(VND)} \qquad (2.17)$$

In which: P_W is processing unit price of DSW in year t; Q is the amount of DSW treated in year t.

2.3.2.6. Identifying Benefits from selling products from DSWT process (B_2)

$$B_2 = P_e \times Q \quad \textit{(VND/year)} \qquad (2.18)$$

$$B_2 = P_{RDF} \times Q \quad \textit{(VND/year)} \qquad (2.19)$$

$$B_2 = P_{compost} \times Q \quad \textit{(VND/year)} \qquad (2.20)$$

In which: P_e, P_{RDF}, $P_{compost}$ are electricity selling prices, RDF and organic fertilizer; Q is the project's power output, RDF and compost.

2.3.2.7. Identifying the benefits from using products (B_3)

- Benefit of reducing GHGE from using electricity produced from the project:

$$B_3 = CE \text{ x } P_{CO_2} \quad \textit{(ton/year)} \qquad (2.21)$$

In which: CE is the amount of CO_2 emitted when producing electricity; P_{CO_2} is the price of CO2 exchanged on the carbon market.

- Benefit of reducing GHGE from using RDF:

$$B_3=\left(Q_{RDF}\times\frac{T_{RDF}}{T_{coal}}\times EF_{coal}-Q_{RDF}\times EF_{RDF}\right)\times P_{CO_2}\quad (Gg/\textit{year}) \qquad (2.22)$$

Trong đó: E_{RDF} is the GHGE of RDF menthos; EF_{RDF} is the GHG factor when use RDF; Q_{RDF} is the amount of RDF; T_{RDF} is the thermal value of RDF; T_{than} is the thermal value of coal; EF_{than} is the GHG factor of coal when used; P_{CO_2} is the price of CO_2 exchanged on the carbon market.

2.3.3. Net present value (NPV)

$$NPV=(B_0-C_0)+\frac{B_1-C_1}{(1+r)^1}+\ldots+\frac{B_t-C_t}{(1+r)^t}=\sum_{t=0}^{n}\frac{B_t-C_t}{(1+r)^t}\quad (\textit{VND}) \qquad (2.24)$$

$$BCR=\frac{B_0+\frac{B_1}{(1+r)}+\ldots+\frac{B_t}{(1+r)^t}}{C_0+\frac{C_1}{(1+r)}+\ldots+\frac{C_t}{(1+r)^t}}=\frac{\sum_{t=0}^{n}\frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n}\frac{C_t}{(1+r)^t}} \qquad (2.25)$$

In which: B_t, C_t are benefits and costs of year t of the project; n is the number of years of operation of the project; r is the discount rate.

2.3.4. NPV of one unit of DSW in each treatment method

$$NPV_W=\frac{NPV}{W}\quad (\textit{mil of VND/Ton of waste}) \qquad (2.26)$$

In which: NPV_W is net present value of unit of DSW, reflecting ECE from the perspective of DSWT; W is the amount of waste to be treated.

2.3.5. Calculating effectiveness of each alternative DSWT methods in compared to a treated unit of DSW method

$$\Delta NPV_W = NPV_{PW} - NPV_{BW}\quad (\textit{mils of VND/ton of waste}) \qquad (2.27)$$

In which: NPV_{PW} is the net present value of alternative DSWT method per an unit of DSW; NPV_{BW} is the net present value of the base case (landfill) per an unit of DSW.

2.4. Evaluating ECE of methods of reducing GHG in DSWT

2.4.1. Identifying TES to reducing GHG in DSWT

The TES to reducing GHG in DSWT include: Burying with recovered gas being used to generate electricity (MO1); Semi-aerobic burial (MO2); Producing compost, producing SW for generating and landfilling (MO3); Compost production, RDF production and landfilling (MO4); Anaerobic treatment with biogas recovery for heat generation, burning SW for generating and landfilling(MO5); Anaerobic treatment with biogas recovery for heat generation, RDF production and landfilling (MO6).

2.4.2. Calculation of GHGE and potentials to reduce GHGE of technologies in reducing GHG in DSWT

- Calculation of basic scenario of GHGE.
- Calculation of GHGE in TES to reducing GHG.

$$TPE=\sum_{i=1}^{n} ERR_i \times W_i \quad \textit{(ton } CO_{2eq}\textit{)} \qquad (2.28)$$

In which: ERR_i and W_i are emission factors and amount of DSW treated in DSWT method i in TES.

