Supplementary Materials

S1. Potential biogas capacity and greenhouse gas emission calculations

Methane emission from manure management is calculated as follow:

$$CH_4 = \Sigma_{ik} A_{ik} * EF_{ik} \quad (S1)$$

Where

CH_4 = Methane emissions from manure management (kg/yr)

A_{ik} = population of livestock (head) i by climate region k

EF_{ik} = emission factor for the defined livestock population i by climate region k (kg/head/yr)

i = livestock categories

k = climate region (temperate, warm)

Sources: Revised 1996 &2006 IPCC guidelines on National Greenhouse Gas Inventories [1]

Emission factors for manure management is referred as 408.3 kg CO2 eq/head/year [2] based on the guidelines for calculating baseline farms' pig feces stored in anaerobic conditions of the UNFCCC (AMS-III.D, version 16). In case of Hanoi, values are taken from the default values of the Revised 1996 & 2006 IPCC guidelines, Table B-6, Asia for only swine type (i) in Red River Delta Climate Region (k) which is temperate with the annual average temperature is from 15 to 25 °C inclusive and application for biogas treatment.

After that, methane converted from carbon dioxide equivalence by division of 25 (over a time span of 100 years). Energy generated from available pig manure in case study is estimated as follow:

$$Energy = CH_4 * 21.5 * 100/60/3.6/0.67 \text{ (kWh)} \quad (S2)$$

The methane content normally accounts for 60% of total biogas production. Therefore, in order to calculate energy from biogas production from pig waste, it should be converted to biogas (natural gas) production from kg in m^3 per year. At normal temperature and pressure, methane has a density of approximately 0.67 kg/m^3[1]. The heating value of natural gas is 21.5 MJ/m^3 [3][4].

Capacity of biogas plants from available swine manure in case study is estimated based on productivity of an average biogas plant functioning 7,500 h per year with the below formulation:

$$Capacity = Energy/7{,}500 \text{ (kW)} \quad (S3)$$

1 year = 8,760 h. In term of theory, at 100% of capacity, for instance, a power plant with 1 MW will produce 8,760 MWh but in fact, most of the power plant usually produce less power than their capacity for maintenance, dependence of input materials, etc. It is assumed that the power plant operates in 7,500 h/year [5].

Nitrous oxide (N_2O) in manure management is generated during storage and treatment of animal waste before it is released into the atmosphere to the soil. While the manure is stored, part of the nitrogen in manure is converted into N_2O through the activity of microorganisms.

Nitrous oxide emissions from manure management are estimated by using IPCC default values with N-excretion/intake values and manure management system usage data. It is calculated as follow:

$$(N_2O - N)_{(mm)} = \sum_{(S)}\{[\sum_{(T)}(N_{(T)} * Nex_{(T)} * MS_{(T,S)})] * EF_{3(S)}\} \quad (S4)$$

where

$(N_2O\text{-}N)(mm)$ = N_2O-N emissions from manure management (kg N_2O-N/yr)

N(T) = Number of head of livestock species/category T

Nex(T) = Annual average N excretion per head of species/category T (kg N/animal/yr)

MS(T,S) = Fraction of total annual excretion for each livestock species/category T that is managed in manure management system S

EF3(S) = N_2O emission factor for manure management system S (kg N_2O-N/kg N in manure management system S)

S = Manure management system

T = Species/category of livestock

Sources: Revised 1996 & 2006 IPCC guidelines on National Greenhouse Gas Inventories [1]

In case of Hanoi, values are taken from the default values of the Revised 1996 & 2006 IPCC guidelines, Table B-6, Asia for only swine type (T) in Red River Delta Climate Region (k) which is temperate climate with the annual average temperature is from 15 to 25 °C inclusive and application for five systems including pasture, daily spread, anaerobic lagoon, anaerobic digester, aerobic treatment (S) as follows:

Nex(T): is the default value of "Asia and Far East" in the Revised 1996 &2006 IPCC guidelines. Next for swine is 16 kg N/head/yr Fraction of total annual excretion for pig in biogas treatment

MS for pasture, daily spread, anaerobic lagoon, anaerobic digester, aerobic treatment with 10; 2.3; 9.9; 16.4; 61.4% respectively.

