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Biomass Resource Mapping in Vietnam

FINAL REPORT ON BIOMASS ATLAS FOR VIETNAM

AUGUST 2018

This report was prepared by Full Advantage, Simosol, Institute of Energy and Enerteam, under contract to The World Bank.

It is one of several outputs from the biomass resource mapping component of the activity "Renewable Energy Resource Mapping and Geospatial Planning – Vietnam" [Project ID: P145513]. This activity is funded and supported by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank, under a global initiative on Renewable Energy Resource Mapping. Further details on the initiative can be obtained from the ESMAP website.

This document is an **interim output** from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to full peer review. The final, validated, peer reviewed output from this project will be the Vietnam Biomass Atlas, which will be published once the project is completed.

BIOMASS RESOURCE MAPPING IN VIETNAM

FINAL REPORT
ON BIOMASS ATLAS FOR VIETNAM

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AEZ	Agro-Ecological Zone
AHAV	Animal Husbandry Association of Vietnam
CTU	Can Tho University
DARD	Department of Agriculture and Rural Development (of the provinces)
DOIT	Department of Industry and Trade (of provinces)
DONRE	Department of Natural Resources and Environment (of provinces)
ENERTEAM	Energy Conservation Research and Development Center (Vietnam)
ESA	European Space Agency
ESMAP	Energy Sector Management Assistance Program
FA	Full Advantage Co., Ltd. (Thailand)
FAO	Food and Agriculture Organization
GDE	General Department of Energy (under MOIT)
GIZ	Gesellschaft fur Internationale Zusammenarbeit (Germany)
GIS	Geographic Information System
GOV	Government of Vietnam
HUST	Hanoi University of Science and Technology
IE	Institute of Energy (Vietnam)
M&E	Monitoring and Evaluation
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Resources and Environment
MSW	Municipal Solid Waste
NFIS	National Forest Inventory and Statistics
NLU	Nong Lam University
NPDP	National Power Development Plan
PCF	Power Capacity Factor
PITCO	PITCO Private Limited (Pakistan)
RE	Renewable Energy
REDP	Renewable Energy Development Project
RERM	Renewable Energy Resource Mapping
SAR	Synthetic Aperture Radar
S-1	Sentinel-1
SNV	SNV Netherland Development Organization
TOR	Terms of Reference
USTH	University of Science and Technology of Hanoi
VDA	Vietnam Diary Association
VFU	Vietnam Forestry University
VNUA	Vietnam National University of Agriculture
VSSA	Vietnam Sugar and Sugarcane Association
WB	World Bank

UNITS

MW	Megawatt
GW	Gigawatt
MWh	Megawatt-hour
GWh	Gigawatt-hour
MJ	Megajoule
GJ	Gigajoule
TJ	Terajoule
MWh_{th}	Megawatt-hour thermal
GWh_{th}	Gigawatt-hour thermal
kg	kilogram
m	meter
km	kilometer
ha	hectare

1. Executive Summary

The present report is the Final Report on the Biomass Resource Assessment Study for Vietnam. The report summaries the achievements of the study and presents the Biomass Atlas for Vietnam as its final product.

Overall Achievements of the Study	All the expected outputs of the study were achieved as per the TOR. The outputs/deliverables of the project can be accessed at *https://esmap.org/re_mapping_vietnam*.
Biomass Atlas for Vietnam	The Biomass Atlas consists of raw survey data, the atlas datasets and the maps. The Biomass Atlas contains two sections: the first one related to biomass feedstock availability and the second one related to the potential use of the biomass feedstock for energy generation. The residues of 18 crops were included in the Biomass Atlas. The crop residues are divided into two categories: crop harvesting residues and crop processing residues. Crop harvesting residues are generated in the field during crop harvesting activities while crop processing residues are produced during crop processing operations at agro-industrial sites. Both theoretical and technical potentials of crop residues were assessed. The theoretical biomass feedstock potential was estimated at about 59.89 million tonnes/year with an energy potential of 768,853 TJ/year (213,570 GWh_{th}/year) for crop harvesting residues and 20.86 million tonnes/year with an energy potential of 245,094 TJ/year (68,082 GWh_{th}/year) for crop processing residues. Based on the existing uses of the residues, the technical potential of crop harvesting residues was estimated at about 15.22 million tonnes/year with an energy potential of 195,773 TJ/year (54,381 GWh_{th}/year). If the farmers' willingness to sell their biomass residues is taken into consideration, the technical potential of crop harvesting residues decreases to about 7.95 million tonnes/year with an energy potential of 101,068 TJ/year (28,075 GWh_{th}/year). The analysis of the electricity generation potential at the biomass producing sites shows that bagasse offers the highest potential via their use as fuel in cogeneration plants. The total power capacity output of the cogeneration plants using bagasse generated from the 40 existing sugar mills in 2016-2017 milling season in Vietnam is estimated at about 600 MW. Municipal Solid Wastes (MSW) can also be used in large-scale grid-connected power plants with a combined installed power capacity of 130 MW. However, rice husk, wood residues and livestock manure seem to offer a limited energy potential which is limited to captive power plants that generate electricity to cover the power requirements of the rice mills, wood processing mills or livestock farms. It should be noted that the analysis does not cover

	all the existing MSW landfills, rice mills, wood processing mills and livestock farms in Vietnam due to limited resources for carrying out an exhaustive survey. The potential for greenfield power plants using crop harvesting residues was assessed based on their site suitability indicators. These site suitability indicators take into account the feedstock sourcing area size, the transport network density in the region, and the distance to a grid. A high site suitability value indicates a good site for a potential power plant, whereas a low value indicates a poor location. The site suitability maps were produced for 18 different combinations of energy conversion technologies and power plant capacities.
Information Dissemination and Capacity Building	During the process of the study, several seminars, workshops and trainings were conducted to present the study objectives or to disseminate the study results to the local stakeholders and to build their capacity in usage and maintenance of the Biomass Atlas. Seven (7) multi-stakeholder seminars and workshops were conducted. These events attracted a total of 178 participants. In addition, several individual meetings with local institutions and companies were organized during the missions of the consultants to Vietnam.
Key Lessons Learned	The key lessons learned can be summarized as follows: • The field survey and collection of the data is a hard, time-consuming exercise. It needs to be well planned and excellently coordinated; • The use of universities specialized in agriculture (i.e. NLU and VNUA) was key to the success of the field survey; • Comprehensive training of enumerators is essential. Each enumerator should conduct at least 5 test surveys to make sure that he/she is familiar with the Survey App on smartphone, questionnaires and develops interview skills. • For remote areas where people do not speak Kinh language, a translator is needed. • The involvement of local agriculture officers in the field surveys was essential to facilitate the contact with farmers; • Good knowledge of the biomass producers and consumers by the local consultants is necessary to facilitate the industrial surveys; • A well-designed and continuous data validation process helped the international consultants (Simosol and FA) to immediately check and correct any erroneous data; • The constructive feedback received from local stakeholders during the seminars/workshops was essential to finalize the production of a most appropriate Biomass Atlas for Vietnam.

2. INTRODUCTION

According to the "National Power Development Plan (NPDP) for the period of 2011-2020 with an outlook to 2030" (referred to as PDP VII)[1], the Government of Vietnam (GOV) has set a national target for increasing the total amount of power generation and import from about 19,500 MW in 2010 to 75,000 MW and 146,800 MW by 2020 and 2030, respectively. The total electricity generation and import is expected to be 330 billion kWh in 2020 and 695 billion kWh in 2030. The amount of electricity generated from renewable energy (RE) sources would be around 42 billion kWh in 2030, accounting for 6% of the total amount of electricity generation and import.

The revised NPDP (PDP VII-revised) promulgated by the Prime Minister of Vietnam in 2016[2] has reduced the total electricity demand projection for 2030 from 695 to 572 TWh/year. However, the target for electricity generation from RE sources (excluding large-scale and pumped-storage hydropower plants) was increased from 42 TWh/year to around 61 TWh/year, making up 10.7% of the total electricity generated and imported in 2030. Solar power will account for 3.3% of the total electricity generation and import, followed by small hydropower (3.2%), wind power (2.1%), and biomass and MSW (2.1%).

In order to attain such ambitious targets, the GOV has endeavored to exploit various sources of power generation and supply: fossil fuels (coal and gas), hydropower, nuclear power, RE and imported power. As Vietnam has a huge potential of RE resources, the GOV has set a goal to increase the total installed power capacity of RE sources from around 2,400 MW in 2015 to 23,350 MW in 2030. The installed power capacity is expected to be 6,000 MW for wind power, 12,000 MW for solar power, 3,350 MW for small hydro power (with a capacity below 30 MW), and 2,000 MW for biomass (including MSW) by 2030.[3]

The Ministry of Industry and Trade (MOIT) is implementing the Renewable Energy Development Project (REDP) funded by the World Bank. The objective of the REDP is to increase the supply of electricity to the national grid from RE sources on a commercially, environmentally and socially sustainable basis. The REDP has three components: (i) Investment Implementation; (ii) Regulatory Development and (iii) Project Pipeline Development. MOIT is implementing several technical assistance activities to strengthen the capacity of government agencies and stakeholders for exploiting the sizable RE resources of Vietnam.

In addition to studies on supporting mechanisms for development of RE and cumulative impact assessment for cascade hydropower projects, MOIT has requested the assistance of the World Bank for a Renewable Energy Resource Mapping (RERM) project, with funding from the Energy Sector Management Assistance Program (ESMAP), a global knowledge and technical assistance program administered by the WB and supported by eleven bilateral donors. The development objective of this project is to increase the output and diversity of renewable electricity generation in Vietnam. The outcome objective is to improve the awareness of the government and the private sector of the resource potential for biomass, small hydropower, and wind, and providing the government with a spatial planning framework to guide commercial investments.

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[1] *Decision 37/2011/QD-TTg dated 14 June 2011 of the Prime Minister of Vietnam*
[2] *Decision 428/QD-TTg dated 18 March 2016 of the Prime Minister of Vietnam*
[3] *Vietnam: Energy sector assessment, strategy, and road map. Asian Development Bank, December 2015.*

Under this RERM project, the World Bank has contracted a Consortium of consultants led by Full Advantage Co., Ltd. (FA) to develop a Biomass Atlas for Vietnam (hereafter called "FA Consortium"). The FA Consortium involves several Finnish companies led by Simosol Oy, and two local partners: the Institute of Energy (IE) and the Energy Conservation Research and Development Center (ENERTEAM). The Vietnam National University of Agriculture (VNUA) and Nong Lam University (NLU) were contracted by MOIT to conduct the field survey and data collection on crop and industrial biomass residues.

The overall objective of this biomass resource mapping project is to support the sustainable expansion of electricity generation from biomass by providing the national government, provincial authorities and commercial developers in Vietnam with an improved understanding of the location and potential of biomass resources. The specific objective is to support RE mapping and geospatial planning for biomass resources in Vietnam. The project consists of three phases:

- Phase 1: Project inception, team building, data source identification, preparation of terms of reference (TOR) for field survey and data collection, and implementation planning;
- Phase 2: Data collection/analysis and creation of draft Biomass Atlas;
- Phase 3: Production and publication of a validated Final Biomass Atlas for Vietnam.

3. PROJECT OUTPUTS AND DELIVERABLES

3.1 Expected Outputs of the Project

According to the Terms of Reference (TOR), the expected outputs of the project include:

Phase 1:

- Conduct of inception meetings, identification and assessment of existing data sources needed for the project, and team building;
- Development of an Implementation Plan for Phase 2;
- Preparation of the TOR for field survey and data collection to be conducted by the local contractors hired by MOIT;
- Conduct of Phase 1 Workshop

Phase 2:

- Conduct of remote data collection and analysis;
- Conduct of a training workshop on field survey and data collection;
- Support and validation of the data collected by the local survey contractors;
- Acquisition of GIS data of other driving components
- Conduct of data analysis and development of draft biomass atlas;
- Conduct of stakeholder data validation workshop.

Phase 3:

- Production of final Biomass Atlas for Vietnam;
- Conduct of workshops to disseminate the Biomass Atlas;
- Conduct of trainings for local stakeholders in using and updating the Biomass Atlas.

3.2 Summary of Achievements vs Expected Outputs

The expected outputs and the summary of achievements of the project are presented in Table 1.

Table 1: Summary of Achievements vs Expected Outputs

Activity	Expected outputs	Achievements
PHASE 1:		
Conduct of inception meetings, identification and assessment of existing data sources needed for the project, and team building	• Inception meetings conducted • Existing data sources identified and assessed • Local counterparts identified, and their capacity assessed • Inception Report prepared and submitted	• A kick-off meeting with WB and MOIT was held in Hanoi on 2 Jun 2015. Twelve (12) participants attended the meeting. • An inception meeting was conducted in Hanoi on 3 Jun 2015. Twenty one (21) participants attended the meeting. • Site visits to a sugar mill in Hau Giang province and a rice mill in Can Tho City. • Twelve (12) existing studies and publications were obtained and reviewed. The reviews were reported in the Inception Report • Several local stakeholders (GIZ, SNV, NLU, VNUA, HUST, VFU, USTH, CTU, etc.) were contacted to obtain existing information on the biomass mapping exercises in Vietnam. • The Inception Report was developed and submitted on 27 Jun 2015.
Development of an Implementation Plan for Phase 2	• Implementation Plan prepared and submitted	• Implementation Plan for Phase 2 was developed and submitted on 15 Oct 2015.
Preparation of the TOR for field survey and data collection to be conducted by the local contractors hired by MOIT	• TOR prepared and submitted	• TOR for nationwide field survey and data collection were prepared, submitted to and approved by WB and MOIT on 9 Oct 2015.
Conduct of Phase 1 Workshop	• Phase 1 Workshop conducted	• A workshop was held in Hanoi on 16-17 Sep 2015 to present the outputs and results of Phase 1 of the project.
PHASE 2:		
Remote data collection and analysis	• Remote data collected and analyzed	• Satellite images were acquired from Sentinel-1 and were analyzed to produce the raw biomass cluster images for field observation and inspection. • A field inventory plan was developed.
Training on data collection for enumerators	• Training on field survey and data collection conducted	• MHG Biomass Manager was developed. • Required smartphone applications for navigation, data entry and data transfers were acquired. • Training on field survey and data collection was conducted on 28-29 September 2016 for 32 participants from Nong Lam University (NLU) and Vietnam National University of Agriculture (VNUA).

Data collection and validation	• Field surveys conducted, and data collected (by the local consultants hired by MOIT) • Collected data validated by FA Consortium	• Field surveys were conducted, and the data on crop biomass residues were collected in ALL 63 cities/provinces of Vietnam with 21,212 farmers interviewed. Collected data on crop biomass residues were validated, and 19,985 datasets were accepted. • Field surveys on industrial biomass residues were conducted in Vietnam. 261 datasets from seven industrial sectors (including 40 sugar mills, 54 rice mills, 38 MSW landfills, 67 livestock farms, 40 wood processing mills, 16 brick-making factories and 6 pulp and paper mills) were collected and validated.
Acquisition of GIS data of other driving components	• GIS data of other driving components (road network, power T&D network, etc.) acquired and verified.	• Power grid sub-station locations (digitized at the World Bank from a paper map), OpenStreetMap road and waterway network data were acquired.
Data analysis and development of draft biomass atlas	• A comprehensive database necessary for biomass resource mapping, including raw data files elaborated • Draft biomass resource maps developed	• The collected data were processed and integrated into a comprehensive database. • Draft biomass resource maps were produced.
Conduct of stakeholder data validation workshop	• A stakeholder data validation workshop conducted	• A stakeholder data validation workshop was conducted on 15 November 2017. Twenty four (24) participants attended the workshop.
PHASE 3:		
Production of final Biomass Atlas for Vietnam	• Final Biomass Atlas for Vietnam including associated GIS files and datasets produced	• The final Biomass Atlas for Vietnam including associated GIS files and datasets was produced.
Conduct of workshops to disseminate the Biomass Atlas and organize training on its usage and maintenance	• Dissemination and training workshops conducted	• Biomass Atlas Dissemination Workshops and Training Workshops on Biomass Atlas Usage were conducted in Hanoi (15 Aug 2018) and Ho Chi Minh City (17 Aug 2018). They were attended by a total of 61 participants (31 in Hanoi and 30 in Ho Chi Minh City). A training workshop on the Biomass Atlas Maintenance was also conducted in Hanoi on 15 Aug 2018.

4. Vietnam Biomass Atlas

Based on the Implementation Plan approved by the WB in March 2015, five types of biomass resources are included in the Biomass Atlas for Vietnam:

- Crop harvesting residues;
- Crop processing residues;
- Livestock residue;
- Municipal Solid Waste (MSW), and
- Wood processing residues

The Biomass Atlas for Vietnam has two main components: the maps and datasets. The maps are derived from the atlas datasets and each visually illustrates one specific aspect of the biomass-based energy production potential in Vietnam. The datasets contain the full results of the mapping project and can be used in numerical analysis with a GIS program. It should be noted that the Biomass Atlas and its associated datasets provide information on the potential and suitability of biomass-based power generation in Vietnam from the technical feedstock availability and from an infrastructure point of view. For each concrete project to be developed in the future, its economic and financial viability as well as an optimal biomass supply chain should be assessed during the project feasibility study.

The mapping methodology is described in Annex 1. The maps and main datasets are introduced in the following sections, while the full set of datasets is provided in Annex 3.

Training materials directed to familiarize novice GIS users with the use and update of the Biomass Atlas data using GIS software is included in Annexes 4 and 5.

4.1 Crop Biomass Feedstock Potential

The *theoretical crop biomass feedstock potential* is based on the total amount of crop production. The crop residues are divided into two categories: crop harvesting residues and crop processing residues. Crop harvesting residues are generated in the field during crop harvesting activities while crop processing residues are produced during crop processing operations at agro-industrial sites.

For Vietnam, the crop residues of 18 crops were included in the Biomass Atlas. Estimates of both crop residue categories were generated individually for each Agro-Ecological Zone (AEZ) of Vietnam. The delineation of AEZs is based on similarities in environmental attributes such as temperature, rainfall, soil characteristics and topography. These attributes essentially determine the types of crops, as well as their growth period and productivity. The amount of crop production was estimated using two main information sources: the land use classification based on the Sentinel-1 satellite images, and the district level crop yields obtained from the field survey. The land use classification was carried on for each of the 20 m x 20 m pixel covering Vietnam in the Sentinel-1 images. The crop harvesting residues were aggregated for the atlas to 1 km x 1 km pixels based on cropping season information in the 20 m x 20 m land use classification.

Figure 1: Agro-Ecological Zones of mainland Vietnam

The annual production of the crop type *j* in the land pixel *i* is calculated using the formula:

$$P_{ij} = A_{ij} * CY_{ij} \qquad [1]$$

Where:

- P_{ij} = annual production of the crop type *j* in the land pixel *i*, in tonnes/year
- A_{ij} = combined cultivation area of the crop type *j* in the land pixel *i* (1 km x 1 km) over the cropping seasons, in ha
- CY_{ij} = crop yield of the crop type *j* in the land pixel *i*, in tonnes/ha/cropping season

The district level crop yields based on the field survey executed within the project are used for calculating the crop production.

The crop production was converted to the annual theoretical production of crop residues by using the conversion factors (residue-to-crop ratios) and the formula:

$$CR_{ijk,theo} = P_{ij} * RCR_{jk} \qquad [2]$$

The theoretical amounts of firewood generated from pruning the perennial industrial crops (cashew nut, rubber, tea, coffee and pepper) and fruit crops (grape, mango, orange, mandarin, longan, litchi and rambutan) are calculated using the formula:

$$CR_{ijk,theo} = A_{ij} * RCR_{jk} \qquad [3]$$

Where:

$CR_{ijk,theo}$ = annual theoretical production of crop residue type *k* produced from the crop type *j* in the land pixel *i*, in tonnes/year

RCR_{jk} = average residue-to-crop ratio of the crop residue type *k*, in tonne/tonne of crop type *j* produced or tonne/ha.year of crop type *j* cultivated in the land pixel *i* (see Table 2)

The annual theoretical production of the crop residue type *k* from the crop type *j* for the whole country ($CR_{jk,theo}$) is calculated using the formula:

$$CR_{jk,theo} = \sum_i^n CR_{ijk,theo} \qquad [4]$$

The annual technical production of the crop residue type *k* from the crop type *j* in the land pixel *i* ($CR_{ijk,tech}$) of the crop harvesting residues was derived from its annual theoretical production ($CR_{ijk,to}$) by excluding the existing uses of the residues based on the field survey results.

$$CR_{ijk,tech} = CR_{ijk,theo} - CR_{ijk,uses} \qquad [5]$$

During the field survey, the following existing uses of crop harvesting residues were recorded: animal fodder, domestic burning (cooking), selling to biomass supplier, selling to industry, organic fertilizer or open field burning. Only the crop harvesting residues that would have been burnt at the fields were included in the technical feedstock potential.

The annual technical production of the crop residue type *k* from the crop type *j* for the whole country ($CR_{jk,tech}$) is calculated using the formula:

$$CR_{jk,tech} = \sum_i^n CR_{ijk,tech} \qquad [6]$$

The theoretical and technical energy potentials of the crop residue type *k* can be calculated by multiplying the annual production of the crop residue by its LHV.

The type of crops, the type of crop residues, their RCR and the LHV of the residues are provided in Table 2 and 3.

Table 2: Residue to crop ratios used for the atlas

Type of crop *j*	Type of crop residue *k*	Unit	RCR_{jk}, (used in this study)	RCR range
Crop biomass residue (after harvesting)				
Paddy	Rice straw	t/t of paddy	1.00	0.33 – 2.15
Sugarcane	Sugarcane trash	t/t of sugarcane (stem)	0.10	0.05 – 0.30
Maize	Maize trash	t/t of maize (grain)	2.20	1.00 – 3.77
Peanut	Peanut straw	t/t of peanut (in-shell)	2.00	2.00 – 2.30
Cassava	Cassava stalks	t/t of cassava (root)	0.30	0.06 – 0.30
Soybean	Soybean straw	t/t of soybean (grain)	0.30	in/a
Sweet potato	Sweet potato straw	t/t of sweet potato (root)	0.30	in/a
Cotton	Cotton stalks	t/t of cotton harvested	3.40	2.76 – 4.25
Cashew nut	Firewood	t/ha.year	0.70	in/a
Rubber	Firewood	t/ha.year	0.50	in/a
Coffee	Firewood	t/ha.year	0.70	in/a
Tea	Firewood	t/ha.year	0.50	in/a
Pepper	Firewood	t/ha.year	0.50	in/a
Coconut	Firewood	t/ha.year	6.50	in/a
Grape	Firewood	t/ha.year	0.50	in/a
Mango	Firewood	t/ha.year	0.50	in/a
Orange	Firewood	t/ha.year	0.50	in/a
Mandarin	Firewood	t/ha.year	0.50	in/a
Longan	Firewood	t/ha.year	0.50	in/a
Litchi	Firewood	t/ha.year	0.50	in/a
Rambutan	Firewood	t/ha.year	0.50	in/a
Agro-industrial biomass residues (after crop processing)				
Paddy	Rice husk	t/t of paddy	0.20	0.15 – 0.36
Maize	Corn cobs	t/t of maize (grain)	0.30	0.20 – 0.50
Maize	Maize shells (husks)	t/t of maize (grain)	0.20	0.20 – 0.40
Sugarcane	Sugarcane bagasse	t/t of sugarcane (stem)	0.30	0.14 – 0.40
Peanut	Peanut shells	t/t of peanut (in-shell)	0.30	0.30 – 0.48
Cassava	Cassava peels	t/t of cassava (root)	0.12	0.10 – 0.15
Cashew nut	Cashew nut shells	t/t of cashew nut (in-shell)	0.60	0.50 – 0.70
Coffee	Coffee husk	t/t of coffee bean	0.40	0.21 – 0.46
Coconut	Coconut husk	t/t of coconut fruit	0.30	0.30 – 0.53
Coconut	Coconut shells	t/t of coconut fruit	0.15	0.12 – 0.15
Wood processing residues				
Wood logs	Wood edges, slabs, etc.	t/t of wood logs	0.78	0.62 – 0.83
Wood logs	Sawdust	t/t of wood logs	0.22	0.17 – 0.38

Notes: in/a: Information is not available; Firewood refers to the tree bark, leaves and branches, shrubs, etc. from pruning the perennial industrial crops (cashew nut, rubber, tea, coffee, pepper and coconut), fruit crops (grape, mango, orange, mandarin, longan, litchi and rambutan).

The RCRs are country-specific values for Vietnam which were obtained from the field surveys as well as from studies conducted by various local and international institutions (IE, ENERTEAM, GIZ, SNV, ADB). The RCR values used in this study mainly come from the report on the "Strategy and Master Plan for Renewable Energy Development in Vietnam up to 2020 with an outlook to 2030" prepared by IE for the Ministry of Industry and Trade in 2011. It should be noted that, for most of residue types, the range of RCR values used in this study fall within the range of values used in FAO's Bioenergy and Food Security (BEFS) Rapid Appraisal Tool for crop residues assessment.