- Calculating the potential for reduction in GHGE in TES in treatment of DSW:

$$TER= TBE-TPE \quad \textit{(ton } CO_{2eq}\textit{)} \qquad (2.29)$$

$$TERR=\frac{TER}{TW} \quad \textit{(ton } CO_{2eq}\textit{/ton SW)} \qquad (2.30)$$

In which: TBE, TPE are the basic emissions scenario and GHGE reduction scenario; TW is the total amount of DSW to be treated.

2.4.3. Calculations of ECE of TES to reducing GHG according to each unit of reduced GHG

ECE of TES to reducing GHG is evaluated via acceptable net benefits exchanged for one unit of GHG.

$$\Delta NPV_{CO_2}=\frac{\Delta NPV_W}{|ERR|} \quad (\textit{mil VND/ton } CO_{2eq}) \qquad (2.31)$$

$$\Delta TNPV_{CO_2 i}=\sum_{j=1}^{n} \Delta NPV_{CO_2 j} \text{ x } R_{Wj} \quad (\textit{mil VND/ton } CO_{2eq}) \qquad (2.32)$$

$$\Delta TNPV_i = TER_i \text{ x } \Delta TNPV_{CO_2 i} \quad (\textit{mil VND}) \qquad (2.33)$$

In which: $\Delta TNPV_{CO_2 i}$ is the ECE to reduce emissions for TES i, showing that in order to reduce one unit of CO_{2eq} by TES, how much net social benefits have to be exchanged for; $\Delta NPV_{CO_2 i}$ is the ECE in reducing emission of treatment method j; RW_j is the proportion of DSW treated by method j in TES i. $\Delta TNPV_i$ is the total increase or decrease of social benefits due to the application of TES i to treat DSW.

2.5. Data used in the thesis

Investigating, surveying from SW treatment facilities in Hanoisurvey from health facilities near SW treatment area; data from reports, proposals and investment projects of SW treatment facilities; The data was collected and synthesized from reports, scientific articles, previous relevant studies.

CHAPTER 3: ECONOMIC EFFICIENCY OF TECHNOLOGICAL SOLUTIONS FOR GREENHOUSE GAS EMISSION REDUCTION IN DOMESTIC SOLID WASTE TREATMENT IN HANOI

3.1. The potential to reduce GHGE by DSWT methods

3.1.1. GHGE of normal landfilling – base method

GHGE level of Nam Son landfill Nam Son is about 1.15 mil tons of CO_{2eq}. The amount of Kieu Ky landfill emission is 1.85 mil tons of CO_{2eq}.

3.1.2. Potentials **for reducing** *GHGE in landfilling method with recovery*

Potentials for reduction in GHGE is 4.36 mil tons of CO_{2eq} reducing factor of GHGE is 0.7 tons of CO_{2eq}/ton of waste.

3.1.3. Potential for reducing GHGE by the semi-aerobic landfill method

The potential of reducing the GHG is 684 thousand tons CO_{2eq}; the reduction factor of the GHG is 0.47 tons CO_{2eq}/ton of waste.

3.1.4. Potential for reducing greenhouse gas emissions by compost producing

The potential for reduction of GHG is 356 thousand tons CO_{2eq}; the reduction factor of GHG is 0.77 ton CO_{2eq}/ton of waste.

3.1.5. Potential for reducing GHGE by anaerobic treatment with biogas recovery for electricity generation

The potential reduction of GHG is 374 thousand tons CO_{2eq}; the reduction factor of GHG is 1.03 ton CO_{2eq}/ton of waste.

3.1.6. Potential for reducing GHGE by the SW burning method for electricity generation

This is the method to increase the capacity, the coefficient of increase of the capacity is 3.72 tons CO_{2eq}/ton of waste.

3.1.7. Potential for reducing GHGE from the production of solid fuel panels

The potential reduction of GHG in this method is 335 thousand tons CO_{2eq}.

3.2. Evaluate the ECE of each SW treatment method

3.2.1. Conventional landfill method

The NPV of Nam Son SW disposal project is VND 10,553.41 billion; BCR reached 3.04; NPV_W is 0.4663 million VND/ton of waste. The NPV of Kieu Ky SW disposal project is VND 1,152.84 billion; BCR is 2.86; NPV_W is 0.5013 million VND/ton of waste.