EF_3 for pasture, daily spread, anaerobic lagoon, anaerobic digester, aerobic treatment with 0.02; 0; 0.001; 0.001; 0.02 respectively (kg N_2O–N/kg N) [6]

Conversion of (N_2O – N) emissions to N_2O emissions is performed by applying conversion factor of 44/28. After that, nitrous oxide then converted to carbon dioxide equivalence with factor of 298 over a time span of 100 years.

Avoided carbon dioxide emissions from electricity generation from biogas can be calculated based on average emission for electricity production from biogas plant as follows:

$$CO_2\ a = Energy \times 0.8795 \quad (S5)$$

Where

CO_2 a: Avoided carbon dioxide emissions (ton/year)

0.8795: the grid emissions factor for electricity production in Vietnam based on operating margin method (ton/MWh) [7].

Net GHG emissions from decomposing manure and replacing conventional electricity production per year is calculated as follows:

$$T = CH_4 + N_2O + CO_2\ a \quad \text{(S6)}$$

Where
T: Net GHG emissions (ton/year)
CH_4: methane in CO_2 equivalent (ton/year)
N_2O =: Nitrous oxide in CO_2 equivalent (ton/year)
CO_2 a: Avoided carbon dioxide emissions (ton/year)

References

1. IPCC. Chapter 10: Emissions from Livestock and Manure Management. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf (accessed on 21 July 2020).
2. UD Partnership. NAMA Proposal: Biogas for Onsite Power Generation for Medium/Large Pig Farms. Available online: http://www.lowcarbondev-support.org/-/media/Sites/FIRM_Facilitating_Implementation_and_Readiness_for_Mitigation/Final-Country-Reports-Phase-1/FIRM-Vietnam-Biogas-NAMA.ashx?la=da&hash=37145779AF752C4A3C904B316753BEC2CF404741 (accessed on 28 July 2020).
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5. Venier, F.; Yabar, H. Renewable energy recovery potential towards sustainable cattle manure management in Buenos Aires Province: Site selection based on GIS spatial analysis and statistics. *J. Clean. Prod.* **2017**, *162*, 1317–1333.
6. IPCC. Chapter 4 Agriculture. Good Practical Guidance and Uncetyainty Mngt in National GHG Inventories. Available online: https://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf (accessed on 3 February 2020).
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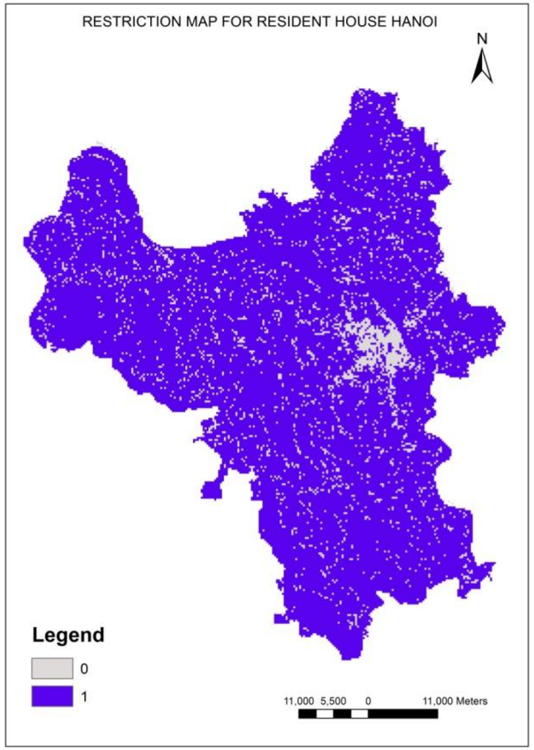
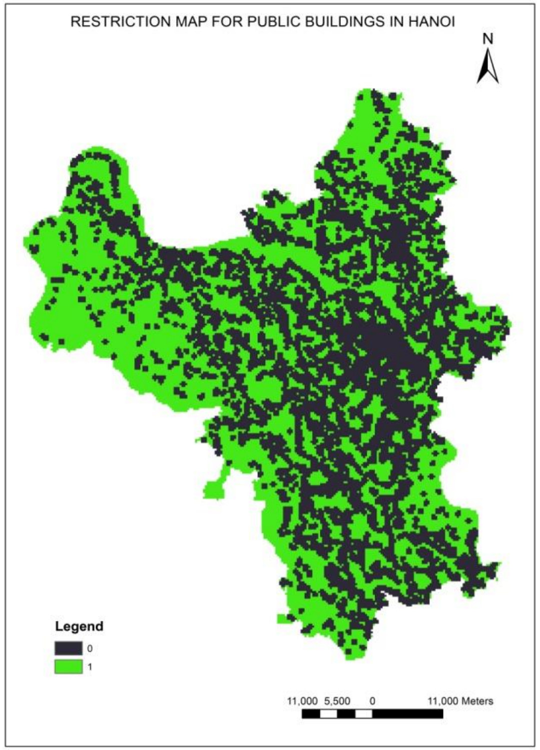
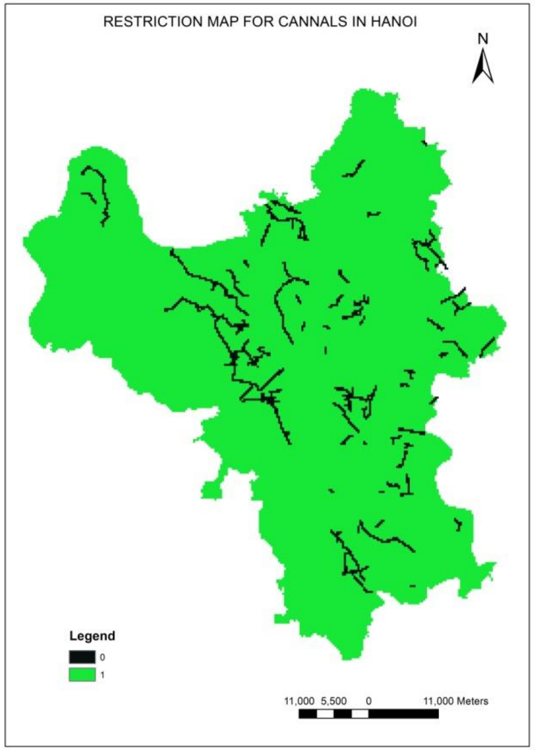
S2. Examples of Restriction Maps