Table 3: Lower heating values of different biomass residues

Type of crop *j*	Type of crop residue *k*	Moisture content of residues (%)	LHV (MJ/kg)	LHV (MWh_{th}/tonne)
Crop biomass residue (after harvesting)				
Paddy	Rice straw	12.0	12.60	3.50
Sugarcane	Sugarcane trash	25.0	12.50	3.47
Maize	Maize trash	16.0	12.50	3.47
Peanut	Peanut straw	15.0	15.00	4.17
Cassava	Cassava stalks	15.0	17.00	4.72
Soybean	Soybean straw	15.0	12.40	3.44
Cotton	Cotton stalks	12.5	15.00	4.17
Various	Firewood	30.0	12.20	3.39
Agro-industrial biomass residues (after crop processing)				
Paddy	Rice husk	10.5	13.00	3.61
Maize	Corn cobs	17.6	14.10	3.92
Maize	Maize shells (husks)	16.0	12.50	3.47
Sugarcane	Sugarcane bagasse	50.0	7.50	2.08
Peanut	Peanut shells	9.0	16.40	4.56
Cassava	Cassava peels	40.0	8.40	2.33
Cashew nut	Cashew nut shells	10.4	17.80	4.94
Coffee	Coffee husk	11.0	16.70	4.64
Coconut	Coconut husk	9.0	12.90	3.58
Coconut	Coconut shells	10.0	16.90	4.69
Wood processing residues				
Wood logs	Wood edges, slabs, etc.	20.0	14.30	3.97
Wood logs	Sawdust	30.0	12.20	3.96

The moisture content of "as-received" biomass residues was obtained from the studies conducted by various local and international institutions (IE, ENERTEAM, GIZ, SNV, ADB). The LHVs used in this study are country-specific for Vietnam which mainly come from the draft report on the "Strategy and Master Plan for Renewable Energy Development in Vietnam up to 2020 with an outlook to 2030". In case the country-specific LHV values for certain types of biomass residues are not available, they will be calculated based on the global-average LHV values of moisture-free biomass residues and moisture content of as-received biomass residues.

The annual calculated theoretical potentials of crop harvesting residues and crop processing residues are presented in Tables 4 and 5, respectively.

Table 4: Country-level annual theoretical potential of crop harvesting residues

Type of crop *j*	Type of residues *k*	Annual production of residues (tonnes)	Energy potential of residues	
			TJ/year	GWh_{th}/year
Paddy	Rice straw	35,766,728	450,661	125,184
Maize	Maize trash	16,147,141	201,839	56,066
Sugarcane	Sugarcane trash	1,842,331	23,029	6,397
Peanut	Peanut straw	1,040,245	15,604	4,334
Soybean	Soybean straw	13,293	165	46
Cassava	Cassava stalks	3,246,617	55,192	15,331
Perennial crops	Firewood	1,831,488	22,344	6,207
Fruit crops	Firewood	1,548	19	5
Total		**59,889,391**	**768,853**	**213,570**

Table 5: Country-level annual theoretical potential of crop processing residues

Type of crop *j*	Type of residues *k*	Annual production of residues (tonnes)	Energy potential of residues	
			TJ/year	GWh_{th}/year
Paddy	Rice husk	7,153,346	92,993	25,832
Maize	Corn cobs	2,201,883	31,047	8,624
Maize	Maize shells (husk)	1,467,922	18,349	5,097
Sugarcane	Sugarcane bagasse	5,526,992	41,452	11,515
Cassava	Cassava peels	1,298,647	10,909	3,030
Coffee	Coffee husk	1,558,343	26,024	7,229
Coconut	Coconut husk	922,116	11,895	3,304
Peanut	Peanut shells	156,037	2,559	711
Cashew nut	Cashew nut shells	116,507	2,074	576
Coconut	Coconut shells	461,058	7,792	2,164
Total		**20,862,851**	**245,094**	**68,082**

Figure 2 illustrates the theoretical feedstock potential of crop residues over the map of Vietnam. While this map shows the potential for the total amount of generated biomass residues, the Biomass Atlas's GIS datasets contain a more detailed description of the potential, broken down by the type of the crop residue, as well as the location down to the 1 km x 1 km resolution. The map contains both the crop harvesting residues and processing residues. The location as far as the processing residues are concerned is not accurate, as these residues are not produced at the site of cultivation but rather at the site of industrial processing of the crop. Therefore, for processing residues, the location indicated is a proxy location pinpointing the site of original biomass production.

The links to access the Biomass Atlas map and GIS datasets for the theoretical potential of crop residues are provided in Annex 3.

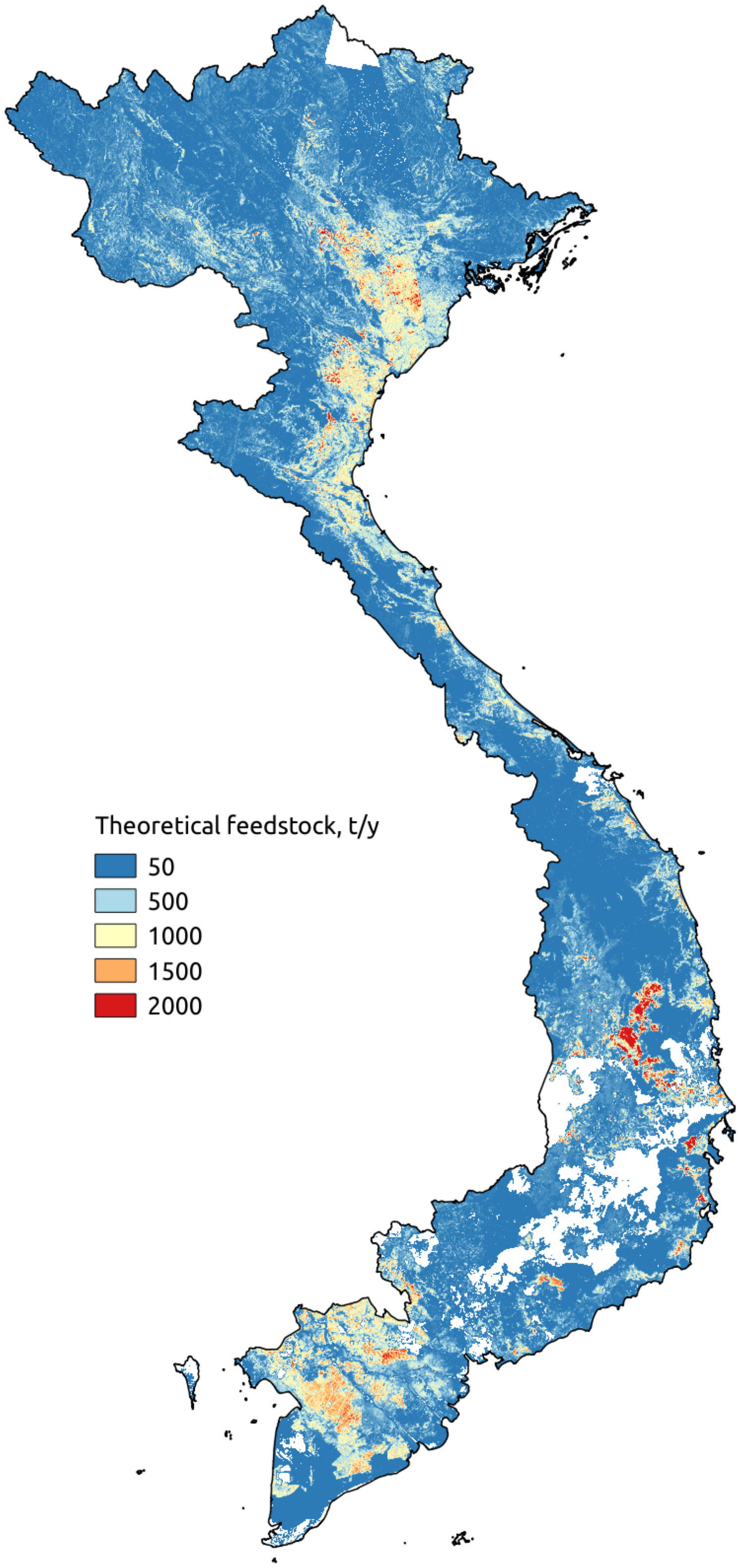

Figure 2: Theoretical potential of crop residues, including both harvesting and processing residues for all crops

The technical crop feedstock potential of the crop residues was derived from the theoretical feedstock potential by excluding the existing use of the harvesting residues based on the field survey results. During the field survey, the following uses of crop harvesting residues were recorded: animal fodder, domestic burning (cooking), selling to biomass supplier, selling to industry, organic fertilizer or open field burning. Only the crop harvesting residues that would have been burning at the fields were included in the technical feedstock potential. Table 6 and Figure 3 present the technical potential of the crop harvesting residues based on their existing uses.

Table 6: Technical potential of crop harvesting residues based on their existing uses

Type of crop *j*	Type of residues *k*	Annual technical potential of residues (tonnes)	Energy potential of residues	
			TJ/year	GWh_{th}/year
Paddy	Rice straw	8,714,689	109,805	30,501
Maize	Maize trash	3,763,194	47,040	13,067
Sugarcane	Sugarcane trash	1,270,724	15,884	4,412
Peanut	Peanut straw	169,631	2,544	707
Soybean	Soybean straw	1,500	19	5
Cassava	Cassava stalks	959,601	16,313	4,531
Perennial crops	Firewood	341,315	4,164	1,157
Fruit crops	Firewood	350	4	1
Total		**15,221,004**	**195,773**	**54,381**

Another aspect affecting the availability of the crop harvesting residues for power generation is the willingness of the farmers to participate in the biomass feedstock supply chain (i.e. to sell their biomass residues to the market). This aspect was also covered in the survey and was aggregated to the district level from the individual surveys by weighing the farmer responses. Figure 4 presents the technical feedstock potential of the crop residues based on the existing uses and the farmers' willingness to sell the crop harvesting residues. Table 7 lists the technical potential for crop harvesting residues after taking into account both the existing uses and the willingness to sell.

Table 7: Technical potential of crop harvesting residues based on their existing uses and farmers' willingness to sell

Type of crop *j*	Type of residues *k*	Annual technical potential of residues (1000' tonnes)	Energy potential of residues	
			TJ/year	GWh_{th}/year
Paddy	Rice straw	4,903,776	61,788	17,163
Maize	Maize trash	2,387,979	29,850	8,292
Sugarcane	Sugarcane trash	300,966	3,762	1,045
Peanut	Peanut straw	143,991	2,160	600
Soybean	Soybean straw	159	2	1
Cassava	Cassava stalks	187,230	3,183	884
Perennial crops	Firewood	26,455	323	90
Fruit crops	Firewood	2	0	0
Total		**7,950,558**	**101,068**	**28,075**

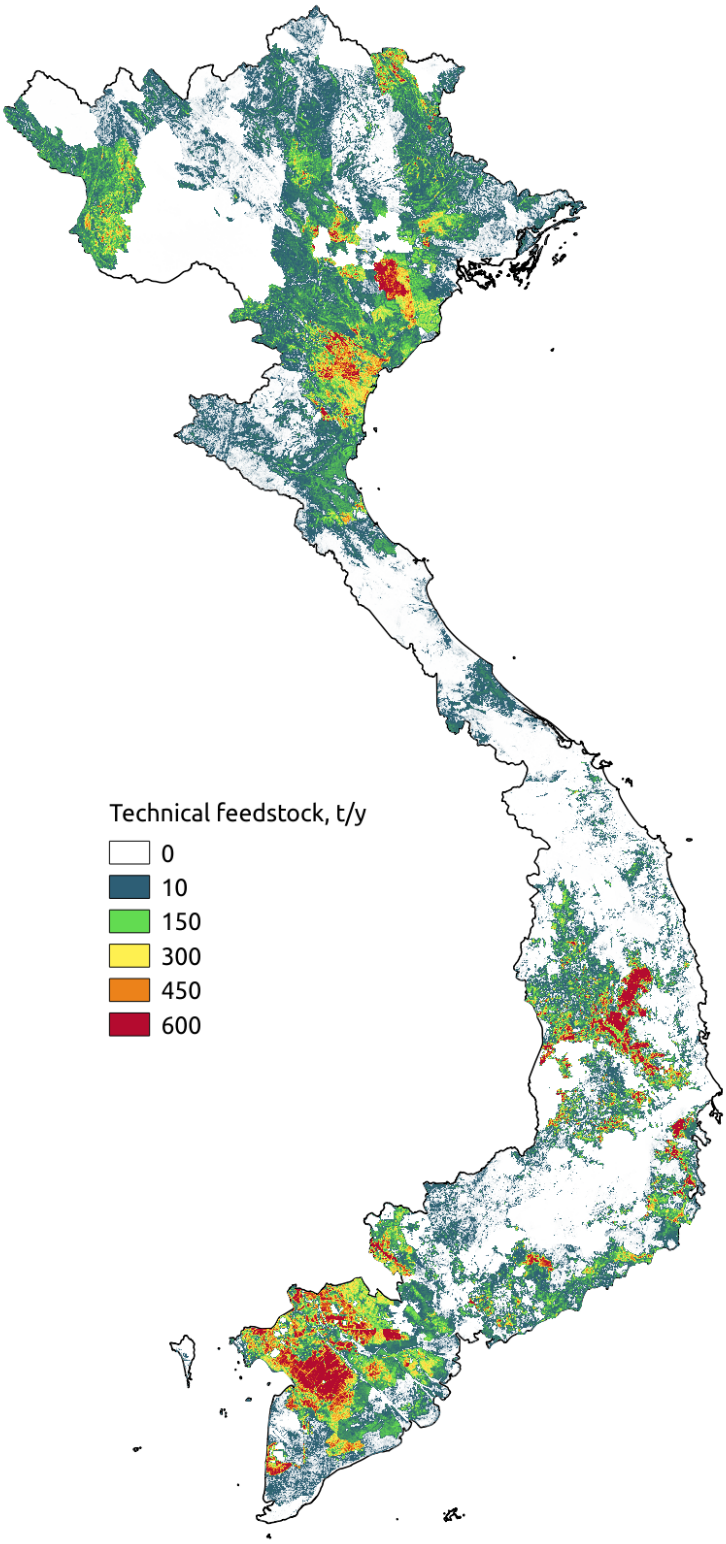

Figure 3: Technical potential of crop residues based on the existing uses of crop harvesting residues

Note: the color scale was changed compared to the theoretical potential map

[Background map: Microsoft® Bing™ Maps]

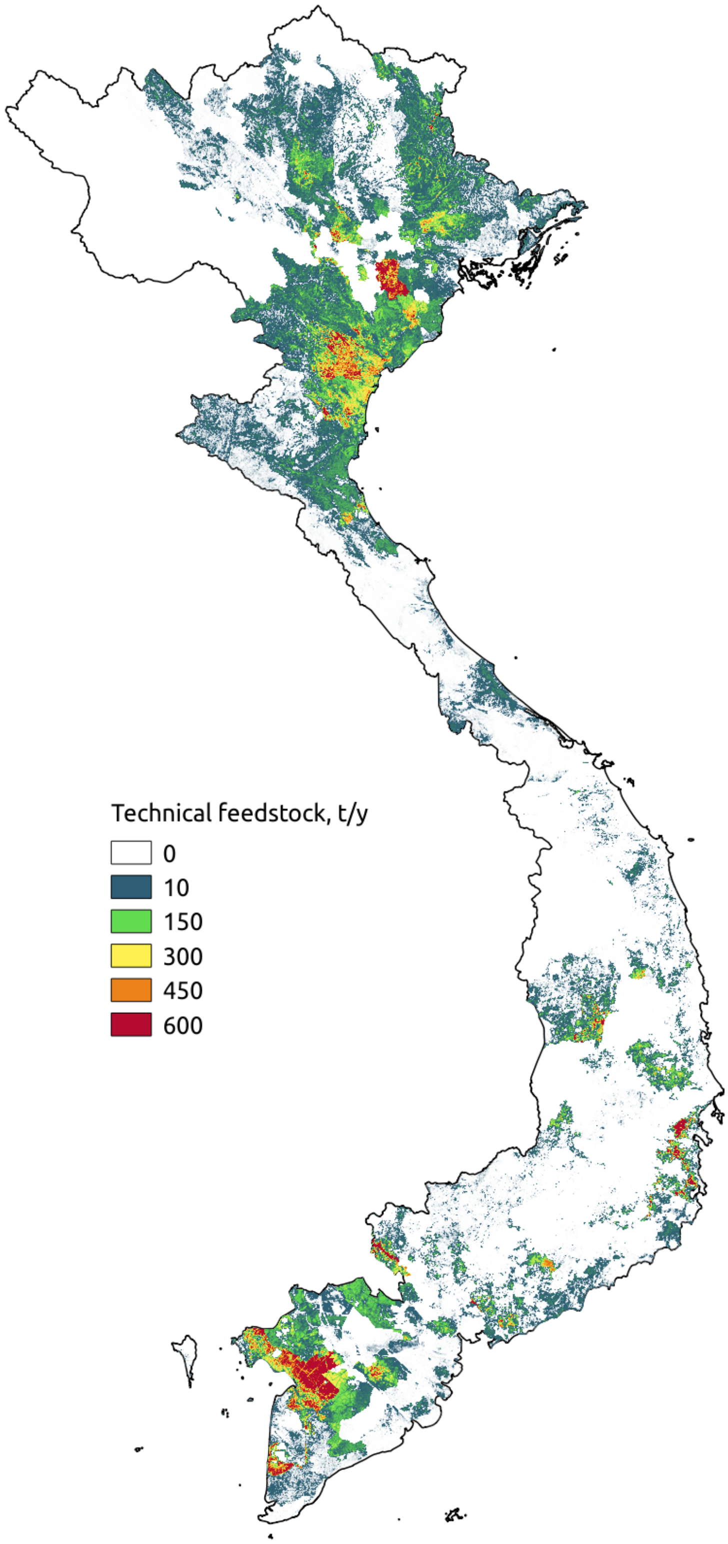

Figure 4: Technical potential of crop residues based on the existing uses and farmers' willingness to sell crop harvesting residues

Note: the color scale was changed compared to the theoretical potential map

The links for access to the Biomass Atlas map and GIS datasets for the technical potential of crop residues are provided in Annex 3.

The crop processing residues are included in the maps of feedstock potential presented in Figures 2 to 4, but as noted, they are generated at the agro-industrial sites, not in the field. Therefore, for the two most important crop processing residues, bagasse and rice husk, their real technical potential for energy generation at the agro-industrial sites, i.e., sugar and rice mills, is analyzed and presented in section 4.3.

Table 8 contains the confidence intervals for the yearly production of different crop residues based on the 504 surveyed districts. It should be noted that these figures cover only the parts of the country shown in Figure 5, not the whole country. However, the upper and lower confidence interval bounds can be used to get an indication of same bounds for the whole country.

Table 8. The mean annual potential with 95% confidence interval for different types of crop residues for the sampled 504 districts

Type of residues	Feedstock type	Mean annual potential with a 95% confidence interval (1000' t/yr)	+/-
Cassava, peel	Theoretical	1,299	150
Cassava, stalk	Theoretical	3,247	374
	Technical, based on residue use	960	17
	Technical, based on residue use and farmers' willingness to sell	187	4
Coconut, husk	Theoretical	922	53
Coconut, shell	Theoretical	461	27
Coconut, firewood	Theoretical	928	0
	Technical, based on residue use	261	71
	Technical, based on residue use and farmers' willingness to sell	25	29
Coffee, husk	Theoretical	1,558	6
Coffee, firewood	Theoretical	450	0
	Technical, based on residue use	9	8
	Technical, based on residue use and farmers' willingness to sell	0	1
Cashew nut, shell	Theoretical	117	0
Cashew nut, firewood	Theoretical	51	0
	Technical, based on residue use	4	2
	Technical, based on residue use and farmers' willingness to sell	0	0
Litchi, firewood	Theoretical	1	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0
Longan, firewood	Theoretical	1	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0
Maize, cob	Theoretical	2,202	87
Maize, shell	Theoretical	1,468	58
Maize, trash	Theoretical	16,147	635
	Technical, based on residue use	3,763	179
	Technical, based on residue use and farmers' willingness to sell	2,388	155
Mandarin, firewood	Theoretical	0	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0

Orange, firewood	Theoretical	0	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0
Peanut, straw	Theoretical	1,040	51
	Technical, based on residue use	170	30
	Technical, based on residue use and farmers' willingness to sell	144	15
Peanut, shell	Theoretical	156	8
Pepper, firewood	Theoretical	7	0
	Technical, based on residue use	3	1
	Technical, based on residue use and farmers' willingness to sell	1	0
Rambutan, firewood	Theoretical	0	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0
Rice, husk	Theoretical	7,153	277
Rice, straw	Theoretical	35,767	1,383
	Technical, based on residue use	8,715	292
	Technical, based on residue use and farmers' willingness to sell	4,904	202
Rubber, firewood	Theoretical	394	0
	Technical, based on residue use	64	16
	Technical, based on residue use and farmers' willingness to sell	1	0
Soybean, straw	Theoretical	13	0
	Technical, based on residue use	2	0
	Technical, based on residue use and farmers' willingness to sell	0	0
Sugarcane, bagasse	Theoretical	5,527	340
Sugarcane, trash	Theoretical	1,842	113
	Technical, based on residue use	1,271	3
	Technical, based on residue use and farmers' willingness to sell	301	1
Tea, firewood	Theoretical	0	0
	Technical, based on residue use	0	0
	Technical, based on residue use and farmers' willingness to sell	0	0

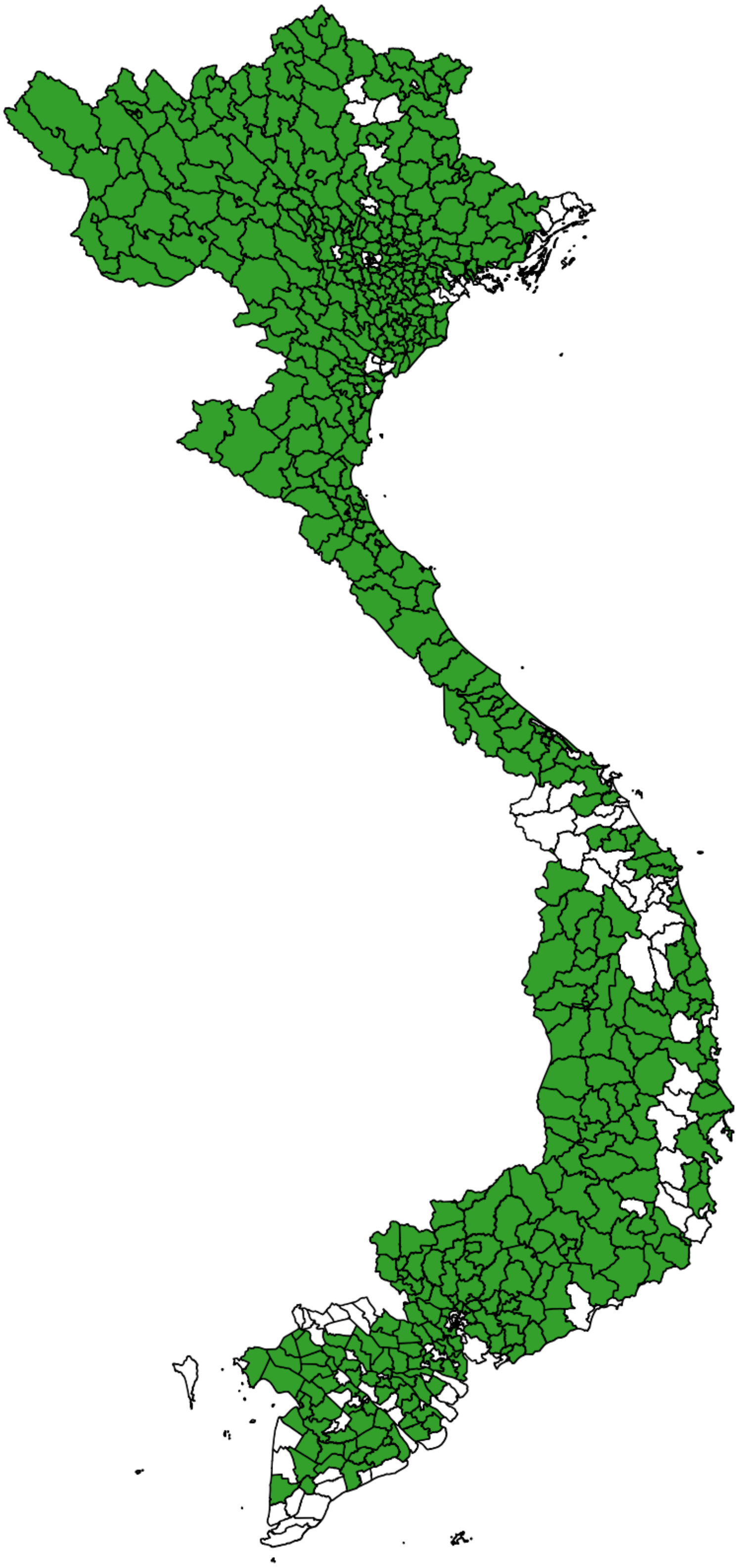

Figure 5. Distribution of the 504 districts targeted by the field survey
(shown in green on the map)

4.2 Greenfield Power Plant Potential

This part of the Biomass Atlas consists of site suitability indicator maps for greenfield power plants using crop harvesting residue feedstock. A high site suitability value indicates a good site for a potential power plant, whereas a low value indicates a poor location.