3.2.2 Method of landfill with gas recovery for electricity generation

NPV is 6,143.2 billion, BCR also reaches 4.91; NPV_W is 0.27 million VND/ton of waste, ΔNPV_W is -0.1949 million VND/ton of waste.

3.2.3. The method of semi-aerobic burial

NPV of 302.34 billion VND, BCR also reached 2.35, NPV_W was 0.2071 million VND/ton of waste, ΔNPV_W was -0.223 million VND/ton of waste.

3.2.4. Method of producing compost

NPV is 101.13 billion, BCR is 1.32, NPV_W is 0.2199 million VND/ton of waste, the ΔNPV_W indicator is -0.2464 million VND/ton of waste.

3.2.5 Anaerobic treatment method to recover biogas

The NPV is 85.62 billion VND, the BCR is up to 3.12, the ΔNPV_W is 0.2346 million VND/ton of waste, the ΔNPV_W target is -0.204 million VND/ton of waste.

3.2.6. Method of burning SW for electricity generation

NPV is -732.42 billion, BCR is only 0.21, NPV_W is -1.3378 million VND/ton of waste, ΔNPV_W is -1.804 million VND/ton of waste.

3.2.7. RDF solid fuel sheet production method

NPV is 357.14 billion, BCR is 1.96, NPV_W is 0.6115 million/ton of waste, ΔNPV_W is 0.11452 million/ton of waste.

In summary, from an economic perspective, to treat SW and to reduce GHG, the preferred method is RDF production. However, this method has limitations in practice such as consumption market, technology, capacity... so the implementation of this method is not popular. The preferred method will then be anaerobic treatment with biogas power generation, burial with gas recovery for power generation and compost producing.

3.3. Evaluations of ECE in methods in reducing GHGE in DSW in Hanoi

3.3.1. Basic GHGE scenario

The volume of GHGE in 2050 of the 3.27% scenario is 6.56 million tons CO_{2eq}, 2.89 times higher than that in 2017, the total GHGE period 2017-2050 is 137.83 million tons CO_{2eq}. In the 10% scenario, the amount of GHGE in 2050 is 46.45 million tons of CO_{2eq}, 23.23 times in 2017 and 8 times higher than the same period in the same scenario of 3.27%, total GHGE in the period 2017-2050 is 490.94 million tons of CO_{2eq}, 3.5 times higher than the scenario of 3.27%.

With such an increase, it can be seen that the Hanoi DSWT sector is one of the potential areas to reduce GHG by changing the methods of DSWT and applying the technologies to reduce DSW on a large scale.

3.3.2. Potential for reducing GHGE of technological

If the socio-economic aspect of the society is not concerned, the two ECE MO4 and MO6 are the preferred options when replacing the conventional landfill method to treat MSW, followed by MO3 and MO1.

Table 3.7. Potential for reducing GHGE of technological in DSWT

Group of method	**TER of year 2050** *(mil tons)*		**TER of 2017-2050** *(mil tons)*		**TER of annual average** *(mil tons)*		**TERR of 2017-2050**
	KB 3,27%	**KB 10%**	**KB 3,27%**	**KB 10%**	**KB 3,27%**	**KB 10%**	
MO1	3,99	28,23	83,78	298,42	2,46	8,38	0,62
MO2	3,54	25,05	74,32	264,72	2,19	8,78	0,55
MO3	4,76	33,72	100,06	356,40	2,94	7,79	0,74
MO4	6,54	46,32	137,45	489,58	4,04	10,48	1,02
MO5	3,54	25,07	74,39	264,97	2,19	14,40	0,55
MO6	5,32	37,67	111,78	398,16	3,29	11,71	0,83

3.3.3. ECE of TES to reduce GHGE according to an unit of GHG reduced

All TES have a net social benefit per tonne of CO_{2eq} reduced is negative.

Among the TES, the most effective solution is MO6. This is also an effective solution in terms of reducing GHG. However, the widespread implementation of this TES in practice is not easy due to limitations of product quality, market, technical or waste separation mechanism at source as well as capacity of DSWT.