S3. AHP process analysis

In Table S3.1, S3.3, S3.5, S3.7, the priorities of the comparison (for each factors pair) are set based on the fundamental scale from 1 (equal value) to 9 (extremely different) where higher number means the chosen factor is considered more important in greater degree than other factor being compared with (Table 2). Calculations are based on Section 3.1.2 with equation 4 and 5.

In Table S3.2, S3.4, S3.6, S3.8, normalization of the matrix is done basing on the equation 6 and 7. Consistency measure is calculated by equation 8. Consistency index (CI) is estimated by equation 9. Consistency ratio (CR) is calculated by equation 10.

Table S3.10 is the result of multiplying the weight for criteria and the pair wise matrix in Table S3.9 which syntheses from three average columns of three criteria.

1. Collection Efficiency

Table S3.1. Matrix for Collection Efficiency criteria

	Road	Elevation	Flood Area
Road	1	4	7
Elevation	0.25	1	4
Flood Area	0.142857143	0.25	1
Total	1.392857143	5.25	12

Table S3.2. Normalization of Matrix and Weight vector for Collection Efficiency criteria

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.717948718	0.761905	0.583333333	2.063187	0.687729	3.155792277
Elevation	0.179487179	0.190476	0.333333333	0.703297	0.234432	3.061523438
Flood Area	0.102564103	0.047619	0.083333333	0.233516	0.077839	3.01512605
					CI	0.038740294
					RI	0.58
					CR	0.066793611

2. Safety

Table S3.3. Matrix for Safety criteria

	Road	Elevation	Flood Area
Road	1	0.2	0.142857143
Elevation	5	1	0.333333333
Flood Area	7	3	1
Total	13	4.2	1.476190476

Table S3.4. Normalization of Matrix and Weight vector for Safety criteria

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.076923077	0.047619	0.096774194	0.221316	0.073772	3.012691633
Elevation	0.384615385	0.238095	0.225806452	0.848517	0.282839	3.062386854
Flood Area	0.538461538	0.714286	0.677419355	1.930167	0.643389	3.121456994
					CI	0.032755914
					RI	0.58
					CR	0.056475713