The process of analysis of the greenfield power plant potential is as follows:

(1) *Calculating the relative fuel sourcing distance:*

$$I_{fs} = (D_f - D_{ss}) / D_f \quad [7]$$
$$I_{fm} = (D_f - D_{sm}) / D_f \quad [8]$$

Where,

I_{fs} = relative sourcing distance for the most abundant single feedstock, (0 to 1)
I_{fm} = relative sourcing distance for the most abundant feedstock, and auxiliary feedstock suitable for mixing with it, (0 to 1)
D_{ss} = sourcing distance for the most abundant single feedstock, given the capacity of the power plant, km
D_{sm} = sourcing distance for multiple feedstock, given the most abundant single feedstock and the capacity of the power plant, km
D_f = maximum feedstock distance, 50 km

(2) *Calculating the relative transport network density:*

$$I_t = DE_d / DE_m \quad [9]$$

Where,

I_t = relative transport network density, (0 to 1)
DE_d = transport network density for the district the site is located in, km/km^2
DE_m = maximum transport network density across all districts, km/km^2

(3) *Calculating the relative grid station connection distance:*

$$I_g = (D_{gm} - D_g) / D_{gm} \quad [10]$$

Where,

I_g = relative grid station connection distance, (0 to 1)
D_{gs} = grid substation connection distance for the site, km
D_{gm} = maximum grid substation distance cut-off, 100 km

(4) *Calculating the site-suitability index: ...*

$$SI_{sf} = 100 * (0.6 * I_{sf} + 0.3 * I_g + 0.1 * I_t) \quad [11]$$

$$SI_{mf} = 100 * (0.6 * I_{mf} + 0.3 * I_g + 0.1 * I_r) \quad [12]$$

Where,

SI_{sf} = site-suitability index based on single fuel feedstock, (0 to 100)
SI_{mf} = site-suitability index based on multi-fuel feedstock, (0 to 100)

This part of the Biomass Atlas consists of site suitability indicator maps for greenfield power plants using crop harvesting residue feedstock. A high site suitability value indicates a good site for a potential power plant, whereas a low value indicates a poor location.

This site suitability indicator takes into account the feedstock sourcing area size, the road network density in the region, and the distance to a grid power station. The first two factors serve as proxies for site-dependent operational costs, and the third one as site dependent investment cost proxy.

The site suitability indicator map can be used by the potential project developers/investors for initially screening the locations for greenfield biomass-based power plant. In order to select the best site, more detailed investigation and assessment of biomass residues availability and their supply chains should be conducted during the project feasibility study phase.

Each of the indicator components get values between 0 and 100, scaled linearly between the worst and best values for the component in the dataset. This means that a component gets value 100 for smallest sourcing area, shortest direct distance to a grid power station and the highest road network density in the whole dataset, and vice versa for value 0. The three components are then combined so that the site suitability indicator also gets values between 0 and 100, where 100 indicate a site where all the three factors are optimal. The weights used in combining the components were 0.6 for feedstock sourcing area, 0.3 for grid power station distance and 0.1 for road network density.

The maximum direct sourcing distance allowed was 50 km. The maximum feedstock sourcing area, and hence distance, is determined by both the power plant capacity and the technology used. The power plant modeling includes a compatibility matrix between different crop residues and technology & capacity combinations. Other factors included in the model are feedstock pre-processing and storage.

The site suitability indicator value was computed for 18 different combinations of energy conversion technologies and power plant capacities as shown in Table 9.

Table 9: Analyzed combinations of power plant technologies and capacities

Technology	Power plant capacity (MW)
Grate combustion steam boiler + steam turbine	3, 8 and 15
Bubbling fluidized bed combustion steam boiler + steam turbine	8, 15, 25, 50 and 100
Circulating fluidized bed combustion steam boiler + steam turbine	15, 25, 50 and 100
Gasifier + syngas engine/turbine	0.5 and 1.5
Anaerobic digester + biogas engine/turbine	0.5,1.5, 3 and 8

Each combination can be illustrated with a map. Figures 6, 7 and 8 illustrate the site suitability indicator maps for various power plant technologies with different gross power capacities.

The links for access to the results of site suitability analysis are provided in Annex 3.

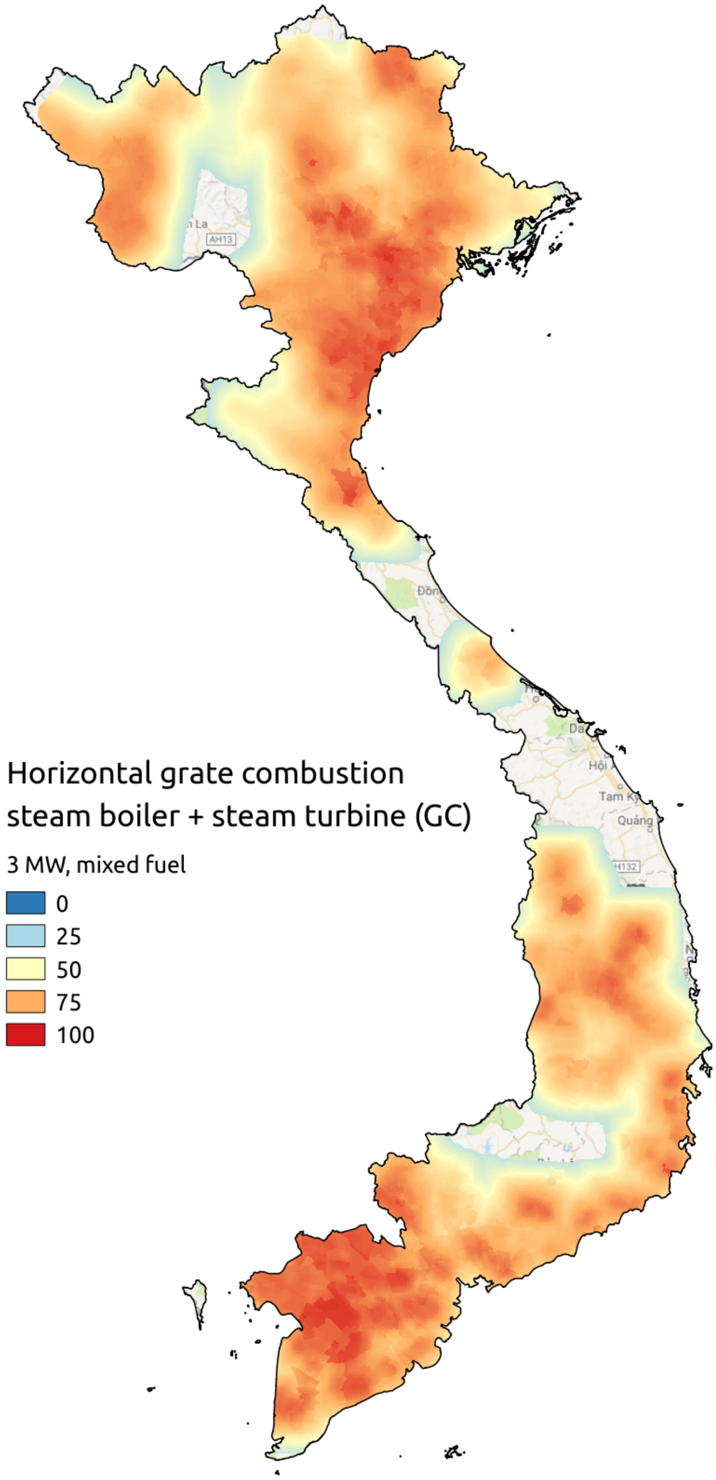

Figure 6: Site suitability indicator map for 3 MW power plants with grate steam boiler
Note: Red color indicating high potential and blue color potential approaching zero
[Background map: Google® Google Streets™]

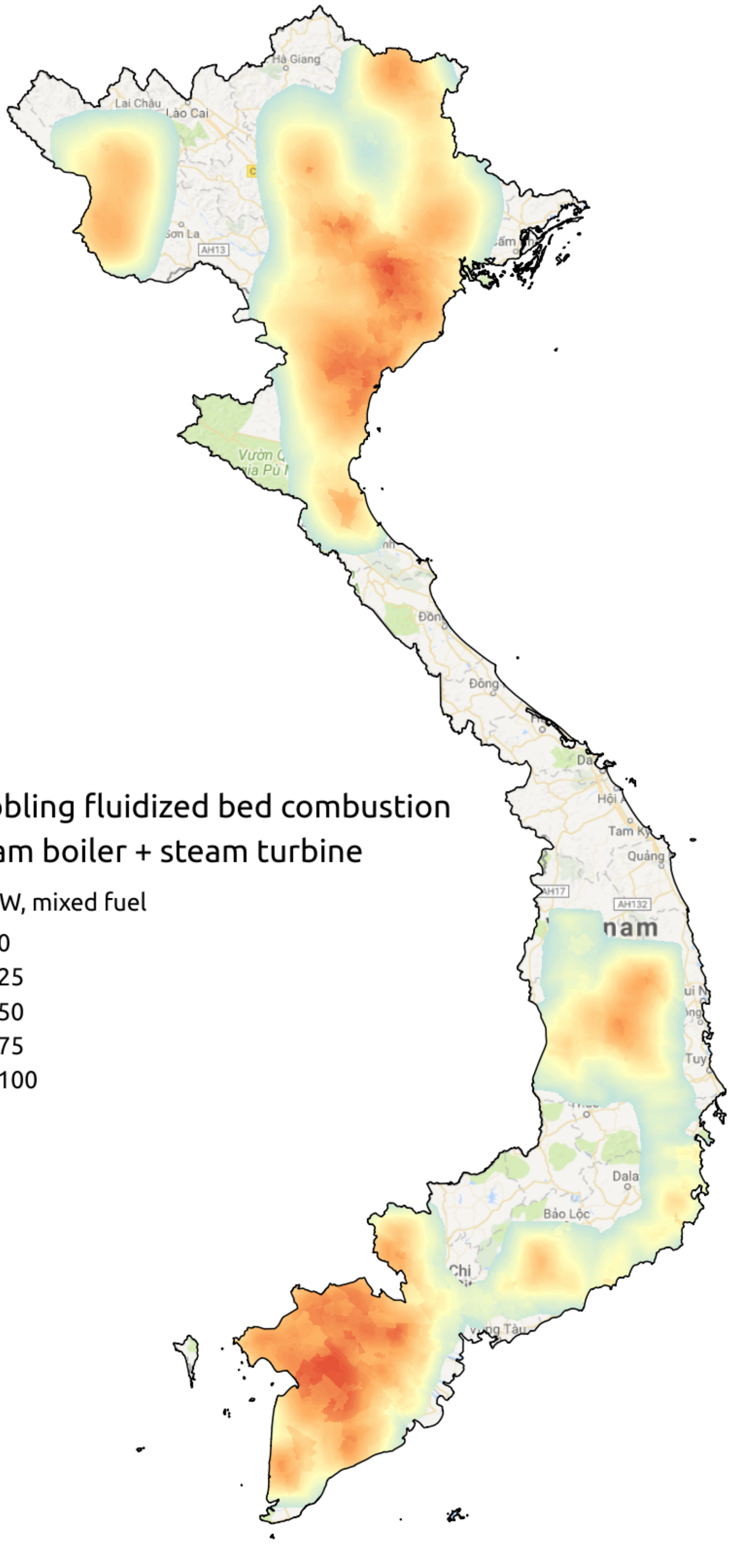

Figure 7: Site suitability indicator map for 15 MW power plants with BFB steam boiler
Note: Red color indicating high potential and blue color potential approaching zero
[Background map: Google® Google Streets™]

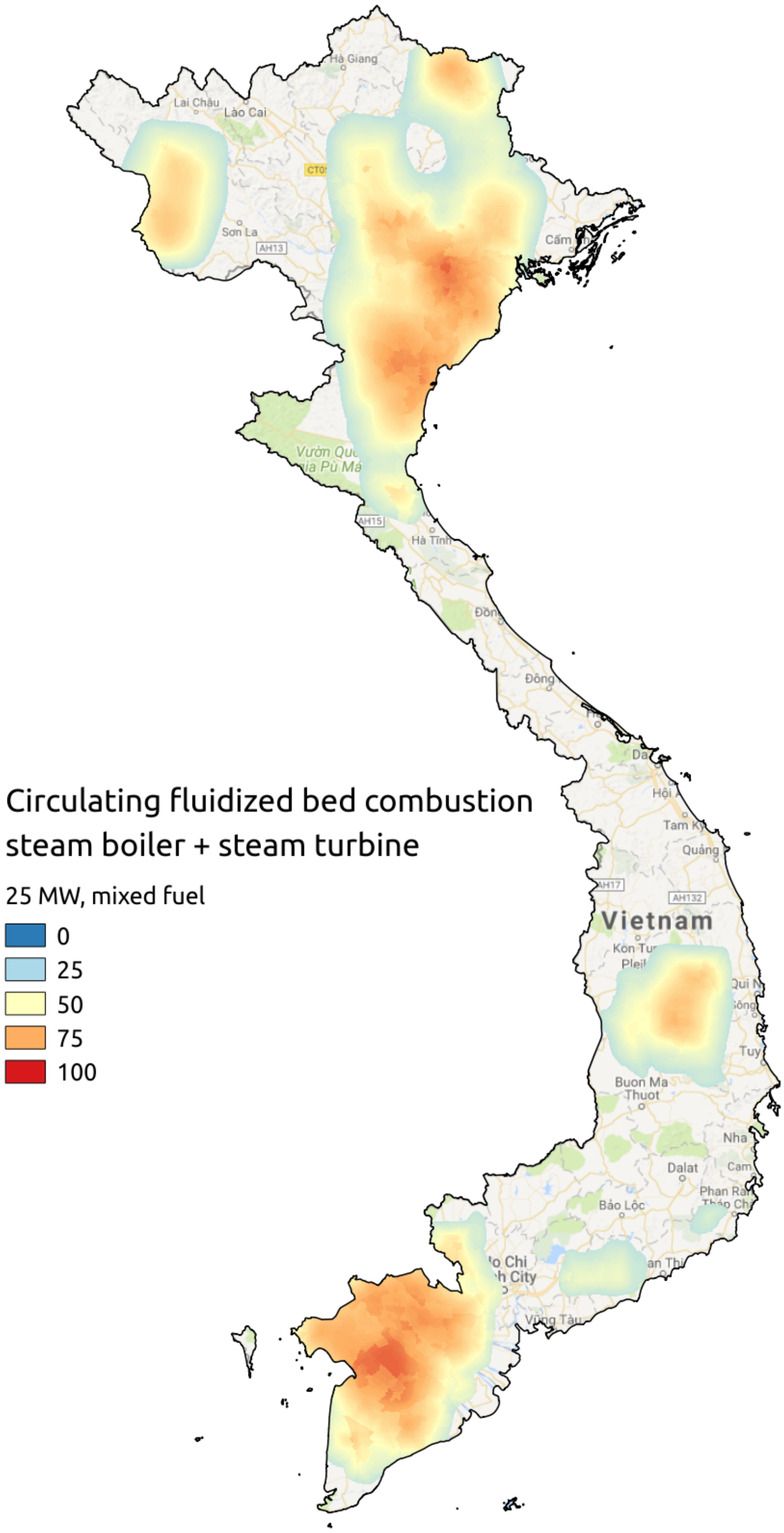

Figure 8: Site suitability indicator map for 25 MW power plants with CFB steam boiler

Note: Red color indicating high potential and blue color potential approaching zero

[Background map: Google® Google Streets™]

4.3 Electricity Generation Potential at Biomass Producing Sites

An analysis of agro-industrial sites covered by the industrial survey was conducted with the aim of evaluating the potential of each site for implementing a biomass-based power or cogeneration plant.

4.3.1 Sugar Mills

All 40 existing sugar mills in Vietnam with a total design sugarcane crushing capacity of 165,750 TCD were surveyed. In the last crushing season 2016-17, about 17.1 million tonnes of sugarcane were processed in these sugar mills with an average operating time of 2,990 hours (around 125 days).

Based on the industrial survey, a total of 5.1 million tonnes/year of bagasse was generated in the 40 surveyed sugar mills. About 98.6% of this amount of bagasse is used as fuel in cogeneration plants to produce electricity and low-pressure process steam for covering the energy demand of the sugar mills. Most existing cogeneration plants are equipped with low-pressure steam boilers and back-pressure steam turbines working between 18 and 38 bar. Only eight mills have already installed a high-pressure (65 or 98 bar) steam boilers. The total installed power capacity for the 40 surveyed cogeneration plants was at 522 MW. However, only around 158 MW with an electricity amount of 397.1 GWh/year were sold to the grid.

Electricity consumption of the surveyed sugar mills varied from 30 to 48 kWh/tonne of sugarcane crushed (36.7 kWh/tonne in average). The process steam consumption was between 450 to 660 kg/tonne of sugarcane crushed (555 kg/tonne in average).

There is a large technical potential for implementing new high-pressure cogeneration plants using bagasse at the sugar mills. The potential is calculated based on the assumption that all existing low pressure back-pressure steam turbine-based cogeneration systems would be converted into high-pressure systems using extraction condensing steam turbines. It should be noted that the use of new extraction condensing steam turbine allows the high-pressure cogeneration system to run during the off-milling season by utilizing additional biomass feedstock sourced from the vicinity of the sugar mill. Although the investment costs to convert the existing low-pressure to high-pressure cogeneration systems are high[4], the implementation of high-pressure cogeneration systems should be considered as a priority for sugar mills in order to optimize the use of bagasse for power generation. Sticking to old, inefficient and polluting low-pressure systems should not be an option anymore.

The process of analysis of new high-pressure cogeneration systems at sugar mills is as follows:

(1) *Calculating the energy input from bagasse (GWh_{th}/year):* For each sugar mill, the energy input from bagasse to the new high-pressure cogeneration plant is calculated based on the annual amount of bagasse produced at the sugar mill and the LHV of bagasse. The data on bagasse production was obtained from the industrial survey.

$$ENI_{bg} = (P_{bg} * LHV_{bg}) / 1000 \qquad [13]$$

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[4] *Based on the Consultant's experience in the region, the investment costs are USD 0.9 - 1.2 million/MW of installed power capacity for the capacity range of 15 - 35 MW. For the small-scale systems (<10 MW), the investment costs may reach USD 1.5 million/MW.*

Where,

ENI_{bg} = energy input from bagasse, in GWh_{th}/year
P_{bg} = bagasse production, in tonnes/year
LHV_{bg} = lower heating value of bagaase (7.5 MJ/kg or ~2.083 MWh_{th}/tonne)
1000 = conversion factor from MWh_{th} *to* GWh_{th}

(2) *Calculating the total energy output from a cogeneration plant in case only bagasse is used:* An overall cogeneration efficiency of 75% was conservatively assumed for the cogeneration system at each sugar mill. Based on this assumption and the energy input from bagasse, the total energy output (i.e., steam thermal energy for process and electricity generation) from a cogeneration plant can be calculated.

$$ENO_{bg} = ENI_{bg} * OEE_{cp} \qquad [14]$$

Where,

ENO_{bg} = total energy output from bagasse-based cogeneration plant, in GWh/year
ENI_{bg} = energy input from bagasse, in GWh_{th}/year
OEE_{cp} = overall energy efficiency of bagasse-based cogeneration plant, in %

(3) *Calculating the process steam consumed by the sugar mill (GWh_{th}/year):* In order to calculate the process steam consumption (in thermal energy unit) of the sugar mill, it was assumed that low pressure steam at 2.5 bar and 130°C is used for the sugar mill.

$$PSE_{sm} = SPS_{sm} * SC_{sm} * h_{ps} / 1000 \qquad [15]$$

Where,

PSE_{sm} = process steam thermal energy consumed by the sugar mill, in GWh_{th}/year
SPS_{sm} = specific process steam consumed by the sugar mill, in tonne of steam/tonne of sugarcane processed
SC_{sm} = amount of sugarcane processed by the sugar mill, in tonne/year
h_{ps} = enthalpy of the process steam, in MWh_{th}/tonne (enthalpy of process steam at 2.5 bar and 130°C is 2721.9 kJ/kg (~ 0.756 MWh_{th}/tonne)
1000 = conversion factor from MWh_{th} *to* GWh_{th}

(4) *Calculating the gross electricity output of the cogeneration plant in case only bagasse is used:* The gross electricity output of the cogeneration plant is calculated by subtracting the process steam thermal energy consumed by the sugar mill from its total energy output.

$$EG_{bg} = ENO_{bg} - PSE_{sm} \qquad [16]$$

Where,

EG_{bg} = gross electricity output of the cogeneration plant in case only bagasse is used, in *GWh/year*

(5) *Calculating the gross power output of the cogeneration plant in case only bagasse is used:* The gross power output of the cogeneration plant is calculated based on the calculated gross electricity output (EG_{bg}) and the operating time of the sugar mill (obtained from the industrial survey).

$$PG_{bg} = EG_{bg} * 1000 / OPT_{sm} \quad [17]$$

Where,

PG_{bg} = gross power output of the cogeneration plant, in MW
OPT_{sm} = operating time of the sugar mill, in hours/year
1000 = conversion factor from G*Wh to MWh*

(6) *Calculating the net electricity output in case only bagasse is used:* This value is calculated from the gross electricity generation and an assumed parasitic load (electricity own-consumption) of the cogeneration plant.

$$EN_{bg} = EG_{bg} * (100\% - EOC_{cp}) \quad [18]$$

Where,

EN_{bg} = net electricity output of the cogeneration plant in case only bagasse is used, in GWh/year
EOC_{cp} = electricity own-consumption of the cogeneration plant, in % of the gross electricity output. This value was assumed based on the gross power output of the cogeneration plant.

(7) *Calculating electricity export to the grid (GWh/year) in case only bagasse is used:* The amount of electricity exported to the grid is calculated by subtracting the electricity consumed by the sugar mill from the net electricity output of the cogeneration plant. The electricity consumption of the sugar mill is calculated based on the assumption that 30 kWh of electricity is required for processing one tonne of sugarcane.

$$EX_{bg} = EN_{bg} – PEC_{sm} \quad [19]$$

Where,

EX_{bg} = electricity export to the grid in case only bagasse is used, in GWh/year
PEC_{sm} = electricity consumption by the sugar mill, in GWh/year. This value is calculated based on the amount of sugarcane processed in a year (SC_{sm}) and the specific electricity consumption of the sugar mill (kWh/tonne of sugarcane processed). These data are obtained from the industrial survey.

(8) *Calculating the energy input from additional biomass feedstock for year-round operation of the cogeneration plant:* Based on the results of the industrial survey, the operating time of the sugar

mills during the milling season 2016-17 varied from 1,490 to 5,630 hours/year (equivalent to an annual Plant Capacity Factor (PCF) of 17.0 - 64.3%). Assuming that the annual PCF of the cogeneration plant increases to 85%, the annual PCF of the cogeneration plant running on additional biomass feedstock during off-milling season is calculated at 68.0 - 20.7%. Based on these PCF values and the rated gross power capacity defined in step (5), the gross electricity generation of the cogeneration plant running on additional feedstock can be calculated.

(9) *Calculating the electricity export to the grid from the cogeneration plant running on additional biomass feedstock during off-milling season:* The net electricity output (i.e., electricity exported to the grid) of the cogeneration plant running on additional biomass feedstock is calculated from the gross electricity generation defined in step (7) and the assumed parasitic load (electricity own-consumption) of the cogeneration plant.

(10) *Calculating the amount of additional biomass feedstock and its sourcing area:* Then, the amount of energy input from additional biomass feedstock is calculated using an assumed value of 25% for electrical efficiency of the cogeneration plant running in pure-power generation mode. For the additional biomass feedstock, the fuel deterioration during storage for a period of six months was taken into account. Based on the required amount of the energy input from additional biomass feedstock and the technical potential of suitable crop harvesting residues in the vicinity of the sugar mill, the amount of additional biomass feedstock *(tonnes/year)* and the sourcing area will be calculated. In other words, the sourcing area for additional biomass feedstock *(km^2/GWh)* takes into account the real distribution of the crop fields and crop residues within the vicinity of the sugar mill.

The additional biomass feedstock sourcing area matches the best-case scenario, which is able to source all of the technically available crop harvesting residues suitable for the cogeneration plant from the immediate neighborhood of the sugar mill. Therefore, it helps ranking the sugar mills in terms of the ease of sourcing the additional biomass feedstock.

The results of the sugar mills analysis show that the new high-pressure cogeneration plants at 40 sugar mills could have a combined power capacity output of around 600 MW during the crushing season of 2016-17. In order to run these cogeneration plants at an annual PCF of 85% (7,446 hours/year), around 3.413 million tonnes/year of additional biomass feedstock are needed. A total amount of about 958.3 GWh/year of electricity could be exported to the grid if only bagasse is used during the milling season, which is about 2.4 times higher than the total power capacity of all 40 existing low-pressure cogeneration plants. In case both bagasse and additional biomass feedstock are used as fuels for the cogeneration plants all year round, about 3,363 GWh/year of electricity could be exported. Table 10 summarizes the results of the analysis of the 40 surveyed sugar mills. The detailed analysis results for each sugar mill are provided in Annex 2.

Table 10: Summarized results of the analysis of the 40 surveyed sugar mills

Description	Unit	Value
Number of sugar mills surveyed		40
Total design sugarcane crushing capacity	t/day	165,750
Total sugarcane crushing capacity during the season 2016-17	t/day	137,460
Total sugarcane processed	t/year	17,127,181
Total bagasse generated	t/year	5,142,220
Total additional biomass feedstock sourced	t/year	3,412,876

Power generation technology used		High pressure
Total gross power capacity output	MW	600
Total gross electricity generated	GWh/year	4,467.6
Total net electricity output	GWh/year	4,007.2
Total electricity consumption by the sugar mills	GWh/year	644.2
Total electricity exported to the grid, of which:	GWh/year	3,363.0
From bagasse only (during the milling season)	GWh/year	958.3
From additional feedstock (during the off-milling season)	GWh/year	2,404.8

The map of potential high-pressure cogeneration plants at the 40 surveyed sugar mills in Vietnam is shown in Figure 9. In this figure, the size of the circle is proportional to the potential power plant capacity output (ranging from 2.4 MW to 55 MW), and the color of the circle relates to the sourcing area for additional biomass feedstock (km^2 for each additional GWh required). The sourcing areas range from dark red at 0.13-0.57 km^2/GWh to dark blue at 1.92-2.36 km^2/GWh, and other color hues in between those two ranges.

The links for access to the survey results, the map and datasets for the sugar mills analysis are provided in Annex 3.