Next is MO5 and MO4. The common point of these 3 TES is that the presence of DSWT methods with good GHGE reduction factor has contributed to improving the effectiveness of the solutions. However, like MO6, these TES are in fact also facing difficulties.

Table 3. 1. Efficiency of methods in reducing GHG of period 2017 - 2050 for Hanoi

Group of method	TER *(mil tons CO_{2eq})*		ΔTNPV *(mil VND)*		$\Delta TNPV_{CO_2}$ *(mil VND/ton of CO_{2eq})*
	KB 3,27%	**KB 10%**	**KB 3,27%**	**KB 10%**	
MO1	83,78	298,42	-23.324	-83.081	-0,278
MO2	74,32	264,72	-40.997	-146.030	-0,552
MO3	100,06	356,40	-20.348	-72.479	-0,203
MO4	137,45	489,58	-23.445	-83.510	-0,171
MO5	74,39	264,97	-10.850	-38.648	-0,146
MO6	111,78	398,16	-12.638	-45.017	-0,113

Source: Calculations by the author

The next most effective TES are MO3 and MO1 solutions. In the immediate future, MO1 may be a feasible solution both technically and economically in practice when only one additional landfill gas recovery system is needed on both existing and closed a landfill. The investment is not required high, the technical and human resources requirements are not too high while the reduction factor is also very good.

In the future, the living standards will increase, the binding of environmental protection responsibilities in economic activities will become more and more stringent, the TES will have a great impact on the environment, emitting more GHG will tend to increase cost and ECE reduction; In contrast, the non-governmental offices with high potential for reducing GHGE have a tendency to increase their effectiveness, even the effectiveness may exceed those grassroots solutions.

CONCLUSIONS AND SUGGESTIONS

Conclusions:

Based on the overview of relevant studies, combined with analysis and application in the field of DSWT, the dissertation has identified the costs, financial and non-financial benefits in the field of DSWT, steps to apply CBA method in combination with GHG inventory methods to evaluate the effectiveness of the TES to reduce GHGE in DSWT. Specifically, the dissertation has developed a system of methods to determine the total volume of GHG that can be reduced, the net benefits of society being lost or earned as well as the level of net benefits of society in exchange for 1 unit of CO_2 which can be reduced by replacing the conventional landfill method with the above-mentioned CPCs.

The dissertation has identified 06 technological solutions in DSWT which is a combination of 01 to 03 MSW treatment methods including: Landfilling and recovering gas for electricity generation (MO1); Semi-aerobic burial (MO2); Producing compost, burning SW for electricity generation and normal burial (MO3); Producing compost, Producing RDF and conventional landfilling (MO4); An aerobic treatment with biogas recovery for heat generation, Combustion of SW for electricity generation and conventional landfilling (MO5); An aerobic treatment with biogas recovery for heat generation, RDF production and Conventional burying (MO6).

The dissertation has built a method of calculating GHGE from TES and calculated and identified all the six above-mentioned solutions that are TES to reduce GHGE in competencies in DSWT. Accordingly, the solution with the lowest reduction potential is MO2 and MO5 with a reduction factor of 0.55 tons CO_{2eq}/1 ton of DSW and the best potential reduction solution is MO4 with a reduction factor of GHGE is 1,02 tons CO_{2eq}/1 ton of DSW.

From the data on the current status of DSW in Hanoi, the dissertation has calculated the ECE of the TES to reduce GHGE in Hanoi City. Based on the calculated data, the dissertation has determined the priority order when selecting TES in DSWT for Hanoi from high to low as follows: 1- MO6; 2- MO5; 3- MO4; 4- MO3; 5- MO1; 6- MO2.

Thus, it could be confirmed that the objectives of the dissertation have been completed. Along with that, the hypotheses set out of the dissertation have also been proved to be true. The dissertation 's research results can suggest many important policy ideas in managing and improving the effectiveness of DSWT activities in a sustainable manner such as calculating the level of support to the conversion of DSWT technology, developing policies to attract private investments in the field of DSWT, identifying future investment priorities in the short, medium and long-term, developing a roadmap to reduce GHG in the sector for successful implementation of NDC in Vietnam as well as in each locality.