3. Cost Minimization

Table S3.5. Matrix for Cost Minimization criteria

	Road	Elevation	Flood Area
Road	1	6	4
Elevation	0.166666667	1	0.333333333
Flood Area	0.25	3	1
Total	1.416666667	10	5.333333333

Table S3.6. Normalization of Matrix and Weight vector for Cost Minimization criteria

	Road	Elevation	Flood Area	Total	Average	Consistency Measure
Road	0.705882353	0.6	0.75	2.055882	0.685294	3.10944206
Elevation	0.117647059	0.1	0.0625	0.280147	0.093382	3.01312336
Flood Area	0.176470588	0.3	0.1875	0.663971	0.221324	3.03986711
					CI	0.027072088
					RI	0.58
					CR	0.046676014

4. Weight for criteria

Table S3.7. Matrix for Weight for criteria

	Collection Efficiency	Safety	Cost Minimization
Collection Efficiency	1	6	0.333333333
Safety	0.166666667	1	0.142857143
Cost Minimization	3	7	1
Total	4.166666667	14	1.476190476

Table S3.8. Normalization of Matrix and Weight for criteria

	Collection Efficiency	Safety	Cost Minimization	Total	Average	Consistency Measure
Collection Efficiency	0.24	0.428571	0.225806452	0.894378	0.298126	3.103909041
Safety	0.04	0.071429	0.096774194	0.208203	0.069401	3.017854508
Cost Minimization	0.72	0.5	0.677419355	1.897419	0.632473	3.182202361
					CI	0.050660985
					RI	0.58
					CR	0.087346526

5. Synthesis

Table S3.9. Weight for criteria and the pairwise matrix

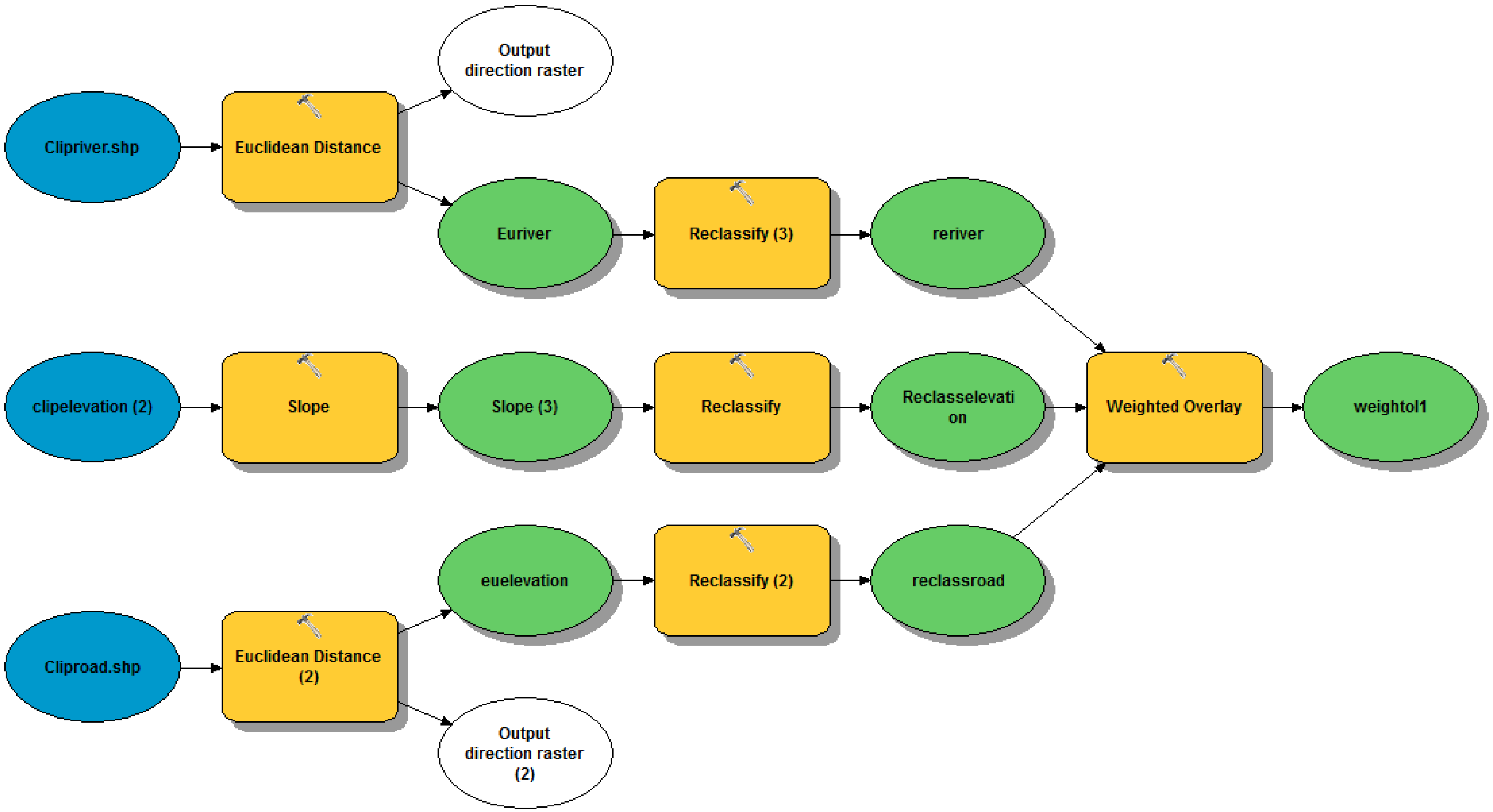
Criteria	Collection Efficiency	Safety	Cost Minimization	Weighted preferences
Road	0.687728938	0.073772	0.685294118	0.298126
Elevation	0.234432234	0.282839	0.093382353	0.069401