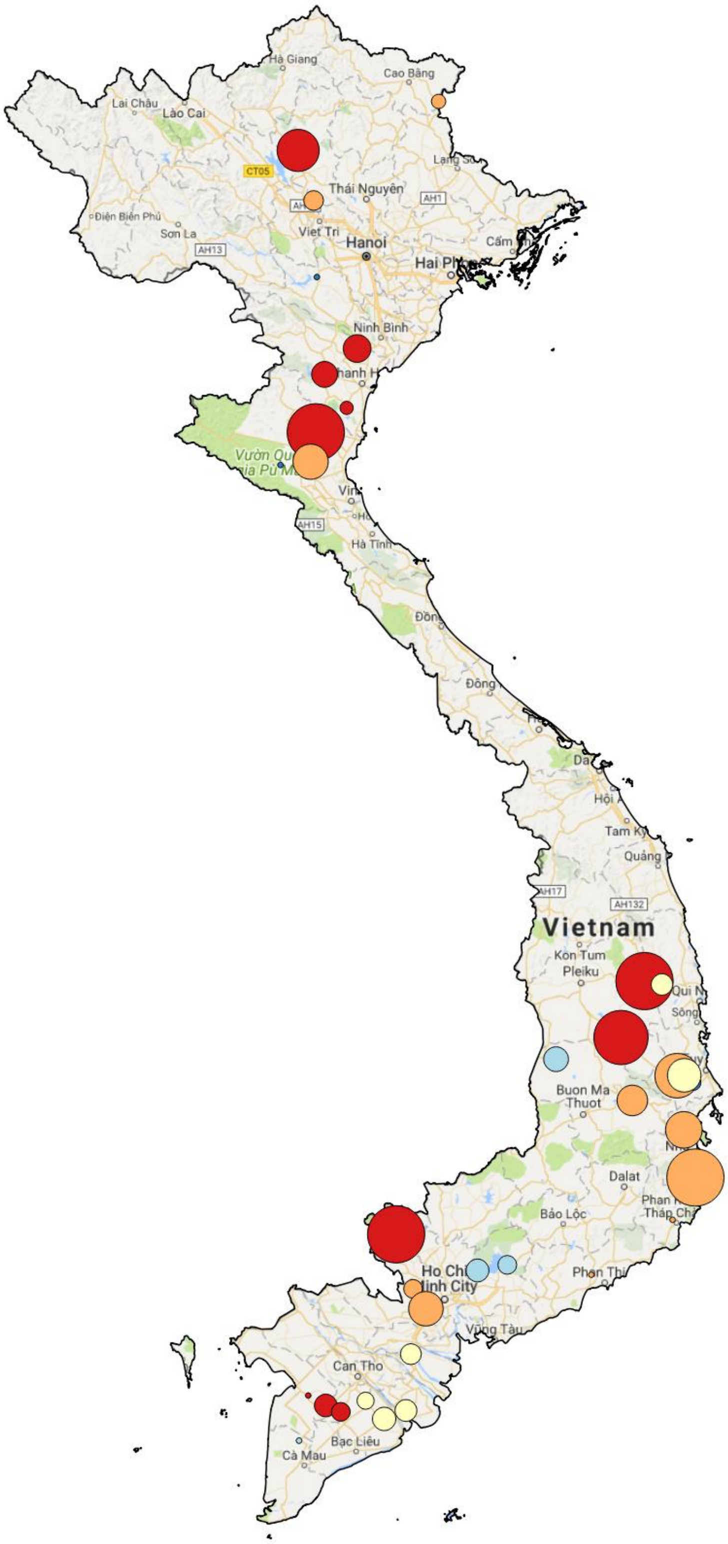


Figure 9: Map of potential high-pressure cogeneration plants at the 40 surveyed sugar mills

Note: The area of the circle denotes the power plant capacity, and the color the relative ranking of sourcing area for additional feedstock: blue hues–larger sourcing area per GWh, red hues–smaller sourcing area per GWh [Background map: Google® Google Streets™]

4.3.2 Rice Mills

It must be mentioned that under the framework of this project, only 54 rice mills were surveyed during the industrial survey. The total amount of paddy milled in these 54 surveyed rice mills was 4.3 million tonnes/year which accounted for only 9.8% of total amount of paddy produced in Vietnam in 2016 (43.69 million tonnes). The total amount of rice husk generated from these rice mills was about 869,797 tonnes/year of which 249,755 tonnes/year (28.7% of the total) was used by the rice mills for in-house purposes (i.e., drying paddy, producing rice husk pellets, etc.). The surplus amount of rice husk (620,042 tonnes/year) was being sold out. If this amount would be used for power generation by the rice mills, it could support around 66.4 MW of power capacity, i.e. an average of around 1.2 MW per mill. These rice husk-based power plants could generate about 465.6 GWh/year of electricity.

Based on the industrial survey, the electricity consumption of the surveyed rice mills varied from 25 to 45 kWh/tonne of paddy milled with an average value of 31.2 kWh/tonne. During the 2016-17 milling season, a total of 129.6 GWh/year of electricity was consumed by the 54 surveyed rice mills.

As the power generation potential (1.2 MW per mill) is too low to attract investors, the use of additional biomass feedstock was considered in the analysis of the power generation potential in order to increase the capacity of each power plant to be able to export power to the grid. It was assumed that the steam boiler of the power plant would be run on rice husk or on other locally sourced biomass feedstock, or on a mixture of them. The minimum fixed power plant capacity of 3 MW is assumed for the power plants at all 54 surveyed rice mills. The additional biomass feedstock was calculated in order to assure an annual plant capacity factor of 80% for all power plants. As for the sugar mills, the analysis results for each rice mill contain the sourcing area (km^2/GWh) for the additional biomass feedstock needed to operate the power plant, with the sourcing area matching the best-case sourcing scenario.

The process of analysis of potential power plants at rice mills is as follows:

(1) *Calculating the energy input from rice husk:* The energy input from rice husk is calculated based on the rice husk production of each rice mill (obtained from the industrial survey) and its LHV. This value varies between rice mills.

$$ENI_{rh} = (P_{rh} * LHV_{rh}) / 1000 \qquad [20]$$

Where,

ENI_{rh} = energy input from rice husk, in GWh_{th}/year
P_{rh} = rice husk production, in tonnes/year
LHV_{rh} = lower heating value of rice husk (13.0 MJ/kg or ~3.611 MWh_{th}/tonne)
1000 = conversion factor from MWh_{th} to GWh_{th}

(2) *Calculating the gross electricity output of the power plant in case only rice husk is used:* As most of rice husk power plants in Vietnam will have a small or medium size, the medium pressure (40-50 bar) grate steam boiler with fully condensing steam turbine system can be used. With these

assumptions, the gross electrical efficiency of the power plant will be 20.8%. The gross electricity output of each power plant using only rice husk is calculated using the formula:

$$EG_{rh} = ENI_{rh} * EE_{pp} \qquad [21]$$

Where,

EG_{rh} = gross electricity output of the power plant in case only rice husk is used, in GWh/year
EE_{pp} = electrical efficiency of the power plant, in % (20.8%)

(3) *Calculating the gross power output of the power plant in case only rice husk is used:* The gross power output of the power plant is calculated based on the calculated gross electricity output (EG_{rh}) and an assumed annual PCF of 80%.

$$PG_{rh} = (EG_{rh} * 1000) / (8760 * PCF) \qquad [22]$$

Where,

PG_{rh} = gross power output of the power plant in case only rice husk is used, in MW
1000 = conversion factor from GWh to MWh
8760 = number of hours in a year

The calculated gross power output of the power plant for some rice mills may be less than 3 MW due to insufficient rice husk production. For such rice mills, as mentioned above, a minimum fixed power plant capacity of 3 MW will be assumed, and the use of additional biomass feedstock considered in the analysis of the electricity generation potential.

(4) *Calculating the net electricity output of the power plant:* This value is calculated from the gross electricity output and an assumed parasitic load (electricity own-consumption) of the power plant.

$$EN_{pp} = EG_{pp} * (100\% - EOC_{pp}) \qquad [23]$$

Where,

EN_{pp} = net electricity output of the power plant, in GWh/year
EG_{pp} = gross electricity output of the power plant, in GWh/year
EOC_{pp} = electricity own-consumption of the power plant, in % of the gross electricity output. This value was assumed based on the gross power output of the power plant.

For a 3 MW power plant, the gross electricity output of the power plant running at 80% annual PCF is calculated at 21.024 GWh/year and the net electricity output is calculated at 17.870 GWh/year.

(5) *Calculating electricity export:* The amount of electricity exported to the grid is calculated by subtracting the electricity consumed by the rice mill from the net electricity output of the power plant.

$$EX_{pp} = EN_{pp} - PEC_{rm} \quad [24]$$

Where,

EX_{pp} = electricity export to the grid, in GWh/year

PEC_{rm} = electricity consumption by the rice mill, in GWh/year. This value is calculated based on the amount of paddy milled in a year (tonnes/year) and the specific electricity consumption of the rice mill (kWh/tonne of paddy milled). These data are obtained from the industrial survey.

(6) *Calculating the energy input from biomass fuel required for a 3 MW power plant:* As mentioned above, in case the calculated gross power output of the power plant running on rice husk is less than 3 MW, a minimum fixed power plant capacity of 3 MW will be assumed. The energy input from biomass fuels (rice husk and other additional biomass feedstock) required for a 3 MW power plant is calculated using the formula:

$$ENI_{bf} = (PG_{pp}/1000) * (8760 * PCF) / EE_{pp} \quad [25]$$

Where,

ENI_{bf} = energy input from biomass fuel required for a 3 MW power plant, in GWh_{th}/year

PG_{pp} = gross power output of the power plant (3 MW)

1000 = conversion factor from MW to GW

PCF = annual plant capacity factor of the power plant (80%)

The energy input from biomass fuel required for a 3 MW power plant running at 80% annual PCF is calculated at 101.1 GWh_{th}/year.

(7) *Calculating the energy input from additional biomass feedstock (GWh_{th}/year):* Energy input from additional feedstock is calculated by subtracting the amount of energy input from rice husk (ENI_{rh}) from the total amount of energy input required for the power plant (ENI_{bf}). For the additional feedstock, the effect of fuel deterioration during the storage period of six months was also taken into account.

(8) *Calculating the amount of additional biomass feedstock (tonnes/year) and its sourcing area (km^2/GWh):* This is done based on the amount of energy input calculated in step (7) and the technical potential of suitable crop harvesting residues. It takes into account the real distribution of fields and crops, but assuming 100% sourcing ability of the available feedstock.

According to the General Statistics Office of Vietnam, a total of 43.69 million tonnes of paddy were produced in 2016. Based on an average rice husk to paddy ratio of 20%, the total amount of rice husk generated in 2016 could be estimated at around 8.738 million tonnes. With a LHV of rice husk of 13.0 MJ/kg, this amount of rice husk would represent an energy potential of about 113,594 TJ

(31,554 GWh_{th}). If 100% of this amount of rice husk would have been collected and used for power generation, the potential power capacity output would be about 937 MW, based on an average electrical efficiency of 20.8% and an annual PCF of 80%.

The results of the rice mills analysis show that, the calculated combined power capacity output of the potential power plants at 54 surveyed rice mills is 188.5 MW. A calculated amount of biomass fuel of 1.863 million tonnes/year is required of which 0.620 million tonnes/year come from rice husk and 1.243 million tonnes/year from additional biomass feedstock. These potential power plants could export about 1,002 GWh/year of electricity to the grid. Table 11 summarizes the results of the analysis of the 54 surveyed rice mills. The detailed analysis results for each rice mill are provided in Annex 2.

Table 11: Summarized results of the analysis of the 54 surveyed rice mills

Description	Unit	Value
Number of rice mills surveyed		54
Total paddy milling capacity	t/day	30,909
Total paddy processed	t/year	4,292,484
Total rice husk generated	t/year	869,797
Total rice husk used by the rice mills	t/year	249,755
Total surplus rice husk (used for power generation)	t/year	620,042
Total additional biomass feedstock sourced	t/year	1,243,489
Power generation technology used		Medium pressure
Total gross power capacity output	MW	188.5
Total gross electricity generated	GWh/year	1,320.9
Total net electricity output	GWh/year	1,132.1
Total electricity consumption by the rice mills	GWh/year	129.6
Total electricity exported to the grid, of which:	GWh/year	1,002.5
From rice husk only	GWh/year	284.5
From additional feedstock	GWh/year	718.0

The map of potential power plants at the 54 surveyed rice mills in Vietnam is provided in Figure 10. The bigger the circle, the higher the capacity of the power plant (ranging from 3 MW to 9 MW). The red circles show “zero” sourcing area for the additional feedstock (i.e., no additional feedstock needed), the dark blue circles indicate sourcing area ranging from 0.36 to 0.47 km^2/GWh while other colors represent intermediate sourcing areas.

The links for access to the survey results, the map and datasets for the rice mills analysis are provided in Annex 3.

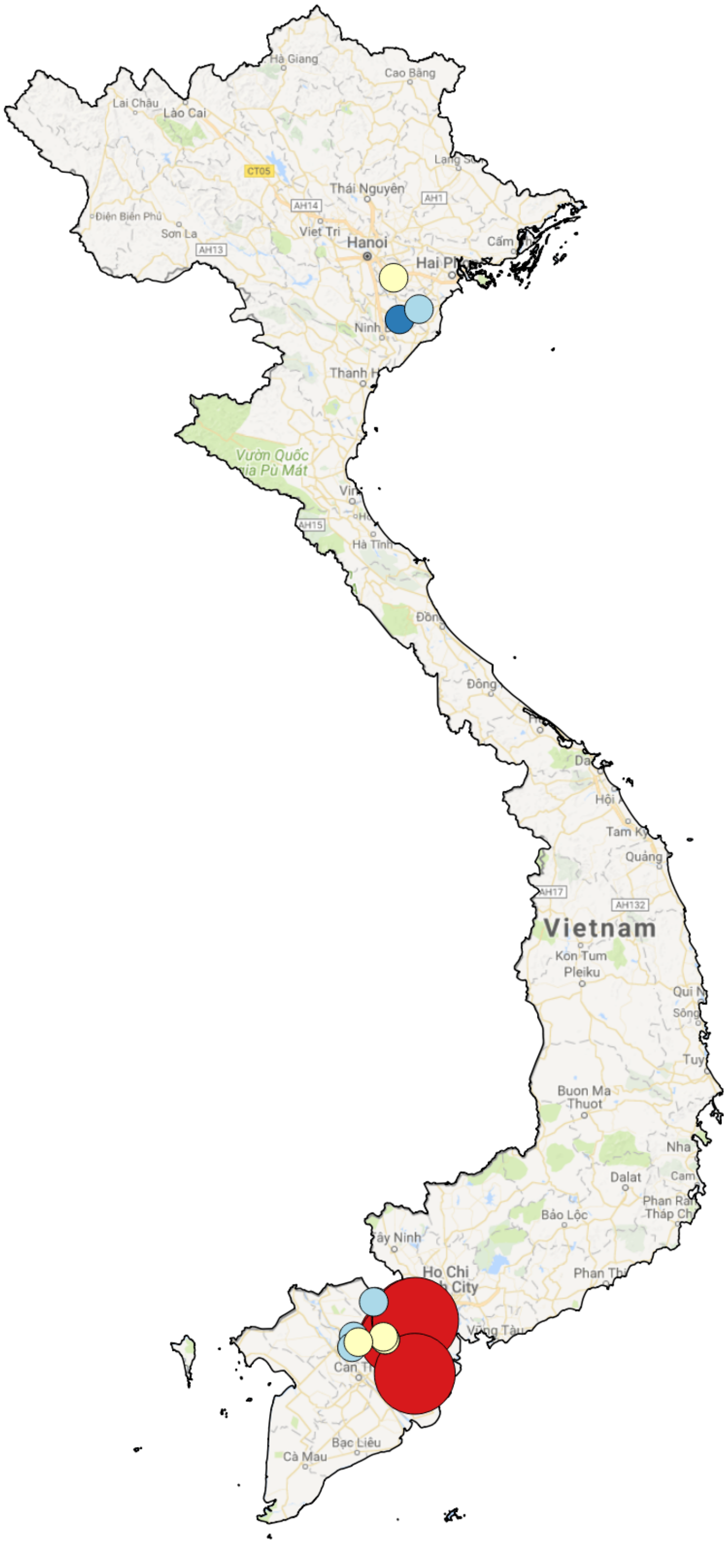


Figure 10: Map of potential power plants at the 54 surveyed rice mills in Vietnam

Note: The color indicates the ranking of the sourcing area for additional feedstock: blue hues – larger sourcing area per GWh, red hues – smaller sourcing area, white – in between [Background map: Google® Google Streets™]

4.3.3 MSW Landfills

There is a potential use of MSW for energy generation at the landfills in Vietnam. The two technologies which are most frequently used for generating electricity and/or heat from MSW include:

- direct combustion of organic materials of MSW in an incinerator/steam boiler to produce high pressure steam. Then, the steam is used in a steam turbo-generator to generate electricity or both electricity and heat;
- anaerobic digestion of the biodegradable fraction of MSW to produce biogas which is used in a gas engine or turbine system to generate electricity or both electricity and heat.

The technology of using incinerator/steam boiler to convert MSW to energy is a relatively old technology. The electrical efficiency of this technology is low (typically, 14-28%) due to the low efficiency of the incinerator/steam boiler burning MSW with high moisture content, i.e. with low LHV. Another problem associated with direct combustion of MSW to generate electricity is the potential for pollutants (such as nitrogen oxides, sulphur dioxide, heavy metals and dioxins) to enter the atmosphere with the flue gases from the incinerator/boiler. In this study, the anaerobic digestion of MSW is proposed as it has a higher electrical efficiency and a lower environmental impact than the direct combustion technology.

The following steps were used for analyzing the potential power plants installed at the landfills based on anaerobic digester combined with gas engine/turbine systems:

(1) *Calculating the annual biogas production for each landfill:* Based on the amount and percentage of organic matter of MSW disposed at each landfill (obtained from the industrial survey), the annual biogas production is calculated by using an average biogas production rate of 120 m^3/tonne of organic MSW as-received basis.

$$BGP_{msw} = MSW * ORG * BGR_{msw} \quad [26]$$

Where,

BGP_{msw} = amount of biogas produced, in m^3/year
MSW = amount of MSW dumped at the landfill, in tonnes/year
ORG = organic matter of MSW, in % of MSW dumped
BGR_{msw} = average biogas production rate, in m^3/tonne of organic MSW

(2) *Calculating the energy input from biogas to the gas engine/turbine:* This value is calculated based on the annual biogas production and biogas LHV. Assuming that biogas produced from MSW consists of 60% of methane, the biogas LHV was calculated at 21.54 MJ/m^3.

$$ENI_{bio,msw} = BGP_{msw} * (LHV_{bio,msw} / 3600) / 1000 \quad [27]$$

Where,

$ENI_{bio,msw}$ = energy input from biogas to the gas engine/turbine, in GWh_{th}/year

$LHV_{bio,msw}$ = low heating value of biogas, in MJ/m^3 (21.54 MJ/m^3)
3600 = conversion factor from MJ to MWh_{th}
1000 = conversion factor from MWh_{th} to GWh_{th}

(3) *Calculating the gross electricity output from the power plant:* The gross electricity output was calculated based on an assumed gross electrical efficiency of 40% for biogas engine-based technology and 30% for biogas turbine-based technology.

$$EG_{msw} = ENI_{bio,msw} * EE_{pp} \quad [28]$$

Where,

EG_{msw} = gross electricity output of the power plant running on biogas produced from MSW, in GWh/year
EE_{pp} = electrical efficiency of the biogas-based power plant, in %

(4) *Calculating the rated gross power capacity:* The rated gross power capacity of each power plant was calculated based on its gross electricity output and annual PCF.

$$PG_{msw} = (EG_{msw} * 1000) / (8760 * PCF_{msw}) \quad [29]$$

Where,

PG_{msw} = gross power output of the power plant running on biogas produced from MSW, in MW
PCF_{msw} = annual plant capacity factor of the power plant, in %. This value was assumed at 90% for all power plants
1000 = conversion factor from GWh to MWh
8760 = number of hours in a year

(5) *Calculating the electricity export:* The amount of electricity export was calculated based on an average parasitic load (electricity own-consumption) of the power plant.

$$EN_{msw} = EG_{msw} * (100\% - EOC_{pp,msw}) \quad [30]$$

Where,

EN_{msw} = net electricity output (electricity export) of the power plant, in GWh/year
EG_{msw} = gross electricity output of the power plant, in GWh/year
$EOC_{pp,msw}$ = electricity own-consumption of the power plant, in % of the gross electricity output. This value was assumed at 5% for all power plants.

According to the Vietnam Status of Environment Report 2016, the amount of MSW generated in Vietnam in 2015 was 38,000 t/day. Based on a growth rate of 12% per year, the amount of MSW generated in 2017 can be estimated at 48,000 t/day (17,520,000 t/yr). With an average organic content of 60%, the amount of organic matter generated was 10,512,000 t/yr. If this amount would have been collected for biogas production, the amount of biogas produced would be around 1,261 million m^3/yr. The theoretical potential power capacity that could be generated from this amount of biogas would be 383 MW.

However, the industrial survey covered only 38 landfills in Vietnam. The combined amount of MSW collected at these landfills is around 20,140 t/day (around 42% of amount of MSW generated in 2017 in Vietnam). Some amount of MSW (1,910 t/day) is being recycled, incinerated or used for fertilizer production, and the remaining amount of around 18,230 t/day is currently dumped at these 38 landfills. This amount of MSW generates around 9,829 t/day of organic MSW. If this organic MSW could be used for electricity generation, around 131 MW of gross power capacity could be generated in the anaerobic digester-based power plants. Table 12 summarizes the results of analyzing the 38 surveyed MSW landfills. The detailed analysis results for each landfill are provided in Annex 2.

Table 12: Summarized results of the analysis of the 38 surveyed MSW landfills

Description	Unit	Value
Number of MSW landfills surveyed		38
Total MSW collected	t/day	20,144
Total MSW dumped	t/day	18,231
Total organic MSW generated	t/day	9,829
Total annual biogas production	million Nm^3/yr	430.5
Power generation technology used		Biogas engine
Total gross power capacity output	MW	131
Total gross electricity generated	GWh/year	1,029.8
Total net electricity output	GWh/year	978.3
Total electricity consumption by the MSW landfills	GWh/year	Data were not available
Total electricity exported to the grid	GWh/year	978.3

The map of potential power plants at the surveyed MSW landfills in Vietnam is provided in Figure 11. The bigger the circle, the higher the capacity of the power plant (ranging from 0.02 MW to 33 MW).

The links for access to the survey results, the map and datasets for MSW landfills analysis are provided in Annex 3.

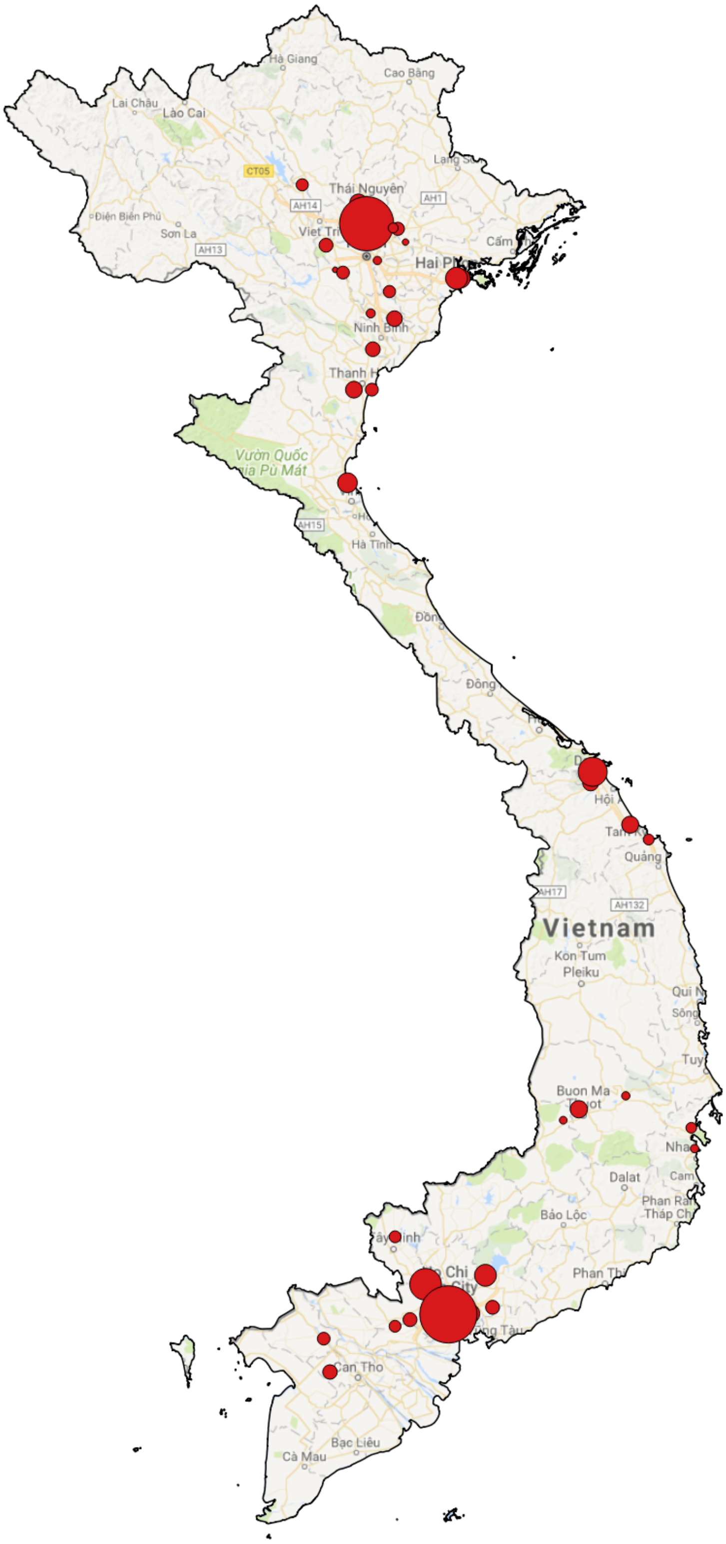


Figure 11: Map of potential power plants at the 38 surveyed MSW landfills in Vietnam
Note: Bigger area of the circle denotes higher capacity [Background map: Google® Google Streets™]

4.3.4 Livestock Farms

The following steps were used for analyzing the potential power plants installed at the livestock farms, based on an anaerobic digester combined with gas engine or turbine systems:

(1) *Calculating the annual biogas production for each livestock farm (m^3/year):* The annual biogas production is calculated based on the amount of manure available at each livestock farm (obtained from the industrial survey) and the average biogas production rate (m^3/t of manure on an as received basis). Based on the industrial survey, the biogas production rate is 30 m^3/t for cow manure, and 40-57 m^3/t for pig manure.