Suggestions:

Due to lots of objective and subjective reasons, especially the limitations of data; time and financial resources, the dissertation still has some shortcomings such as: not enough conditions to survey, researched on modern DSW treatment methods applied in the world but not yet appeared in Vietnam; the emission calculation still relies on some hypothetical data and the default values according to the IPCC guidelines, so it may not be completely true with the conditions of Vietnam... For unsolved problems, a number of further research directions are suggested in the dissertation on the basis of continuing inheriting and developing the results of the dissertation, specifically:

(1) The world today pays much attention to the concept of a circular economy model, whereby the activities of the economy are designed in the direction of extending the life of matter, eliminating negative impacts on the environment. With this model, waste is minimized, recycled and reused. This means the methods of DSWT must also been changed and there are many modern DSWT technologies in the world meeting the requirements of the circular economic model.

Currently, Vietnam has not had a circular economic model in the true sense of the word, but has just stopped at reusing and recycling wastes to bring financial benefits to recycling facilities, but not bringing economic benefits to the society. In many cases, it is the cause of serious environmental pollution and degradation. In the future, when Vietnam transforms into a circular economy, there will be many modern DSWT methods implemented, meeting the characteristics of waste that be minimized, recycled, reused; and reduce the impact on the environment. Therefore, the next research can apply the method of the dissertation, continue to collect figures and data of other modern industrial TES to reducing GHG in DSWT to evaluate ECE, choose effective TES, suitable with the circulating economic model in order to be applied in practice.

(2) Now, the dissertation’s calculation of GHGE is still based on IPCC's coefficients, so it may not be close to specific conditions in Vietnam. In the future, Viet Nam's national emission factors should be developed for SW.

(3) The widespread application of TES requires SW to be properly classified. In fact, in Vietnam, the classification of waste at source has not been nearly implemented, so methods such as anaerobic treatment and compost production face many difficulties and are rarely used. Therefore, it is necessary to conduct research to propose solutions to encouraging the classification of waste at source in order to promote the application of advanced DSWT methods, having less impact on the environment and having low GHGE.

(5). The dissertation has assumed that the products produced by the methods of DSWT are both consumed and not inventory. However, the fact that some products of DSWT projects do not have a market or a small market such as compost/solid fuel panels. Therefore, there is a need for further studies to research and propose governmental support policies to develop markets for these products, contributing to improving the efficiency of DSWT projects, attracting more investments for this sector.

LIST OF SCIENTIFIC WORKS OF THE AUTHORS RELATED TO THE DISSERTATION

1. Do Tien Anh, Tran Nho Hoang, **Tran Phuong** (2017), Potential of reducing greenhouse gas emissions in urban solid waste treatment in Vietnam, Journal of Natural Resources and Environment, (No. 12, June 2017), p. 13-16.
2. **Tran Phuong**, Nguyen Viet Thanh, Do Tien Anh, Huynh Thi Lan Huong, Nguyen Van Thang (2017), Cost benefit analysis of urban solid waste treatment solutions by landfill: Case studies of waste disposal area of Kieu Ky and Nam Son, Hanoi, Journal of Climate Change Science, (No. 2, June 2017), p. 76-84.
3. Do Tien Anh, Nguyen Phuong Thao, Vuong Xuan Hoa, Ngo Minh Nam, Nguyen Viet Thanh and **Tran Phuong** (2017), Introduction of methods to assess the economic efficiency of measures to reduce greenhouse gas emissions in SW management sector, Environment Magazine, (Topic III, November 2017), p. 55-61.
4. **Tran Phuong**, Do Tien Anh, Vuong Xuan Hoa, Tran Nho Hoang (2017), Calculating greenhouse gas emissions from urban solid waste treatment, *Proceedings of the 20th Scientific Workshop on Meteorology, Hydrology, Environment and Climate Change* – Vietnam Publishing House of Natural Resources, Environment and Cartography, Hanoi.
5. Nguyen Phuong Thao, Hoang Tung, Vuong Xuan Hoa, Ngo Minh Nam, Do Tien Anh, Nguyen Viet Thanh and **Tran Phuong** (2017), Methods of estimating the impact of solid waste burying solutions on the health of people in Hanoi, *Proceedings of the 20th Scientific Workshop on Meteorology, Hydrology, Environment and Climate Change* - Vietnam Publishing House of Natural Resources, Environment and Cartography, Hanoi.