Flood Area	0.077838828	0.643389	0.221323529	0.632473

Table S3.10. Final priority for criterion

Criteria	Final Priority
Road	0.64358
Elevation	0.148581
Flood Area	0.207839

S4: Model Calculation for Suitability Weight



S5: Calculations for Scenario 1

FID	Pig (head/farm)	Gi _Bin	CH4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity _y (kW)	ADM2_EN	Total Capacity per year (kW/year)	Total CH4 emission per year (ton CO2 eq/year)	Total N_2O emission per year (ton CO2 eq/year)	Total CO2 emission per year (ton/year)
0	2000	3	29398	430316	57	Son Tay	1218	1733	462.55	8032.878814
1	5000	3	73494	1075790	143	Son Tay				
2	4000	3	58795	860632	115	Son Tay				
3	2000	3	29398	430316	57	Son Tay				
4	2500	3	36747	537895	72	Son Tay				
5	3050	3	44831	656232	87	Son Tay				
6	1600	3	23518	344253	46	Son Tay				
7	2000	3	29398	430316	57	Son Tay				
8	2500	3	36747	537895	72	Son Tay				
9	10700	2	157277	2302192	307	Son Tay				
10	1600	3	23518	344253	46	Son Tay				
11	2000	3	29398	430316	57	Son Tay				
12	3500	3	51446	753053	100	Son Tay				
13	2250	3	33072	484106	65	Thach That	1350	1921	512.68	8903.343891
14	1600	3	23518	344253	46	Thach That				
15	2400	3	35277	516379	69	Thach That				
16	2400	3	35277	516379	69	Thach That				
17	2000	3	29398	430316	57	Thach That				
18	2000	3	29398	430316	57	Thach That				
19	5000	3	73494	1075790	143	Thach That				
20	6000	3	88193	1290949	172	Thach That				
21	1600	3	23518	344253	46	Thach That				
22	2000	3	29398	430316	57	Thach That				
23	3200	3	47036	688506	92	Thach That				
24	2000	3	29398	430316	57	Thach That				
25	3000	3	44096	645474	86	Thach That				

26	4600	3	67614	989727	132	Thach That				
27	3000	3	44096	645474	86	Thach That				
28	4000	3	58795	860632	115	Thach That				
Total							2,568	3,654	975	16936.222

S6:

Calculations for Scenario 2

FID	Pig (head/farm)	Gi _Bin	CH4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity _y (kW)	ADM2_EN	Total Capacity per year (kW/year)	Total CH4 emission per year (ton CO2 eq/year)	Total N_2O emission per year (ton CO2 eq/year)	Total CO2 emission per year (ton/year)
0	1000	3	23935	857671	32	Ba Vi	112			
1	1000	3	23935	857671	32	Ba Vi				
2	1500	3	35902	1286488	48	Ba Vi				
3	1500	3	35902	1286488	48	Son Tay	528	476	180.75	3137.28
4	800	3	19148	686137	25	Son Tay				
5	1000	3	23935	857671	32	Son Tay				
6	1500	3	35902	1286488	48	Son Tay				
7	1100	3	26328	943420	35	Son Tay				
8	1475	3	35304	1265060	47	Son Tay				
9	1100	3	26328	943420	35	Son Tay				
10	1200	3	28722	1029205	38	Son Tay				
11	1200	3	28722	1029205	38	Son Tay				
12	1200	3	28722	1029205	38	Son Tay				
13	1200	3	28722	1029205	38	Son Tay				
14	650	3	15558	557495	21	Son Tay				
15	900	2	21542	771922	29	Son Tay				
16	1000	2	23935	857671	32	Son Tay				
17	750	3	17951	643244	24	Son Tay				
18	750	3	17951	643244	24	Thach That	404	363	132.95	2394.37
19	1000	3	23935	857671	32	Thach That				
20	1200	3	28722	1029205	38	Thach That				
21	1000	3	23935	857671	32	Thach That				

22	1100	3	26328	943420	35	Thach That				
23	1200	3	28722	1029205	38	Thach That				
24	1000	3	23935	857671	32	Thach That				
25	1000	3	23935	857671	32	Thach That				
26	1000	3	23935	857671	32	Thach That				
27	1000	3	23935	857671	32	Thach That				
28	1500	3	35902	1286488	48	Thach That				
29	900	3	21542	771922	29	Thach That				
Total							839	1193	975	5,532

S7: Calculations for Scenario 3

FID	Pig (head/farm)	Gi _Bin	CH4 generation per year (kg/year)	Energy per year (MJ/year)	Capacity _y (kW)	ADM2_EN	Total Capacity per year (kW/year)	Total CH4 emission per year (ton CO2 eq/year)	Total N_2O emission per year (ton CO2 eq/year)	Total CO2 emission per year (ton/year)
0	600	3	14361	514602	19	Ba Vi	32			
1	400	3	9574	343068	13	Ba Vi				
2	202	3	4835	173254	6	Son Tay	308	439	117	2034
3	105	3	2513	90049	3	Son Tay				
4	600	3	14361	514602	19	Son Tay				
5	600	3	14361	514602	19	Son Tay				
6	550	3	13164	471710	17	Son Tay				
7	315	3	7540	270183	10	Son Tay				
8	250	3	5984	214427	8	Son Tay				
9	400	3	9574	343068	13	Son Tay				
10	600	3	14361	514602	19	Son Tay				
11	600	3	14361	514602	19	Son Tay				
12	500	3	11968	428853	16	Son Tay				

13	130	3	3112	111513	4	Son Tay				
14	420	3	10053	360232	13	Son Tay				
15	580	3	13882	497438	18	Son Tay				
16	120	3	2872	102913	4	Son Tay				
17	165	3	3949	141506	5	Son Tay				
18	400	3	9574	343068	13	Son Tay				
19	600	3	14361	514602	19	Son Tay				
20	400	3	9574	343068	13	Son Tay				
21	120	3	2872	102913	4	Son Tay				
22	120	3	2872	102913	4	Son Tay				
23	360	3	8617	308776	11	Son Tay				
24	110	2	2633	94349	3	Son Tay				
25	210	2	5026	180098	7	Son Tay				
26	600	2	14361	514602	19	Son Tay				
27	600	2	14361	514602	19	Son Tay				
28	400	3	9574	343068	13	Son Tay				
29	130	2	3112	111513	4	Son Tay				
30	110	3	2633	94349	3	Son Tay				
31	450	3	10771	385961	14	Son Tay				
32	200	3	4787	171534	6	Thach That				
33	600	3	14361	514602	19	Thach That				
34	450	3	10771	385961	14	Thach That	71			
35	500	3	11968	428853	16	Thach That				
36	500	3	11968	428853	16	Thach That				
Total							308	439	117	2034