(2) *Calculating the energy input from biogas to the gas engine/turbine (GWh_{th}/year):* This value is calculated based on the annual biogas production and biogas LHV. Assuming that biogas produced from livestock manure consists of 65% of methane, the biogas LHV was calculated at 23.33 MJ/m^3.

(3) *Calculating the gross electricity output from the power plant (GWh/year):* The gross electricity output was calculated based on an assumed gross electrical efficiency of 40% for biogas engine-based technology and 30% for biogas turbine-based technology.

(4) *Calculating the rated gross power capacity (MW):* The rated gross power capacity of each power plant was calculated based on its gross electricity output and an annual PCF of 90%.

(5) *Calculating the electricity export (GWh/year):* The amount of electricity exported to the grid was calculated based on an average parasitic load of 5% assumed for all power plants.

According the General Statistics Office of Vietnam, the major livestock population in Vietnam was estimated at around 29.08 million pig-heads and 5.50 million cattle-heads in 2016. With an average manure production rate of 1.76 kg/day/head for pigs and 14.34 kg/day/head for cattle (from the industrial survey), the amount of manure generated in 2016 was about 18.68 million tonnes of pig-manure and 28.79 million tonnes of cattle-manure. If these amounts of manure could be collected and used for biogas production, the amount of biogas produced would be about 2 billion m^3. As the livestock sector in Vietnam is concentrated in small individual household farms, the number of large-scale biogas plants which can be equipped with electricity generation is limited. Assuming that only 15% of manure from pig farms and 5% of manure from cattle farms could be used for biogas production[5], the amount of biogas produced would be about 156 million m^3/year. The potential for electricity generation from that amount of biogas would be around 405 GWh/year with a total installed power capacity of around 50 MW.

The industrial survey covered only 67 livestock farms in Vietnam, including 21 cow farms and 46 pig farms. A total of around 343,770 animals are raised in these 67 livestock farms of which 111,610 are cows and 232,160 are pigs. The combined amount of manure collected at these farms is around 2,010 t/day. Around 16.0% of the collected manure (322 t/day) is being sold out and 57.3% (1,150

[5] Based on WB's report "An Overview of Agricultural Pollution in Vietnam: The Livestock Sector" published in 2017, the volume of manure discharged from household smallholders accounted for 84.5% for pig farms and 96.7% for cattle farms.

t/day) are used for producing dried/composted fertilizer for sales or for in-farm use (18 farms are using all 100% of their manure for these purposes). The remaining amount of 536 t/day (165,617 t/year) of manure available at 49 livestock farms is currently used for production of biogas. The produced biogas is currently used for cooking purpose or flared. Only five of the surveyed farms are using biogas for power generation with a combined installed power capacity of around 0.5 MW.

If 536 t/day of available manure are used for biogas production, a total of 7.41 million m^3 of biogas could be produced and around 2.4 MW of gross power capacity could be generated in the anaerobic digester-based power plants. Table 13 summarizes the results of the analysis of the 67 surveyed livestock farms. The detailed analysis results for each farm are provided in Annex 2.

Table 13: Summarized results of the analysis of the 67 surveyed livestock farms

Description	Unit	Value
Number of livestock farms surveyed		67
Total manure collected	t/day	2,010
Total manure sold out and used for fertilizer production	t/day	1,474
Total manure used for biogas production	t/day	536
Total volume of biogas produced	million Nm^3/year	7.41
Power generation technology used		Biogas engine
Total gross power capacity output	MW	2.4
Total gross electricity generated	GWh/year	19.21
Total net electricity output	GWh/year	18.25
Total electricity consumption by the livestock farms	GWh/year	Data were not available
Total electricity exported to the grid	GWh/year	18.25

The map of potential power plants at the surveyed livestock farms in Vietnam is provided in Figure 12. The bigger the circle is, the higher the capacity of the power plant (from 1 to 576 kW).

The links for access to the survey results, the map and datasets for livestock farms analysis are provided in Annex 3.

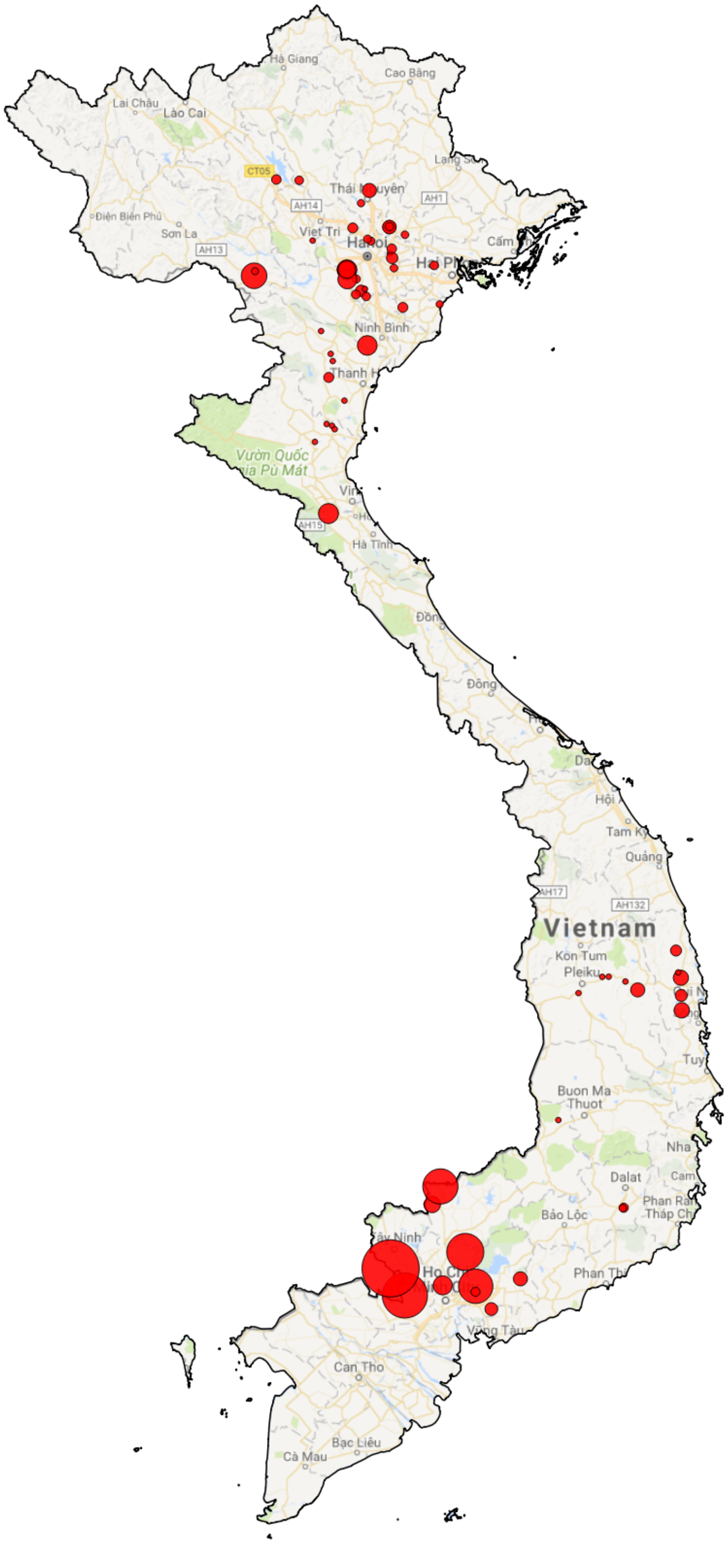


Figure 12: Map of potential power plants at the 67 surveyed livestock farms in Vietnam
[Background map: Google® Google Streets™]

4.3.5 Wood Processing Mills

The industrial survey covered 40 wood processing mills of various types (15 saw mills, 10 furniture manufacturing plants, 10 combined sawmilling and furniture manufacturing factories, 3 plywood production plants and 2 MDF manufacturing mills). The total amount of input wood (logs and sawn wood) processed in these mills in 2017 was around 386,970 tonnes/year. The total amount of wood residues (sawdust, edges and slabs) generated from these surveyed wood processing mills was about 101,630 tonnes/year of which 51,100 tonnes/year (50.3% of the total) was used by the mills for in-house purposes (mainly for wood drying). The surplus amount of wood residues (50,530 tonnes/year) was being sold. If this amount would be used for power generation by the wood processing mills, it could support around 5.4 MW of gross power capacity.

As the power generation potential (0.13 MW per mill) is too low to attract investors, the use of additional biomass feedstock was considered in the analysis of the power generation potential in order to increase the capacity of each power plant to be able to export power to the grid. It was assumed that the steam boiler of the power plant would be run on wood residues or on other locally sourced biomass feedstock, or on a mixture of them. The minimum fixed power plant capacity of 3 MW is assumed for the power plants at all 40 surveyed wood processing mills. The additional biomass feedstock was calculated in order to assure an annual plant capacity factor of 80% for all power plants.

The methodology used for analyzing the electricity generation potential of the power plants at the wood processing mills is similar to that used for the case of rice mills.

The results of the wood processing mills analysis show that, if the surplus amount of wood residues (50,530 tonnes/year) could be used for power generation, the calculated combined power capacity output of the potential power plants at 40 surveyed rice mills is around 120 MW. A calculated amount of biomass fuel of about 1.51 million tonnes/year is required of which 0.05 million tonnes/year come from wood residues and 1.46 million tonnes/year from additional biomass feedstock. These potential power plants could export about 715 GWh/year of electricity to the grid. Table 14 summarizes the results of the analysis of the 40 surveyed wood processing mills. The detailed analysis results for each mill are provided in Annex 2.

Table 14: Summarized results of the analysis of the 40 surveyed wood processing mills

Description	Unit	Value
Number of wood processing mills surveyed		40
Total input wood processing capacity	t/day	2,820
Total input wood processed in the last year 2017	t/year	386,974
Total wood residue generated	t/year	101,628
Total wood residue used by the wood processing mills	t/year	51,096
Total surplus wood residue (used for power generation)	t/year	50,532
Total additional biomass feedstock sourced	t/year	1,459,208
Power generation technology used		Medium pressure
Total gross power capacity output	MW	120
Total gross electricity generated	GWh/year	841.0
Total net electricity output	GWh/year	714.8
Total electricity consumption by the wood processing mills	GWh/year	Data were not available
Total electricity exported to the grid, of which:	GWh/year	714.8
From wood residues only	GWh/year	32.2
From additional feedstock	GWh/year	682.6

The map of potential power plants at the 40 surveyed wood processing mills in Vietnam is provided in Figure 13. The power capacity output is 3 MW for all power plants. The red circles show smaller sourcing area for the additional biomass feedstock, the dark blue circles indicate larger sourcing area.

The links for access to the survey results, the map and datasets for wood processing mills analysis are provided in Annex 3.

Figure 13: Map of potential power plants at the 40 surveyed wood processing mills in Vietnam

[Background map: Google® Google Streets™]

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This report presents the final product of the assignment, i.e. the Biomass Atlas for Vietnam. More details on interim outputs as well as the detailed approach and methodology used for developing the Biomass Atlas for Vietnam can be found in separate reports, which are available at *https://esmap.org/re_mapping_vietnam*. They are:

- the Inception Report,
- the Implementation Plan,
- the Report on Training Workshop on Field Survey and Data Collection in Vietnam,
- the Report on Data Validation Workshop,
- the Report on Phase 2 Implementation and Revised Work Plan for Phase 3.

The Biomass Atlas presents both theoretical and technical potentials of crop residues. Crop residues of 18 crops were included in the Biomass Atlas.

The theoretical potential of crop harvesting residues was estimated at around 59.89 million tonnes/year with an equivalent energy potential of 768,853 TJ/year (213,570 GWh_{th}/year). 58.6% of the total energy potential come from rice straw, 26.3% from maize trash, 7.2% from cassava stalk, 3.0% from sugarcane trash, 2.9% from firewood generated from pruning the perennial crops, and 2.1% from other types of residues (peanut straw, soybean straw and firewood from pruning fruit trees).

The theoretical generation potential of crop processing residues was estimated at 20.86 million tonnes/year with an equivalent energy potential of 245,094 TJ/year (68,082 GWh_{th}/year). Rice husk accounts for 37.9% of this energy potential, followed by bagasse with 16.9%, corn cobs with 12.7%, coffee husk with 10.6%, maize husk with 7.5%, coconut husk with 4.9%, cassava peels with 4.5%, coconut shells with 3.2%, peanut shells with 1.0% and cashew nut shells with 0.8%.

Based on the existing uses of the residues by the farmers, the technical potential of crop harvesting residues was estimated at about 15.22 million tonnes/year with an equivalent energy potential of 195,773 TJ/year (54,381 GWh_{th}/year). Rice straw accounts for 56.1% of this energy potential, followed by maize trash with 24.0%, cassava stalk with 8.3%, sugarcane trash with 8.1%, firewood from pruning the perennial crops with 2.1% and peanut straw with 3.0%. It can be seen from these percentages that large amounts of rice straw, maize trash, peanut straw, cassava stalk and firewood are being used by the farmers (in forms of cooking fuel, animal fodder and fertilizer) or sold to industries.

In case the farmers' willingness to sell their biomass residues is taken into account, the technical potential of crop harvesting residues decreases to about 7.95 million tonnes/year with an equivalent energy potential of 101,068 TJ/year (28,075 GWh_{th}/year). Rice straw accounts for a majority of this energy potential with 61.1%, followed by maize trash with 29.5%, sugarcane trash with 3.7%, cassava stalk with 3.1%. Other types of residues (peanut straw, soybean straw and firewood) account for only 2.5%.

The Biomass Atlas for Vietnam also presents the potential for implementing power plants at the biomass producing sites (such as sugar mills, rice mills, wood processing mills, MSW landfills and livestock farms) as well as the potential for greenfield power plants using crop harvesting residue feedstock.

The analysis showed that bagasse offers the highest potential as fuel for cogeneration plants at the existing sugar mills of Vietnam. It shows that new high-pressure cogeneration plants at 40 sugar mills could have a combined power capacity output of 600 MW, based on a total amount of generated bagasse of about 5.1 million tonnes/year in the 2016-2017 milling season. These potential cogeneration plants could export about 958 GWh/year if only bagasse is used or 3,363 GWh/year if around 3.4 million tonnes/year of additional biomass feedstock are used as fuel for the cogeneration plants.

MSW can also be used for large-scale grid-connected power plants. With a total MSW amount of around 20,140 tonnes/day generated at the 38 surveyed landfills, around 131 MW of gross power capacity could be generated based on the anaerobic digester-based power generating technology. These potential MSW-based power plants could export about 978.3 GWh/year to the grid.

However, rice husk, wood processing residues and livestock manure offer a rather limited energy potential which is limited to captive power plants aiming at generating electricity for covering the power requirements of the mills/farms.

It should be noted that the analysis does not include all the existing MSW landfills, rice mills, wood processing mills and livestock farms in Vietnam due to limited resources for carrying out an exhaustive survey.

The potential for greenfield power plants using crop harvesting residues was assessed based on their site suitability indicators. This site suitability indicator takes into account the feedstock sourcing area size, the road network density in the region, and the distance to the grid. A high site suitability value indicates a good site for a potential power plant, whereas a low value indicates a poor location. The site suitability maps were produced for 18 different combinations of energy conversion technologies and power plant capacities.

5.2 Recommendations

The crop-level accuracy of the land use classification needs to be taken into account when evaluating a single site feasibility. Particularly crops cultivated in small home-gardens or orchards having sizes close to or below the land use mapping resolution of 20 m x 20 m are not well covered in the results.

Except for the sugar sector, broader survey of industrial sites should be conducted to complete the database for the key industrial sectors with high potential of biomass residues. These sectors include rice mills, wood processing mills, MSW landfills and livestock farms.

The Biomass Atlas for Vietnam shall be broadly disseminated via WB, MOIT and other channels.

The stakeholders who have participated in the training on Biomass Atlas usage and maintenance shall share their knowledge and skills with other local stakeholders.

Plans shall be made to secure funds for a regular updating of the Biomass Atlas by the persons who have been trained.

NLU, VNUA and other universities shall use the project study methodologies and outputs as training materials for building the capacity of their students.

6. ANNEXES

Annex 1: Biomass Resource Mapping Methodology

1.1 End User Interaction

During the process of project implementation, the consulting consortium maintained a close interaction with the key local stakeholders who are the potential end-users of the Biomass Atlas of Vietnam. This interaction helped the consulting consortium not only to update the local stakeholders on the progress of the project implementation, but also to receive their feedback on the project.

Seven (7) multi-stakeholder meetings and workshops were conducted. These events attracted a total of 178 participants (see Table 15). In addition, several individual meetings with local institutions and companies were also organized during the missions of the consultants to Vietnam.

The details of these seminars, workshops and meetings were reported in separate reports which are available at *https://esmap.org/re_mapping_vietnam*.

Table 15: List of meetings and workshops conducted

No.	Name of event	Location	Date/Time	No. of Participants
1.	Kick-off meeting	Hanoi	2 Jun 2015	12
2.	Inception meeting	Hanoi	3 Jun 2015	21
3.	Phase I Workshop	Hanoi	16-17 Sep 2015	28
4.	Training Workshop on Field Survey and Data Collection	HCMC (Nong Lam University)	28-29 Sep 2016	32
5.	Stakeholder Data Validation Workshop	Hanoi	17 Nov 2017	24
6.	Final Biomass Atlas Dissemination Workshop and Training Workshop on Biomass Atlas Usage and Maintenance	Hanoi	15 Aug 2018	31
7.	Final Biomass Atlas Dissemination Workshop and Training Workshop on Biomass Atlas Usage	HCMC	17 Aug 2018	30
	Total			**178**

1.2 Mapping Methodology

The mapping methodology for the Biomass Atlas consisted of four distinct components: crop biomass field survey, industrial survey, satellite image analysis and bioenergy potential modeling. Each of these components is described in the following sections.

1.2.1 Crop Biomass Field Survey

As agreed with WB and MOIT during the Inception Mission, while the field survey sampling will cover the whole country, more samples will be collected in areas with abundant biomass. The resulting Biomass Atlas will provide more details on those areas and fewer details on areas with scarce biomass resource.

No field survey was conducted for forested areas. Instead the dataset that was planned to be used for the baseline biomass information is the output of the National Forest Inventory (NFIS) project executed by the forest authority VNFOREST in 2014-2016 as an open data sharing policy is being implemented at the FORMIS II project in VNFOREST. However, to date the open data-sharing policy has not been put into practice, and access to the NFIS data has not been possible.

Field survey on the crop biomass residues

The field survey for crop biomass residue production was conducted by VNUA (based in Hanoi) and NLU (based in Ho Chi Minh City) (hereinafter referred to as "the Local Consultants") after being contracted by MOIT. The FA Consortium was responsible for monitoring and validating the said survey. The field survey was a person-to-person interview by the survey team with the farmers. It was executed with mobile phones using the MHG Mobile Application (a proprietary-software developed by the Consortium partner - MHG Systems Oy Ltd.). The phone application was used to record the responses of the interviewed farmer, indicate the location of the interview, and take geo-referenced photos of the surveyed crop fields. The detailed assignment of the Local Consultants and the procedure of conducting the field survey were described in the TOR for the Local Consultants, which were developed during Phase 1 of the project.

The field survey on the crop biomass residues was carried out in 63 provinces and cities of Vietnam. A total number of 18,900 interviews was proposed (calculated as 63 provinces/cities x 5 main crops x 60 interviews/province). The exact number and locations of the survey/interviews (i.e., district and commune) per province or city were defined by the Local Consultants based on its preliminary discussion with the Department of Agriculture and Rural Development (DARD) of each province/city and were submitted for approval to MOIT by the Local Consultants before executing the survey.

The FA Consortium developed a complete crop biomass survey form (see section 4.1). The Local Consultants were trained by the FA Consortium on how to fill in the survey form using smartphones during the Training Workshop on Field Survey and Data Collection organized at NLU on September 28-29, 2016.

Validation of Crop Biomass Survey

During the field interviews, Simosol downloaded the interview data from the MHG Mobile server, validated the data for logical consistency against agreed validation rules, and reported any invalid data back to the survey teams for checking as daily Excel survey data files, which highlighted the invalid data. The survey teams compiled the corrected daily Excel files into weekly files and sent those directly to Simosol for validation. Once the weekly file passed the validation rules, it was considered the final survey result file for that week.

Another verification executed at Simosol was for the "reference field" of the survey questionnaire. The interviewed farmer selected a single field for which the crops cultivated between Nov 2015 and Nov 2016 were recorded and a photograph of the field was taken. If the crop information recorded and the photograph taken did not match, or the location of the photograph could not reliably be assigned to a field identifiable from a very high-resolution satellite image, the reference field was excluded from the land use classification reference dataset. Figure 14 shows a sample of an accepted reference field, and also demonstrates how the area to include into the reference sample was digitized during the validation process.

Figure 14: A reference field sample that was included into land use classification reference sample data set

(The yellow dots and white line delineate the area that was used as the reference sample for this field)

Figure 15 gives an example of a reference field that was excluded from the reference data set.

Figure 15: An example of a rejected reference field sample due to having been recorded in the middle of a road leaving uncertainty for the actual location of the field.

Results of Crop Biomass Survey

VNUA completed their part of the crop biomass survey on December 8, 2016 and NLU on June 22, 2017. A total of 21,179 farmers in 514 districts were interviewed of which 13,835 interviews were conducted by NLU and 7,344 interviews by VNUA. After the validation, a total of 19,950 datasets were accepted of which 13,516 datasets were collected by NLU and 6,434 datasets were collected by VNUA.

The number of surveyed districts, the number of farmers interviewed, and the number of datasets accepted for each of the provinces are presented in Table 16.

Table 16: Summary of number of districts surveyed, farmers interviewed and datasets accepted

No.	Province	Number of districts surveyed	Number of farmers interviewed	Number of datasets accepted
1	An Giang	8	515	515
2	Ba Ria-Vung Tau	5	213	213
3	Bac Giang	10	272	272
4	Bac Kan	4	110	74
5	Bac Lieu	4	292	269
6	Bac Ninh	8	83	83
7	Ben Tre	4	275	277
8	Binh Dinh	7	297	297
9	Binh Duong	7	369	373
10	Binh Phuoc	8	867	773
11	Binh Thuan	7	731	727
12	Ca Mau	4	273	274
13	Can Tho city	3	146	146
14	Cao Bang	12	238	172
15	Da Nang City	1	14	14
16	Dak Lak	12	999	987
17	Dak Nong	6	611	613
18	Dien Bien	7	279	280
19	Dong Nai	11	534	537
20	Dong Thap	6	489	489
21	Gia Lai	14	1,281	1,126
22	Ha Giang	11	387	309
23	Ha Nam	5	84	84
24	Ha Noi City	5	59	59
25	Ha Tay (now, Ha Noi City)	12	217	217
26	Ha Tinh	11	265	239
27	Hai Duong	12	171	171
28	Hai Phong City	2	96	96
29	Hau Giang	4	250	250
30	Ho Chi Minh City	6	132	125
31	Hoa Binh	11	255	201
32	Hung Yen	10	101	101
33	Khanh Hoa	5	174	278
34	Kien Giang	9	856	856
35	Kon Tum	8	401	402
36	Lai Chau	6	193	173
37	Lam Dong	10	726	583
38	Lang Son	11	210	210

39	Lao Cai	9	166	163
40	Long An	11	588	588
41	Nam Dinh	10	212	212
42	Nghe An	18	576	520
43	Ninh Binh	7	151	116
44	Ninh Thuan	4	148	148
45	Phu Tho	12	202	202
46	Phu Yen	6	245	245
47	Quang Binh	7	198	153
48	Quang Nam	8	224	224
49	Quang Ngai	5	268	268
50	Quang Ninh	9	93	94
51	Quang Tri	8	185	181
52	Soc Trang	7	405	405
53	Son La	11	634	541
54	Tay Ninh	9	625	625
55	Thai Binh	8	174	174
56	Thai Nguyen	7	401	210
57	Thanh Hoa	22	594	492
58	Thua Thien - Hue	9	114	114
59	Tien Giang	7	412	412
60	Tra Vinh	5	294	294
61	Tuyen Quang	6	188	160
62	Vinh Long	5	204	205
63	Vinh Phuc	9	140	105
64	Yen Bai	9	273	234
	Total	**514**	**21,179**	**19,950**

Figure 16: Locations of farms with collected datasets accepted

1.2.2 Industrial Biomass Survey

With the support from FA Consortium, the local consultants (NLU and VNUA) have developed a methodology for the industrial biomass survey, including the following six steps:

- Identification and preparation of a list of industries to be surveyed;
- Sending of the survey questionnaires to the identified industries;
- Compilation and analysis/validation of the data received;
- Selection of sites for on-site visits;
- Conducting site visits to the selected industries;
- Preparation of report on industrial biomass survey.

The local consultants identified the major industries to be surveyed through the list of industries provided by provincial authorities (e.g. DARDs, DOITs, DONREs), by the relevant industry associations (e.g. VSSA, AHAV, VDA), and from other publicly available sources. The background information on the industrial sites (such as name of industrial site, detailed address, email and telephone number of contact person, size of the industrial site, etc.) were also collected.

The survey questionnaires developed by FA Consortium (those were used during the training workshop on field survey and data collection) were sent to the identified industries for collection of relevant data. The local consultants used follow-up calls and e-mails to explain to the industries the purpose of the survey as well as the details of the survey questionnaire.

The data received from the survey questionnaires were compiled and analyzed by the local consultants. Then, they were sent to FA Consortium for preliminary validation.

Based on the analysis of the feedback from industries, and on the results of the preliminary data validation by FA Consortium, the local consultants selected sites for on-site visits to confirm the data provided in the complete questionnaire and, if needed, to collect additional information.

Validation of Industrial Biomass Survey

FA Consortium carried out the validation of the data collected through industrial biomass survey by the local consultants. The preliminary validation was conducted for the preliminary datasets obtained through the survey questionnaires, and the final validation was done for the final datasets collected after on-site visits.

The local consultants compiled the final datasets in an Excel file and sent it to FA Consortium for validation. The following key data/aspects were checked:

- GIS coordinates of the surveyed sites (using Google map);
- Residue-to-Crop Ratio (RCR);
- Characteristics of the biomass residues (e.g. moisture content, LHV);
- Completeness and consistency of the data.

The checked datasets with errors/missing information highlighted were sent back to the local consultants. They re-contacted the contact persons at the surveyed industries to verify the incorrect data and/or to complete the missing information. The validated and verified data were eventually sent back to FA Consortium. That process continued until all datasets were finally accepted.

Results of Industrial Biomass Survey

A total of 261 datasets from seven industrial sectors were validated and accepted, of which 112 datasets were collected by NLU, 123 datasets collected by VNUA and 26 datasets were computed by FA Consortium from its database. Summary of the accepted datasets by industrial sector is given in Table 17.

Table 17: Summary of the accepted datasets by industrial sector

Sector	Datasets collected by NLU	Datasets collected by VNUA	Datasets collected by FA Consortium	Total
Sugar mills	3	22	15	40
Rice mills	46	8	0	54
MSW landfills	4	28	6	38
Livestock farms	14	48	5	67
Wood processing mills	29	11	0	40
Brick-making factories	16	0	0	16
Pulp and paper mills	0	6	0	6
Total	**112**	**123**	**26**	**261**

The map of surveyed industrial sites is presented in Figure 17.

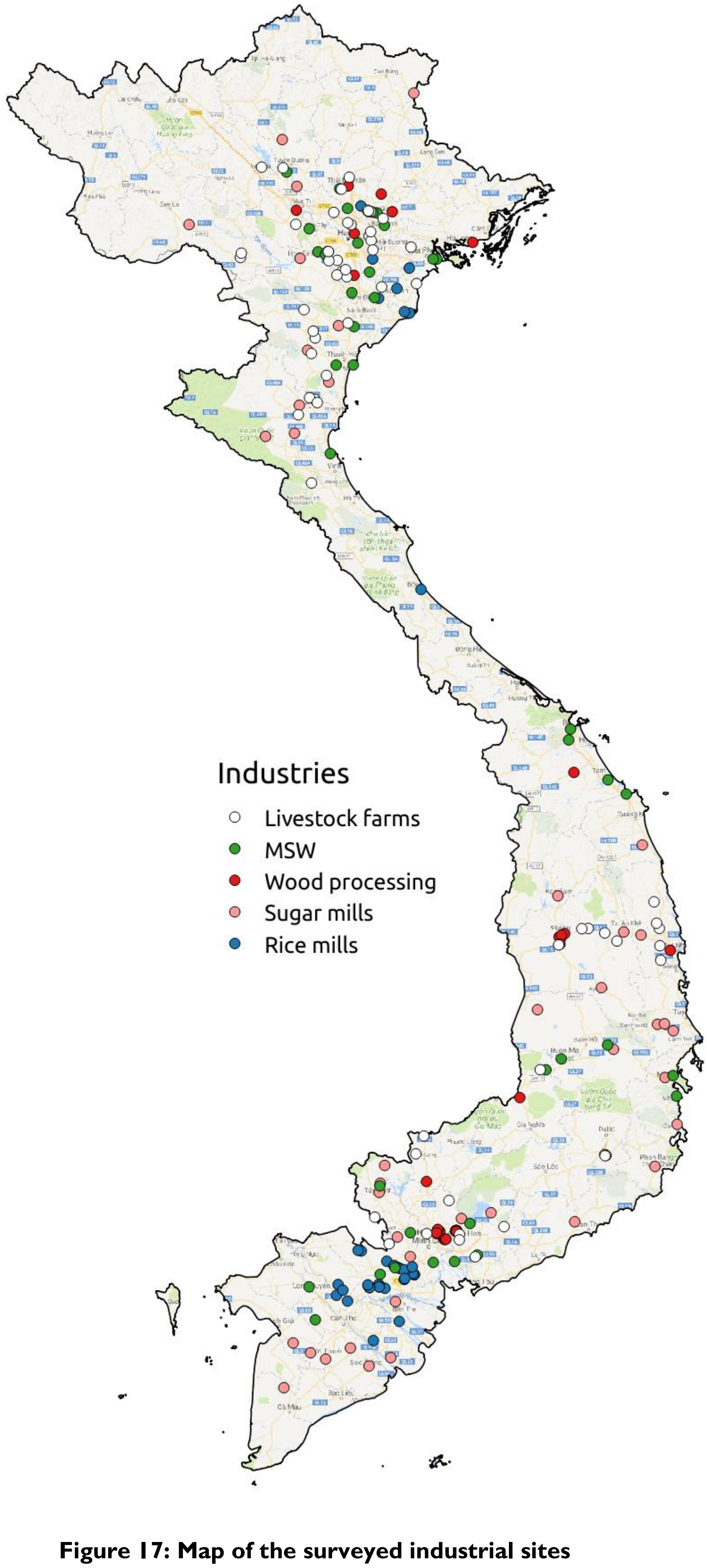


Figure 17: Map of the surveyed industrial sites

1.2.3 Satellite image analysis

The purpose of the satellite image analysis was to produce a land use classification of agricultural fields for the whole country. Together with the crop yield and residue information collected during the field survey, the land use classification forms the basis for estimating the localized biomass feedstock potential from agricultural production.

Gathering of satellite images

The first step in the satellite image analysis was gathering the satellite images. Due to prevailing cloudiness over the country, synthetic aperture radar (SAR) images with 20 m x 20 m ground resolution from the Sentinel-1 (S-1) satellite by the European Space Agency (ESA) were used. The benefit of SAR images is that the radar signal is an active signal sent by the satellite, and this signal penetrates the cloud cover to reach the ground. This increases the availability of images over any given period considerably, compared to the optical satellite images, especially during the rainy season. The S-1 images were downloaded from the Copernicus Open Access Hub[6]. Twenty-four (24) image datasets covering Vietnam and distributed over a timespan of 12 months were used to do the classification at the level of identifying, the cultivated crops for each of the cropping seasons within a year. Figure 18 shows the coverage of the first Sentinel-1 image dataset over the map of Vietnam. Table 18 lists the exact data ranges of the 24 Sentinel-1 image datasets. In total 913 Sentinel-1 images were used in the crop level land use classification. As can be seen in Figure 18, there is a region in Northern Vietnam that was not covered by Sentinel-I images for the time period in question. The same applies also for some of the islands close to the mainland Vietnam.

[6] *https://scihub.copernicus.eu/*

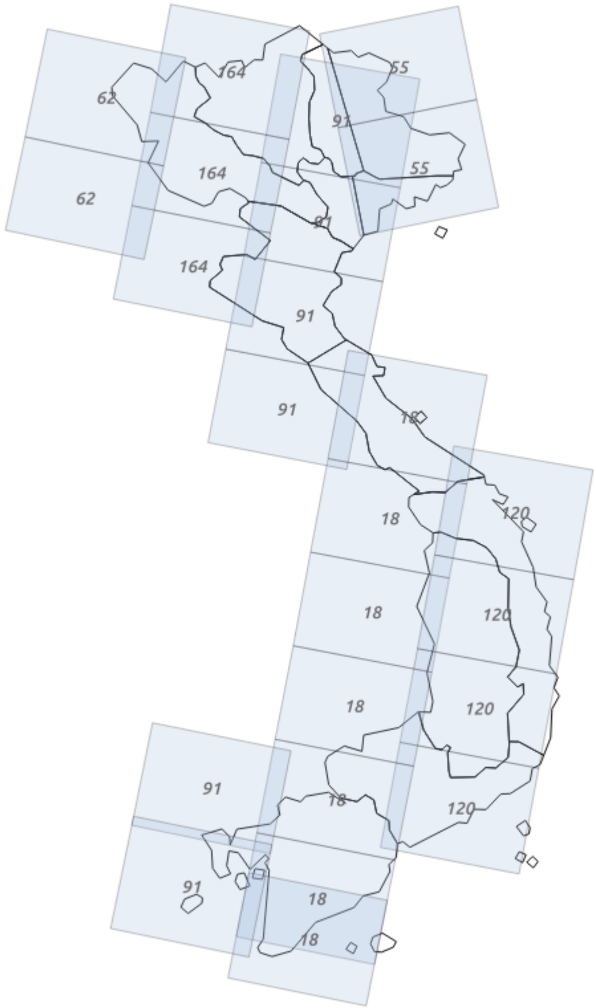


Figure 18: 24 Sentinel-1 image tile sets used in the analysis
(The numbering relates to the relative path of the Sentinel-1 data)

Table 18: The date ranges for 24 Sentinel-1 image sets used in land use classification

Set 1	2015-11-02	2015-11-28
Set 2	2015-11-18	2015-12-14
Set 3	2015-12-02	2015-12-28
Set 4	2015-12-19	2016-01-14
Set 5	2016-01-02	2016-01-28
Set 6	2016-01-19	2016-02-14
Set 7	2016-02-02	2016-02-28
Set 8	2016-02-17	2016-03-14
Set 9	2016-03-02	2016-03-28
Set 10	2016-03-19	2016-04-14
Set 11	2016-04-02	2016-04-28
Set 12	2016-04-18	2016-05-14
Set 13	2016-05-02	2016-05-28
Set 14	2016-05-19	2016-06-14
Set 15	2016-06-02	2016-06-28

Set 16	2016-06-18	2016-07-14
Set 17	2016-07-02	2016-07-28
Set 18	2016-07-19	2016-08-14
Set 19	2016-08-02	2016-08-28
Set 20	2016-08-19	2016-09-14
Set 21	2016-09-02	2016-09-28
Set 22	2016-09-18	2016-10-14
Set 23	2016-10-02	2016-10-28
Set 24	2016-10-19	2016-11-14

For the land use classification, Vietnam was divided into 11 distinctive geographical areas according to agro ecological zones (AEZ) and orbital direction of satellite images (see north/east indication in Figure 19).

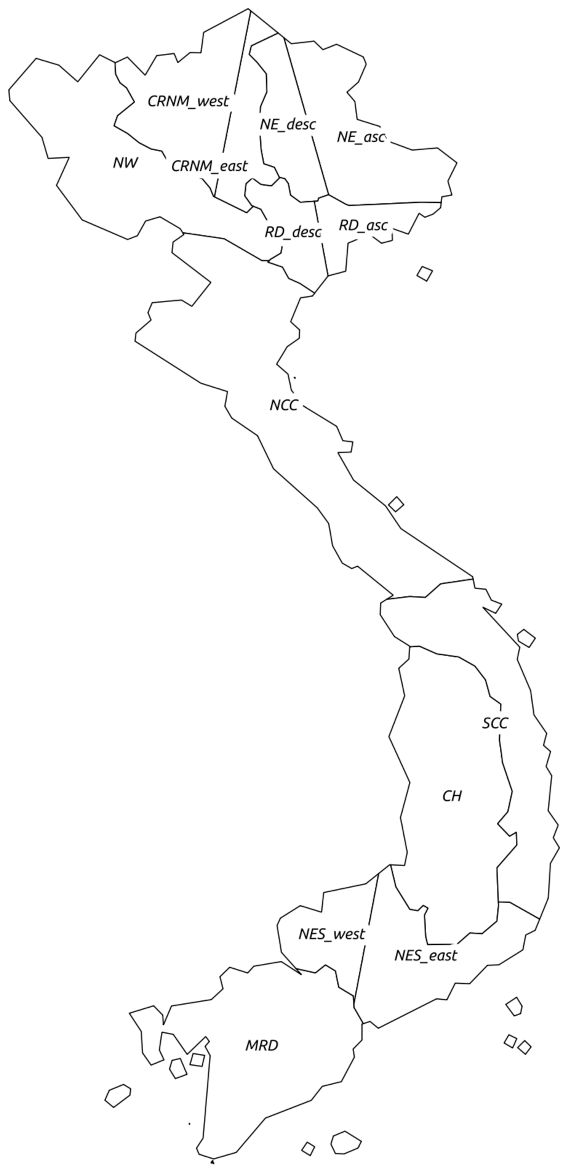


Figure 19: Land cover classification areas used in the analysis

Analysis of satellite images

The satellite image processing consisted of 6 stages described below.

1. ***Image unpacking:*** the unpacking stage extracts the satellite image data and its metadata from the distribution archive downloaded from Scihub Copernicus Open Access Hub.

2. ***Image processing:*** The Sentinel Application Platform (SNAP) was used to process the original Sentinel-1 data to 20m x 20m pixel size. Radiometric corrections, terrain-flattening and terrain-corrections were also applied using the SNAP software.

3. ***Edge masking:*** Sentinel-1 image characteristically have degraded data quality towards the vertical sides of the image. Edge masks of at least 5 km in width were used to erase incorrect data from sides of each satellite image.

4. ***Image mosaicking and stacking:*** Once quality of the images was assured, the images were mosaicked and stacked together to form a time-series that covers the whole country. Separate seamless images cover each AEZ separately in each 24 points-of-time, spread evenly over the analysis date range.

5. ***Ground reference data processing:*** Individual field observations recorded with the MHG Mobile software during the field survey were processed into AEZ specific reference observations. A separate quality control was executed at this stage selecting only those samples that clearly represented a field pixel. In total, 80% field crop references were used for classification, and 20% for the classification result validation. Additionally, 5418 reference samples for the other than agricultural land use classes were generated using very high-resolution imagery available online. Random image samples, covering roughly 300 m x 300 m at sub one-meter resolution, were generated. On each of these, a clear sample of one of the other land use classes (forest, urban, bush, water, bare area) was assigned to a polygon location using visual interpretation of the image content.

6. ***Land cover classification:*** The information in the 24 image time-series mosaic and ground reference samples was used to produce a land cover/land use classification for each of the 20 m x 20 m pixels using a Random Forest classifier separately for each land cover classification area. After the pixel-wise Random Forest classification, the land cover class predictions were further fine-tuned by using the confusion matrix information (see below) and the pixel neighborhood. This means that the final classification was done by changing the classification to the second most likely class from the most likely class, if the second most class was abundant in the 400 m x 400 m context around the pixel, the most likely class was rare in the same context, and the likelihood difference between the most likely and second most likely class was small. The land cover classes used in the classification were derived from the field survey information by analyzing existing combinations of crops. These, along with the non-agricultural classes used are listed in Table 19. Furthermore, for 33 southern provinces, a MONRE land use classification dataset was also available (Figure 20). This dataset was used as an analysis area mask, meaning that only the areas belonging to agricultural production areas were classified for these provinces.

Table 19: The 52 land use classes actually used in the classification

Crop classes	
rubber-rubber-rubber	fallow-fallow-rice
rice-fallow-rice	rice-fallow-fallow
pepper-pepper-pepper	rice-waterlogged-fallow
rice-rice-fallow	rice-rice-other
other-other-other	rice-rice-soybean
rice-rice-rice	rambutan-rambutan-rambutan
cashew_nut-cashew_nut-cashew_nut	mango-mango-mango
sugarcane-sugarcane-sugarcane	orange-orange-orange
fallow-rice-rice	rice-rice-waterlogged
cassava-cassava-cassava	longan-longan-longan
fallow-cassava-cassava	mandarin-mandarin-mandarin
coffee-coffee-coffee	coconut-coconut-coconut
maize-maize-maize	maize-rice-fallow
fallow-fallow-maize	fallow-fallow-cassava
tea-tea-tea	rice-rice-sweet_potato
cassava-fallow-cassava	rice-rice-sugarcane
fallow-rice-fallow	waterlogged-rice-rice
maize-rice-rice	sugarcane-fallow-fallow
fallow-maize-rice	peanut-maize-fallow
litchi-litchi-litchi	fallow-fallow-sugarcane
fallow-litchi-fallow	cassava-maize-fallow
fallow-maize-maize	fallow-maize-fallow
other-rice-rice	sweet_potato-rice-rice
rice-rice-maize	
Other classes	
water	bare_area
forest	bush
urban	

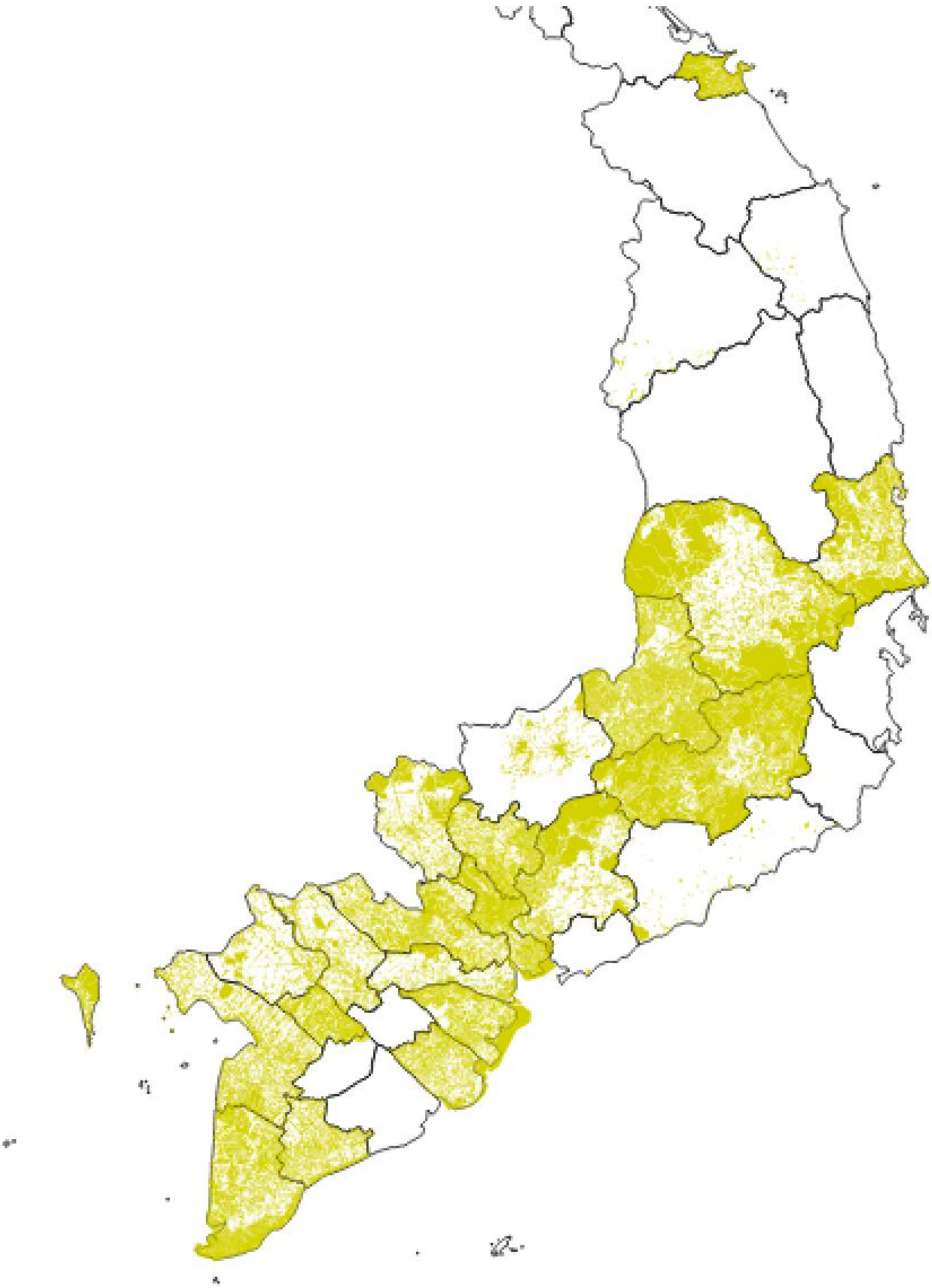


Figure 20: MONRE land use dataset for the 33 southern provinces showing non-agricultural areas used as classification mask.

Figure 21 shows the classification accuracy for the Central Highlands agro-ecological zone. Overall, the classification accuracy is very good, highlighted by the dark blue diagonal in the chart. The values (i.e. the different shades of blue) in the chart show the proportion of the validation samples that have been predicted to be of some class. For example, all 2006 samples of rubber-rubber-rubber have been predicted to be rubber-rubber-rubber, but the class other-other-other has been predicted to be either other-other-other, sugarcane-sugarcane-sugarcane or cassava-cassava-cassava, and the different shades of blue give an indication of how these predictions are distributed across these three classes (most are predicted correctly to be other-other-other).

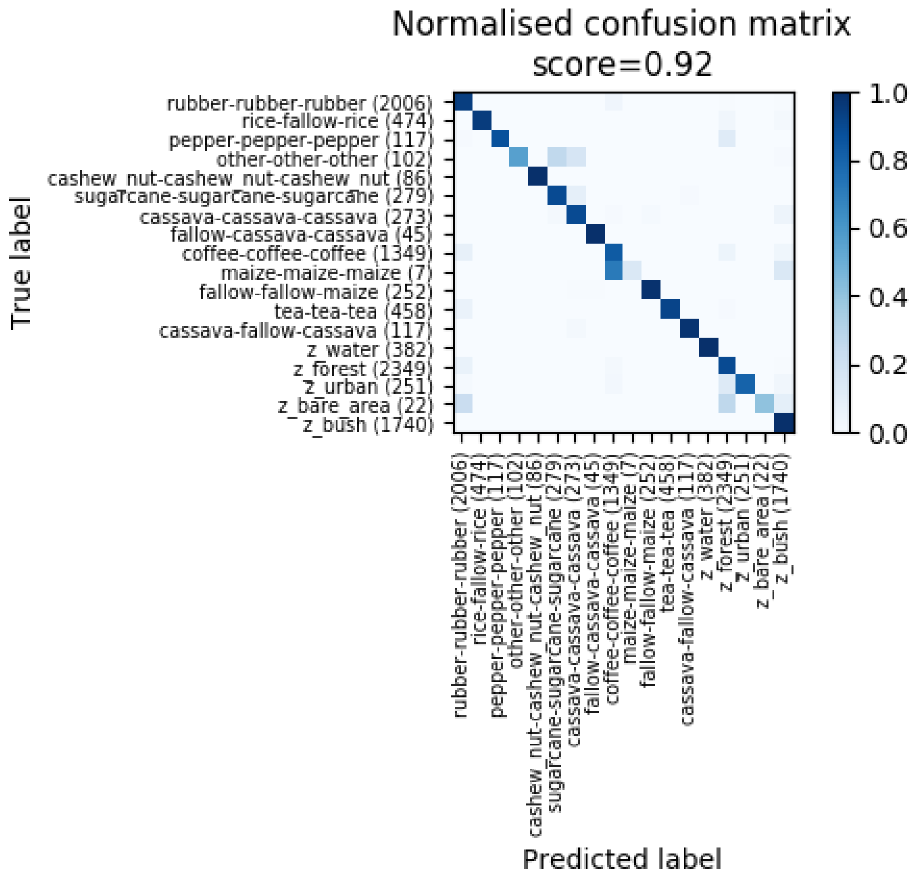


Figure 21: The land use classification result in the Central Highlands. The number of validation samples for the class is in brackets

However, for some of the other AEZs the classification accuracy was not as high. The classification confusion matrix in Figure 22 highlights three problematic areas for the classification; (i) overrepresentation of the most common land use classes in the expense of the less prominent classes (other classes classified as rubber trees, the most prominent crop class), (ii) misclassification between permanent, woody crops (i.e., rubber, cashew nut, coffee, forest, mango, etc.), and (iii) misclassification between the "other" classes and crop classes (cassava and maize classified as “bush” to a small extent).

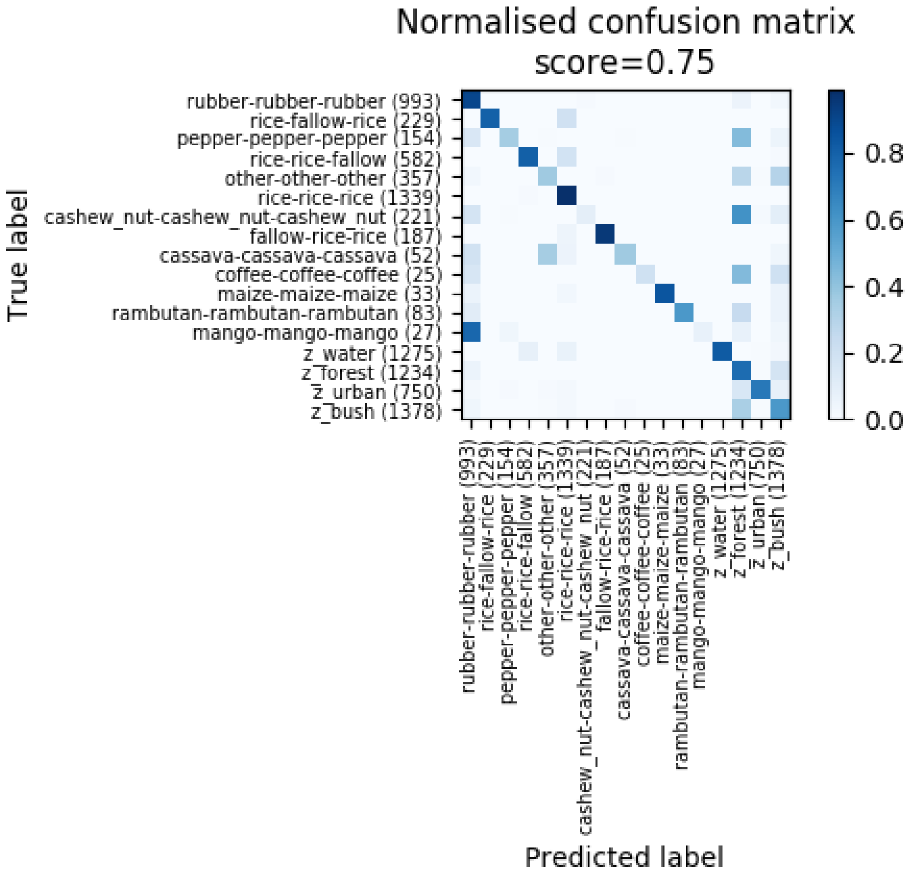


Figure 22: The land use classification result in the South-East AEZ

When utilizing the Biomass Atlas results, the user is strongly advised to take the land use classification accuracy results into account. The full set of the classification confusion matrices containing this information is provided in Figures 23 and 24. When interpreting the matrices, one should also take into account the classes between which the possible misclassification has happened (e.g. for the purpose of evaluating the rice crop residue feedstock availability, a misclassification between two different rice classes is likely to be of no practical relevance).

The confusion matrices were created before masking the analysis areas with the MONRE dataset for those provinces it was available.

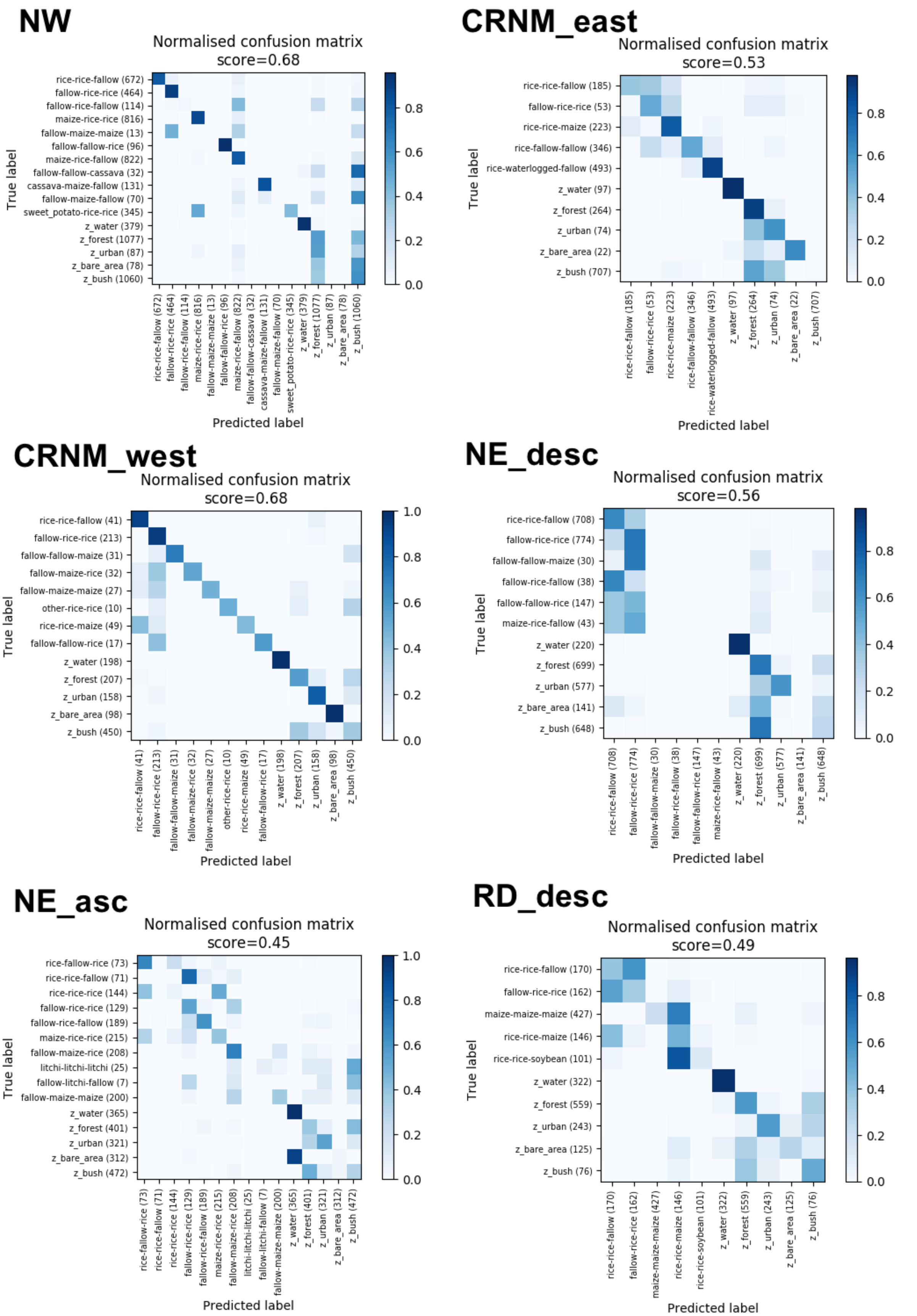


Figure 23: The land use classification accuracy results for six northernmost regions

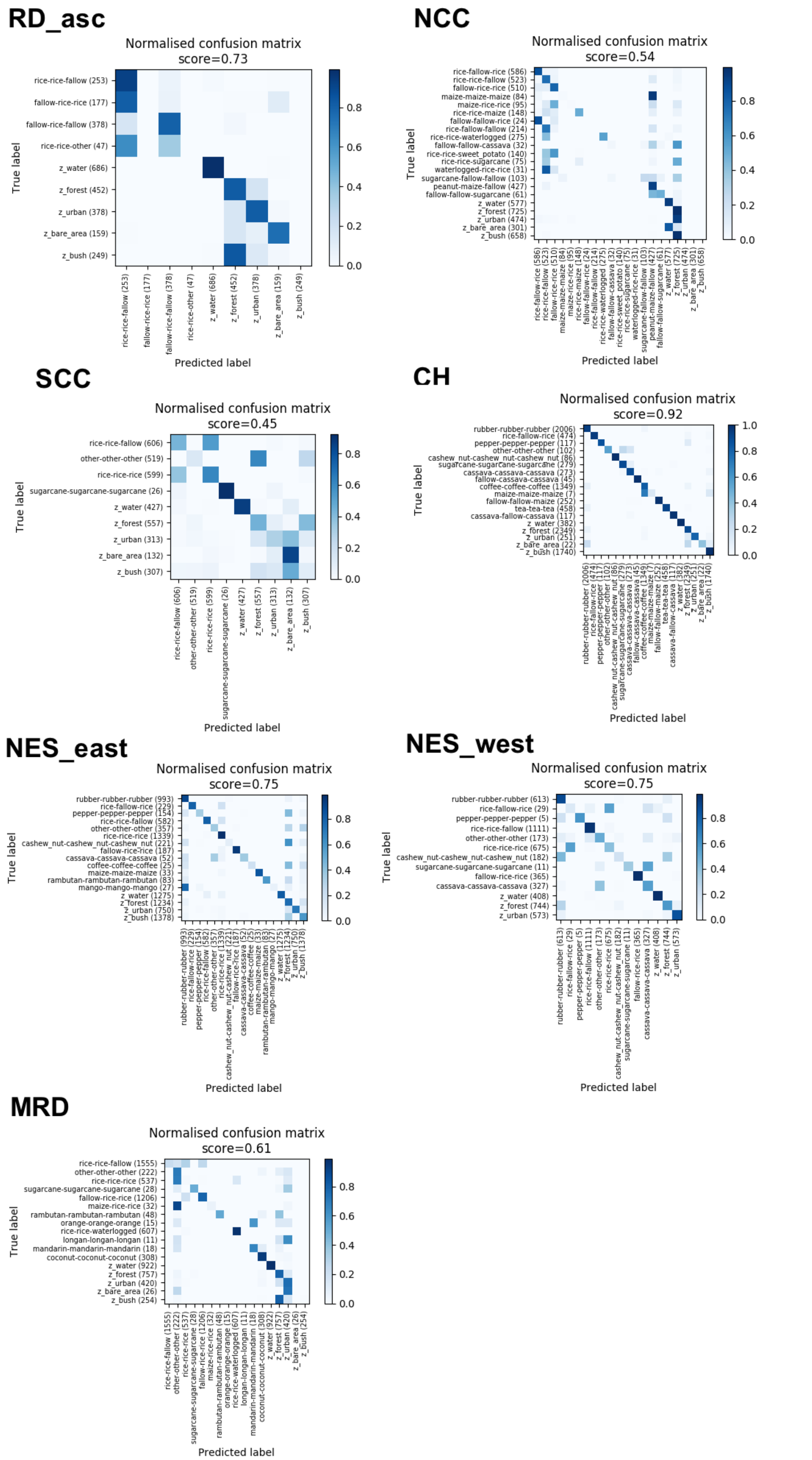


Figure 24: The land use classification accuracy results for seven southernmost regions

1.2.4 Biomass feedstock potential modeling of the Biomass Atlas

The first stage of development of the Vietnam Biomass Atlas is illustrated in Figure 25. The first step of the analysis was the creation of the land cover classification. The details for this step are given in section 1.2.3 of this Annex.

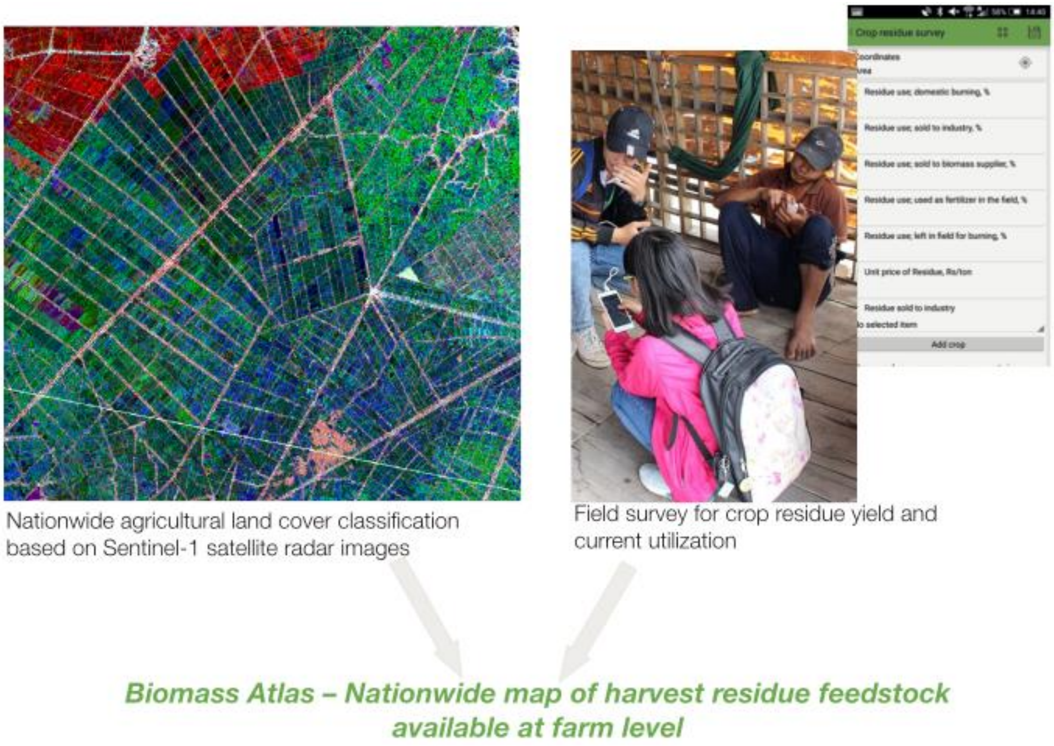


Figure 25: Components of the first atlas and harvest residue feedstock available at farm level

The field survey data were used to derive the harvest biomass residue feedstock map from the land cover classification map. The results for the survey were aggregated at district level. For each crop being analyzed, the crop yield and current utilization patterns for the harvest residues were aggregated from single responses to district level average values, as well as their standard deviation and min-max values. The utilization patterns modeling used the answers to these survey questions:

- Residue use; used as fertilizer in the field, %
- Residue use; sold to biomass trader, %
- Residue use; other, %
- Residue use; left in field for burning, %
- Residue use; directly sold to industry, %
- Residue use; as fuel in household, %
- Residue use; animal fodder, %

In addition, a set of questions about attitudes towards participation in a commercial feedstock supply chain was asked. In the analysis, only the portion currently left in field for burning was considered to be available as feedstock for power generation.

The crop yield values from the survey responses were converted to different types of crop biomass residues based on residue-to-crop-ratios (see Table 2).

Then, the biomass potential map was produced for each of the crop biomass residues. These maps show the amount of the crop harvesting residues available at the farms (see Figures 2, 3 and 4). At the finest level of detail, these maps are at 20x20 m resolution, but for usability, they are further aggregated to 1,000 m x1,000 m resolution, which will reduce the file size to a usable level.

The second step of the data analysis and atlas creation is illustrated in
Figure 26.

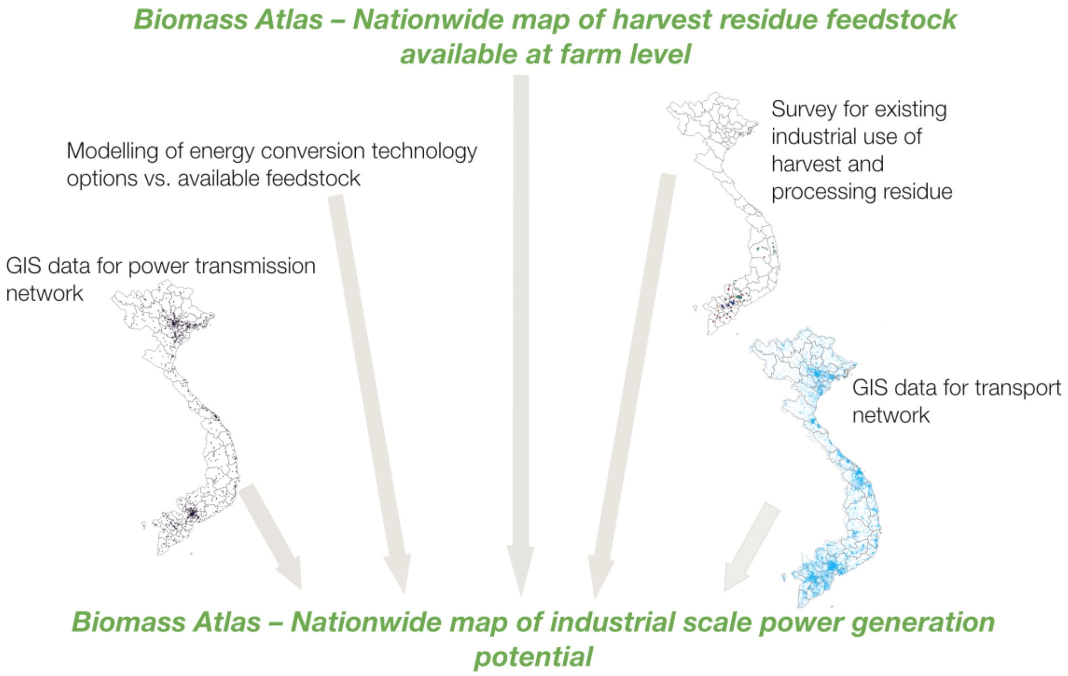


Figure 26: Steps to create the industrial scale power generation potential atlas

The output of the second step is a series of maps highlighting areas of high potential for industrial scale power generation. Each map is for a specific energy conversion technology and plant size. The maps are created based on a concept of a suitability index: the higher the index value, the higher the potential of the site for industrial power generation with the given technology.

The set of analyzed technologies and plant sizes is:

- Grate furnace type steam boiler + steam turbine: 3 MW, 8 MW, 15 MW.
- Bubbling Fluidized Bed Combustion steam boiler + steam turbine: 8 MW, 15 MW, 25 MW, 50 MW, 100 MW.
- Circulating Fluidized Bed Combustion steam boiler + steam turbine: 15 MW, 25 MW, 50 MW, 100 MW.
- Gasifier + syngas engine/turbine: 0.5 MW, 1.5 MW.
- Anaerobic digester + biogas engine: 0.5 MW, 1.5 MW, 3 MW, 8 MW

The site suitability indicator maps were produced for 18 different combinations of energy conservation technologies and power plant capacities (see Figures 6, 7 and 8 as examples).

To derive these maps, the harvesting biomass residue feedstock maps are used to model the distance from which the feedstock must be sourced to the power plant. In order to derive the distance, the applicability of each feedstock for the given technology was graded with a scoring system: 0 – not suitable, 1 – acceptable, 2 – recommended.

The feedstock sourcing distance-modeling principle is illustrated in
Figure 27. The same principle applies also to the other factors used in modeling the site suitability index. First a 1,000 x 1,000 m grid is spanned over the whole country. Then for each grid cell (one marked in the figure with "X") the minimum distance from which the total feedstock amount needed to operate the power plant can be sourced is computed using the feedstock map. This is done for the recommended feedstock for the plant that is most abundantly available: the shorter the sourcing distance, the higher the site suitability index value for the grid cell under analysis.

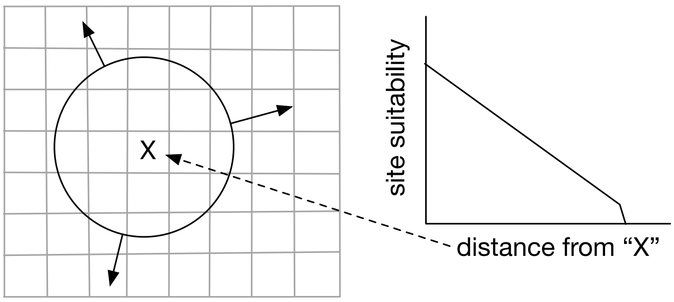


Figure 27: The modeling principle for the different site suitability factors.

However, before computing the site suitability for single fuel availability, the direct, "as-the-crow-flies" minimum sourcing distance is converted to an approximation of the real sourcing distance with the help of road network density in the area. The road network density, shown in Figure 28, was estimated based on road network data downloaded from the OpenStreetMap[7].

[7] *http://wiki.openstreetmap.org/wiki/Downloading_data*

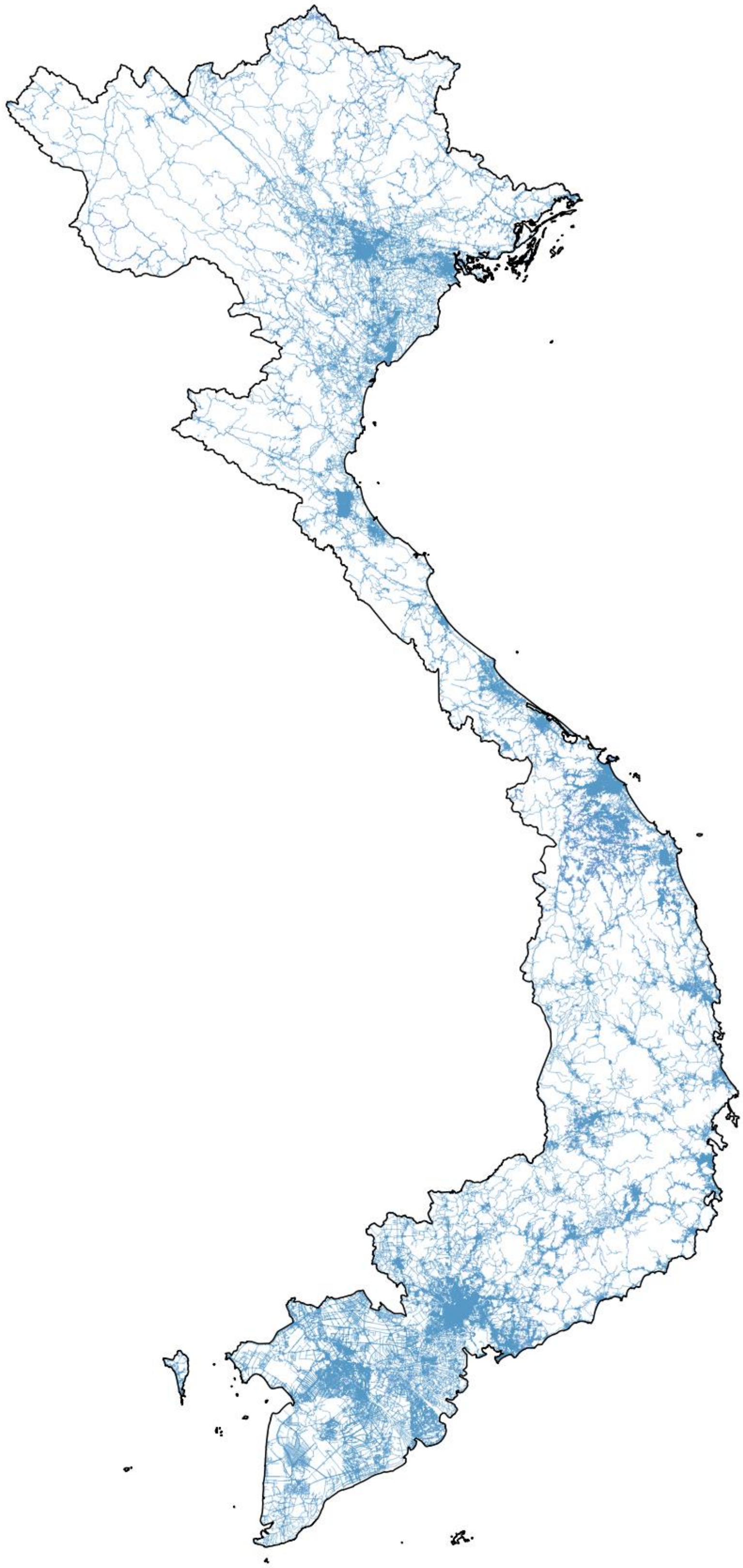


Figure 28: Road and watercourse network data used in the analysis

Next to the single fuel sourcing distance index, the second index to be computed for creating the final site-suitability indices, was the multi-fuel sourcing index. Again, the feedstock suitability was modeled, but now conditional on the primary feedstock, and its minimum share of the feedstock mix. Based on this grading, we computed a multi-fuel sourcing distance index similarly to the single fuel sourcing distance index.

Similar distance-based index was computed for distance to the nearest power transmission network grid station (Figure 29)

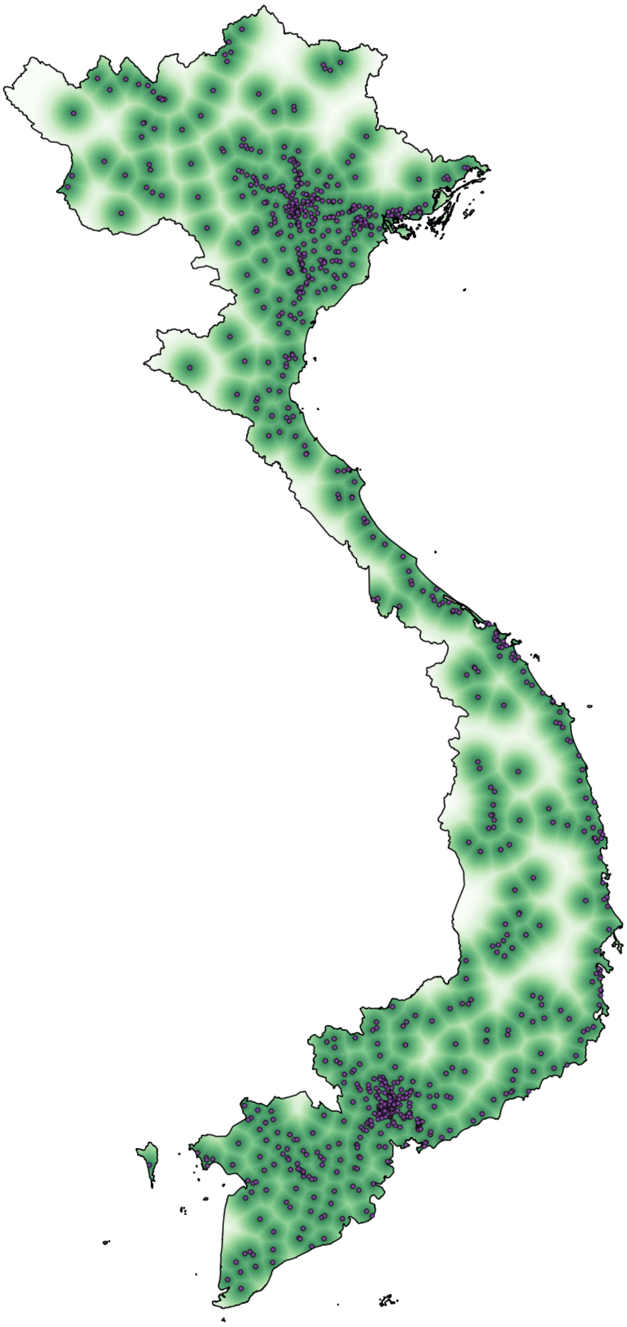


Figure 29: Grid stations, and the computed grid station distance index.
(Darker green indicating higher index values, 50 km maximum distance for the grid connection)

Finally, three distance indices (fuel sourcing, grid station connection and road network density) were combined as a single site-suitability index by weighing the individual indices (0.6 for feedstock procurement distance, 0.3 for grid connection distance and 0.1 for road network density). As there are two indices for the fuel sourcing distance, separate indices were computed for single-fuel and multi-fuel sourcing. The result is the final site-suitability index for each analyzed technology and power plant size combination (see Figure 6 as an example).

The site-suitability index is useful for greenfield projects looking for the most relevant places for an investment for further analysis. Feasibility analyses for power plant installation on an existing industrial site, can utilize the components of the atlas data that are used to derive the site-suitability index map. How to do this in practice was the focus of the training workshops on Biomass Atlas usage and maintenance.

Annex 2: Electricity generation potential at the surveyed biomass producing sites

This Annex presents the key results of analysis of the electricity generation potential at the 239 surveyed biomass-generating industrial sites, including:

1. 40 sugar mills
2. 54 rice mills
3. 38 MSW landfills
4. 67 livestock farms
5. 40 wood processing mills

Table 20: Electricity generation potential at the surveyed sugar mills (the milling season 2016-17)

(ranked by *Gross Power Output*)

No.	Province	District	Sugar mill	Bagasse production (t/yr)	Bagasse available for cogen plant (t/yr)	Gross power capacity output (MW)	Electricity export (use of bagasse only) (GWh/yr)	Electricity export (use of bagasse and additional biomass) (GWh/yr)	Additional biomass feedstock sourced (t/yr)	Biomass feedstock sourcing area (km^2/GWh)
1	Nghe An	Quy Hop	Nghe An Sugar Mill	324,800	323,200	55.0	105.64	336.51	306,887.7	0.323
2	Gia Lai	An Khe Township	An Khe Sugar Mill	450,000	450,000	54.4	93.93	321.25	341,537.9	0.259
3	Khanh Hoa	Cam Ranh Township	KSC Khanh Hoa Sugar Mill	530,000	530,000	47.9	99.19	251.12	213,019.2	0.606
4	Tay Ninh	Tan Chau	Thanh Thanh Cong-Tay Ninh Sugar Mill	288,432	288,432	45.1	76.05	275.98	263,838.0	0.557
5	Gia Lai	Ayun Pa	Ayun Pa Sugar Mill (Gia Lai Sugarcane Thermoelectricity JSC)	181,000	181,000	41.0	81.60	262.74	269,844.7	0.249
6	Phu Yen	Son Hoa	KCP Son Hoa Sugar Mill	332,000	332,000	28.9	43.51	144.81	153,272.3	0.898
7	Tuyen Quang	Ham Yen	Tuyen Quang Sugar Mill	135,000	135,000	26.2	45.54	163.34	160,842.5	0.379
8	Khanh Hoa	Ninh Hoa	Ninh Hoa Sugar Mill	200,000	200,000	20.6	36.22	112.80	114,057.5	0.760
9	Nghe An	Tan Ky	Song Con Sugar Mill	116,000	116,000	19.3	32.75	114.06	109,172.1	0.708
10	Long An	Ben Luc	NIVL Sugar Mill	124,390	124,390	18.6	23.83	109.41	115,572.6	0.673
11	Phu Yen	Son Hoa	Van Phat Sugar Mill	184,000	180,000	17.7	28.51	89.89	94,126.1	1.188
12	Dak Lak	Ea Kar	The 333 Sugar Mill	126,000	100,800	15.2	23.72	85.98	93,934.2	0.925
13	Tay Ninh	Tay Ninh Township	Bien Hoa-Tay Ninh Sugar Mill	111,843	111,843	13.4	22.34	76.13	72,569.3	0.602
14	Thanh Hoa	Thach Thanh	Viet-Dai Sugar Mill	151,306	150,759	13.0	4.26	64.79	83,289.1	0.238
15	Quang Ngai	Duc Pho	Pho Phong Sugar Mill	69,300	69,300	12.7	19.67	75.78	85,883.6	2.711
16	Thanh Hoa	Tho Xuan	Lam Son Sugar Mill	186,160	186,160	11.7	5.05	55.74	69,773.6	0.284
17	Dak Lak	Ea Sup	Dak Lak Sugar Mill	77,500	62,500	10.9	16.55	62.65	69,832.8	1.581

18	Soc Trang	Soc Trang Township	Soc Trang Sugar Mill	120,160	120,160	10.0	23.02	52.45	39,778.3	1.101
19	Dong Nai	Vinh Cuu	Bien Hoa-Tri An Sugar Mill	72,943	72,943	9.7	13.57	53.99	55,759.4	1.764
20	Hau Giang	Vi Thanh Township	Vi Thanh Sugar Mill	134,974	134,974	9.6	12.80	44.80	44,190.9	0.440
21	Tra Vinh	Tra Cu	Tra Vinh Sugar Mill	102,000	100,980	9.1	13.47	46.71	45,909.4	1.297
22	Binh Dinh	Tay Son	Binh Dinh Sugar Mill	73,300	73,300	8.9	4.58	46.07	65,144.3	1.039
23	Kon Tum	Kon Tum Township	Kon Tum Sugar Mill	85,000	85,000	8.7	26.84	47.15	30,665.7	2.773
24	Ben Tre	Chau Thanh	Ben Tre Sugar Mill	82,310	82,310	8.6	14.90	45.59	42,386.0	1.032
25	Tuyen Quang	Son Duong	Son Duong Sugar Mill	76,000	76,000	7.9	7.35	41.90	48,885.4	0.917
26	Dong Nai	Dinh Quan	La Nga Sugar Mill	65,550	65,550	7.5	11.87	40.51	39,509.0	1.506
27	Hau Giang	Long My	Long My Phat Sugar Mill	31,700	31,700	7.5	5.74	44.80	53,900.4	0.360
28	Long An	Duc Hoa	Hiep Hoa Sugar Mill	53,020	53,020	7.4	9.60	41.93	44,650.4	0.980
29	Hau Giang	Phung Hiep	Phung Hiep Sugar Mill	155,043	155,043	6.7	4.62	22.27	24,748.7	1.246
30	Son La	Mai Son	Son La Sugar Mill	108,000	108,000	6.5	6.22	28.13	30,970.8	4.858
31	Phu Yen	Tuy Hoa	Tuy Hoa Sugar Mill	73,000	73,000	6.0	7.68	26.81	30,082.8	2.254
32	Cao Bang	Phuc Hoa	Cao Bang Sugar Mill	42,000	30,000	5.5	3.42	29.97	37,949.2	0.828
33	Thanh Hoa	Nong Cong	Nong Cong Sugar Mill	56,000	56,000	5.1	6.36	26.97	28,730.6	0.384
34	Tay Ninh	Tan Chau	Nuoc Trong Sugar Mill	59,910	59,910	3.7	9.80	15.56	8,230.8	5.318
35	Ca Mau	Thoi Binh	Thoi Binh-Ca Mau Sugar Mill	23,040	23,040	3.7	3.77	20.46	23,846.9	1.833
36	Kien Giang	Giong Rieng	Kien Giang Sugar Mill	19,660	19,660	3.7	3.21	20.91	25,275.4	0.432
37	Binh Thuan	Ham Thuan Bac	MK-Vietnam Sugar Mill	24,000	24,000	3.5	3.93	18.95	21,455.1	0.905
38	Ninh Thuan	P.Rang-T.Cham Township	Phan Rang Sugar Mill	56,879	37,230	3.4	2.41	13.56	15,920.5	0.686
39	Nghe An	Anh Son	Song Lam Sugar Mill	20,000	20,000	3.2	2.54	17.99	22,138.3	1.980
40	Hoa Binh	Hoa Binh Township	Hoa Binh Sugar Mill	20,000	20,000	2.4	2.19	12.54	15,294.7	2.052
	Total			**5,142,220**	**5,063,204**	**600.0**	**958.3**	**3,363.0**	**3,412,876**	

Table 21: Electricity generation potential at the surveyed rice mills (the milling season 2016-17)

(ranked by *Gross Power Output* and *Additional Biomass Feedstock Sourcing Area*)

No.	Province	District	Rice mill	Rice husk generation (t/yr)	Rice husk available for power generation (t/yr)	Gross power capacity output (MW)	Electricity export (use of rice husk only) (GWh/yr)	Electricity export (use of rice husk and additional biomass) (GWh/yr)	Additional biomass feedstock sourced (t/yr)	Biomas feedstock sourcing area (km^2/GWh)
1	Long An	Thanh Hoa	Thanh Phat Limited Liability Company	120,000	84,000	9.0	37.51	37.51	0.0	0.00
2	Ben Tre	Mo Cay	Phat Ngan (Tu Le) Private Enterprise	108,000	75,600	8.1	33.75	33.75	0.0	0.00
3	Long An	Thanh Hoa	Bui Tien Dat Private Enterprise	108,000	75,600	8.1	33.75	33.75	0.0	0.00
4	Tien Giang	Cai Lay	Vu Hoang Private Enterprise	60,000	60,000	6.4	30.65	30.65	0.0	0.00
5	Tien Giang	Cai Lay	Tan Long II Rice Grinding Machine	60,000	60,000	6.4	30.65	30.65	0.0	0.00
6	Tien Giang	Cai Lay	Tan Long Private Enterprise	60,000	60,000	6.4	30.65	30.65	0.0	0.00
7	Long An	Thanh Hoa	Duc Bao Ngoc Private Enterprise	40,000	28,000	3.0	11.87	11.87	0.0	0.00
8	Tien Giang	Cai Lay	Tan Long III Rice Grinding Machine	5,400	5,400	3.0	2.55	16.97	24,738.3	0.146
9	Tien Giang	Cai Lay	Nam Nhan Private Enterprise	5,500	5,500	3.0	2.69	17.05	24,621.5	0.159
10	Tien Giang	Cai Lay	Binh Minh Private Enterprise	3,100	3,100	3.0	1.50	17.39	27,237.3	0.178
11	Tien Giang	Cai Lay	Van Loi II Rice Grinding Machine	3,600	3,600	3.0	1.76	17.33	26,690.8	0.179
12	Tien Giang	Cai Lay	Hoa Mai Private Enterprise	3,420	3,420	3.0	1.61	17.30	26,887.7	0.179
13	Tien Giang	Cai Be	Tai Loc Tai Private Enterprise	7,220	5,000	3.0	2.01	16.69	25,189.8	0.205
14	Tien Giang	Cai Be	Tan Vinh Private Enterprise	7,260	5,000	3.0	2.09	16.77	25,185.9	0.208
15	Tien Giang	Cai Be	Vu Nhung Private Enterprise	6,400	4,500	3.0	1.91	16.91	25,733.4	0.208

16	Dong Thap	Cao Lanh City	Vo Thi Be Tu Private Enterprise	440	440	3.0	0.23	17.82	30,191.4	0.215
17	Tien Giang	Cai Be	Son Lam Private Enterprise	3,200	2,300	3.0	0.96	17.36	28,145.0	0.221
18	Tien Giang	Cai Be	Nam Khoi Private Enterprise	4,100	3,200	3.0	1.31	17.14	27,152.5	0.230
19	Tien Giang	Cai Be	Minh Tam Private Enterprise	2,800	2,000	3.0	0.86	17.45	28,466.3	0.230
20	Hung Yen	An Thi	Duong Loan Rice Milling Enterprise	306	306	3.0	0.13	17.80	30,504.8	0.245
21	Tien Giang	Cai Be	Loan Binh Private Enterprise	10,500	7,000	3.0	2.81	16.21	22,983.6	0.246
22	Tien Giang	Cai Be	Song Thanh Private Enterprise	11,200	7,500	3.0	2.99	16.07	22,436.4	0.246
23	Tien Giang	Cai Be	Phuoc Thanh Private Enterprise	6,000	5,200	3.0	2.43	16.98	24,953.7	0.246
24	Tien Giang	Cai Be	Hai On Private Enterprise	19,200	16,000	3.0	7.36	15.02	13,135.1	0.258
25	Tien Giang	Cai Lay	Cong Thanh Private Enterprise	44,000	24,000	3.0	8.72	11.27	4,377.5	0.276
26	Thai Binh	Dong Hung	Rice Mill of Hung Cuc Co., Ltd.	7,200	2,200	3.0	0.00	16.25	28,287.0	0.277
27	Tien Giang	Cai Lay	Le Ngoc An Machine	5,400	0	3.0	0.00	17.39	30,575.4	0.311
28	Dong Thap	Lap Vo	Hung Thinh Private Enterprise	23,000	23,000	3.0	11.98	15.17	5,476.8	0.320
29	Long An	Moc Hoa	Xuan Thu Rice Grinding Factory	2,400	1,680	3.0	0.71	17.51	28,832.6	0.321
30	Long An	Moc Hoa	Chin Bien Private Enterprise	900	600	3.0	0.25	17.74	30,015.6	0.323
31	Long An	Moc Hoa	My Chau Private Enterprise	5,000	3,500	3.0	1.42	17.06	26,838.6	0.332
32	Dong Thap	Cao Lanh City	Van Buu Private Enterprise	3,060	3,060	3.0	1.60	17.52	27,321.8	0.342
33	Nam Dinh	Nam Dinh City	Rice Mill of Huong Giang Trading JSC	4,000	0	3.0	0.00	17.24	30,770.3	0.463
34	Tra Vinh	Cau Ke	Cauke Food Processing Factory	2,000	0	3.0	0.00	17.57	30,382.6	0.537
35	Dong Thap	Chau	Duc Lap Private	10,000	10,000	3.0	5.13	16.62	19,702.8	0.582

		Thanh	Enterprise							
36	Long An	Tan An Township	Tam Trang Private Enterprise	3,500	0	3.0	0.00	17.36	30,295.4	0.584
37	Nam Dinh	Giao Thuy	Rice Mill of Truong Vi Co., Ltd.	3,000	600	3.0	0.00	17.33	30,048.1	0.587
38	Long An	Tan Tru	Dai Hiep Thanh company limited	1,460	1,168	3.0	0.53	17.65	29,038.6	0.632
39	Long An	Tan Tru	Thinh Vuong II Co. Ltd.	1,890	0	3.0	0.00	17.60	30,302.7	0.632
40	Long An	Tan Tru	Thinh Vuong I Co., Ltd	1,890	0	3.0	0.00	17.60	30,302.7	0.632
41	Long An	Tan Tru	Phuoc Loi Private Enterprise	7,300	0	3.0	0.00	16.97	30,280.1	0.641
42	Long An	Tan An Township	Binh Phuong - Tan Tru Co., Ltd	2,190	2,000	3.0	0.98	17.57	28,172.5	0.642
43	Hai Phong	Vinh Bao	Thanh Ba Rice Milling Enterprise	403	403	3.0	0.14	17.76	30,232.7	0.644
44	Long An	Ben Luc	Pham Thi Cuc Private Enterprise	12,400	2,400	3.0	0.00	16.07	27,809.8	0.690
45	Nam Dinh	Giao Thuy	Ly Lieu Rice Milling Enterprise	1,192	1,192	3.0	0.61	17.72	29,378.4	0.777
46	Long An	Thu Thua	Tri Mai Private Enterprise	14,987	0	3.0	0.00	15.77	30,402.2	0.783
47	Long An	Thu Thua	Thinh Phat Co., Ltd	16,790	0	3.0	0.00	15.41	30,402.2	0.783
48	Long An	Thu Thua	Ngoc Phuong Nam company limited	17,000	3,000	3.0	0.00	15.47	27,161.9	0.839
49	Long An	Tan An Township	Cong Thanh 2 Private Enterprise	10,950	9,950	3.0	4.77	16.29	19,452.9	0.985
50	Long An	Thanh Hoa	Ut Dung Private Enterprise	2,400	1,680	3.0	0.71	17.51	28,797.4	1.026
51	Long An	Thanh Hoa	Van Phat Private Enterprise	2,400	1,680	3.0	0.71	17.51	28,797.4	1.026
52	Long An	Thanh Hoa	Hoai Dung Private Enterprise	7,200	5,040	3.0	2.14	16.79	25,000.6	1.034
53	Bac Giang	Hiep Hoa	Hiep Hoa Rice Mill	66	50	3.0	0.02	17.86	30,670.0	1.206
54	Quang Binh	Dong Hoi City	Hoang Thi Chau Rice Milling Enterprise	173	173	3.0	0.07	17.83	30,108.7	4.518
	Total			**869,797**	**620,042**	**188.4**	**284.5**	**1,002.5**	**1,243,489**	

Table 22: Electricity generation potential at the surveyed landfills

(ranked by *Gross Power Output*)

No.	Province	District	Name of Landfill (Waste Management Company)	MSW collected (tonne/day on wet basis)	MSW dumped (tonne/day on wet basis)	Organic MSW (tonne/day on wet basis)	Annual biogas production (Million m^3/year)	Gross electricity output (GWh/year)	Rated gross power capacity (MW)	Electricity export to the grid (GWh/year)
1	Ho Chi Minh City	Binh Chanh	Da Phuoc Landfill	5,000.0	5,000.0	2,500.0	109,500,000	261.92	33.2	248.83
2	Hanoi City	Soc Son	Nam Son Solid Waste Treatment Complex	4,521.0	4,499.2	2,249.6	98,532,480	235.69	29.9	223.91
3	Ho Chi Minh City	Cu Chi	Tam Tan Landfill	2,000.0	1,500.0	750.0	32,850,000	78.58	10.0	74.65
4	Da Nang City	Lien Chieu	Khanh Son Landfill	900.0	885.0	619.5	27,134,100	64.90	8.2	61.66
5	Hai Phong City	Hai An	Trang Cat Solid Waste Treatment Complex	1,000.0	550.0	330.0	14,454,000	34.57	4.4	32.85
6	Dong Nai	Vinh Cuu	Sonadezi Landfill	650.0	650.0	325.0	14,235,000	34.05	4.3	32.35
7	Dong Nai	Long Thanh	Bau Can Domestic and Industrial Solid Waste Treatment Complex	528.9	528.9	264.5	11,582,910	27.71	3.5	26.32
8	Nghe An	Nghi Loc	Nghi Yen Solid Waste Treatment Complex	514.0	514.0	257.0	11,256,600	26.93	3.4	25.58
9	Hai Phong City	Hai An	Dinh Vu Landfill	1,000.0	400.0	244.0	10,687,200	25.56	3.2	24.29
10	Thai Nguyen	Thai Nguyen City	Da Mai-Tan Cuong Landfill	220.0	220.0	187.0	8,190,600	19.59	2.5	18.61
11	Dak Lak	Buon Ma Thuot City	Cu Ebur Landfill	246.0	230.0	184.0	8,059,200	19.28	2.4	18.31
12	Quang Nam	Nui Thanh	Tam Xuan 2 Solid Waste Treatment and Landfill	252.0	252.0	176.4	7,726,320	18.48	2.3	17.56
13	Thanh Hoa	Don Son	Dong Nam Landfill	280.0	252.0	168.8	7,395,192	17.69	2.2	16.80
14	Quang Nam	Dai Loc	Dai Hiep Solid Waste Treatment and Landfill	209.0	209.0	146.3	6,407,940	15.33	1.9	14.56
15	Nam Dinh	My Loc	Loc Hoa Landfill	200.0	200.0	140.0	6,132,000	14.67	1.9	13.93
16	Ninh Binh	Tam Diep	Ninh Binh Solid Waste Treatment Plant	210.0	195.0	117.0	5,124,600	12.26	1.6	11.65

17	Can Tho City	Co Do	Co Do Landfill	300.0	225.0	112.5	4,927,500	11.79	1.5	11.20
18	Dong Nai	Nhon Trach	Phuoc An Solid Waste Treatment Complex	200.0	200.0	100.0	4,380,000	10.48	1.3	9.95
19	Long An	Thanh Hoa	Tam Sinh Nghia Landfiil	200.0	200.0	100.0	4,380,000	10.48	1.3	9.95
20	Hanoi City	Son Tay	Xuan Son Landfill	248.0	248.0	99.2	4,344,960	10.39	1.3	9.87
21	Bac Giang	Bac Giang City	Da Mai Landfill	120.0	120.0	84.0	3,679,200	8.80	1.1	8.36
22	Thanh Hoa	Sam Son	Sam Son Landfill	118.0	118.0	79.1	3,462,828	8.28	1.1	7.87
23	Hanoi City	Chuong My	Nui Thoong Solid Waste Treatment Complex	160.0	160.0	78.4	3,433,920	8.21	1.0	7.80
24	An Giang	Long Xuyen City	Binh Duc Landfill	150.0	150.0	75.0	3,285,000	7.86	1.0	7.46
25	Hung Yen	Hung Yen City	Hung Yen Solid Waste Treatment Complex	75.0	75.0	67.5	2,956,500	7.07	0.9	6.72
26	Tuyen Quang	Yen Son	Nhu Khe Landfill	97.0	96.8	64.8	2,839,226	6.79	0.9	6.45
27	Tay Ninh	Tan Chau	Tan Hung Solid Waste Treatment Plant	150.0	120.0	60.0	2,628,000	6.29	0.8	5.97
28	Tien Giang	Tan Phuoc	Tan Lap Landfill	120.0	120.0	60.0	2,628,000	6.29	0.8	5.97
29	Quang Nam	Nui Thanh	Tam Nghia Solid Waste Treatment and Landfill	62.0	62.0	43.4	1,900,920	4.55	0.6	4.32
30	Khanh Hoa	Ninh Hoa	Hon Ro Sanitary Landfill	60.0	60.0	42.0	1,839,600	4.40	0.6	4.18
31	Bac Giang	Viet Yen	Doi Ong Mat Landfill	57.5	45.0	31.5	1,379,700	3.30	0.4	3.14
32	Ha Nam	Thanh Lien	Dam Gai Landfill	100.0	30.0	21.0	919,800	2.20	0.3	2.09
33	Khanh Hoa	Ninh Hoa	Hon Ro Sanitary Landfill	20.0	20.0	14.0	613,200	1.47	0.2	1.39
34	Hanoi City	Gia Lam	Kieu Ky Landfill	40.0	40.0	14.0	613,200	1.47	0.2	1.39
35	Dak Lak	Ea Kar	Ea Kar Landfill	15.0	15.0	13.5	591,300	1.41	0.2	1.34
36	Dak Nong	Cu Jut	Cu Jut Solid Waste Landfill	16.0	11.5	8.6	377,775	0.90	0.1	0.86
37	Bac Ninh	Que Vo	Phu Lang Landfill	30.0	30.0	1.5	65,700	0.16	0.02	0.15
38	Hoa Binh	Luong Son	Luong Son Solid Waste Treatment Complex	75.0	0.0	0.0	0	0.00	0.00	0.00
	Total			**20,144.4**	**18,231.4**	**9,829.1**	**430,514,471**	**1,029.8**	**130.5**	**978.3**

Table 23: Electricity generation potential at the surveyed livestock farms

(ranked by *Gross Power Output*)

No.	Province	District	Name of Dairy Farm	Type of farm	Number of animals raised	Manure collected (t/day on as-received basis)	Manure available for biogas production (t/day)	Annual biogas production (m^3/yr)	Gross electricity output (MWh/yr)	Gross power capacity (kW)	Electricity export to the grid (MWh/yr)
1	Tay Ninh	Ben Cau	Tay Ninh Dairy Farm (Vinamilk JSC)	Cow	8,000	160.00	160.00	1,752,000	4,541.2	576.0	4,314.1
2	Long An	Duc Hue	Cow Farm of Huy Long An Co., Ltd.	Cow	5,000	100.00	100.00	1,095,000	2,838.2	360.0	2,696.3
3	Binh Duong	Phu Giao	Nguyen Duc Thang Pig Farm	Pig	20,000	40.00	40.00	730,000	1,892.2	240.0	1,797.6
4	Binh Phuoc	Loc Ninh	Loc Ninh 1-2 Pig Farm (Loc Phat Co., Ltd.)	Pig	14,400	36.00	36.00	657,000	1,702.9	216.0	1,617.8
5	Dong Nai	Trang Bom	Phu Son Livestock Breeding Company	Pig	22,000	57.00	30.00	624,150	1,617.8	205.2	1,536.9
6	Son La	Moc Chau	Dairy Farm of the Moc Chau Dairy Cattle Breeding JSC	Cow	23,698	350.00	30.00	328,500	851.5	108.0	808.9
7	Ha Tinh	Huong Son	Ha Tinh Dairy Farm	Cow	2,000	27.00	17.00	186,150	482.5	61.2	458.4
8	Hanoi City	Chuong My	Pig Farm of Mrs. Dang Thi Nam Phuong	Pig	3,000	10.96	10.96	182,500	473.0	60.0	449.4
9	Ninh Binh	Tam Diep	Tam Diep Pig Farm of the Thuy Phuong Swine Research Center	Pig	6,000	11.50	9.70	177,025	458.8	58.2	435.9
10	Ho Chi Minh City	Cu Chi	Gia Phat Pig Farm	Pig	2,600	9.10	9.10	166,075	430.5	54.6	408.9
11	Hanoi City	Chuong My	Pig Farm of Mr. Nguyen Van Tien	Pig	2,500	9.13	9.13	164,250	425.7	54.0	404.4
12	Hanoi City	Chuong My	Pig Farm of Mr. Nguyen Viet Do	Pig	2,000	7.42	7.42	135,050	350.0	44.4	332.5
13	Hanoi City	Chuong My	Pig Farm of Mr. Luu Huu Quyen	Pig	2,000	7.31	7.31	120,450	312.2	39.6	296.6
14	Binh Phuoc	Loc Ninh	Dong Thanh 2 Pig Farm	Pig	10,630	20.35	6.11	111,325	288.6	36.6	274.1
15	Binh Dinh	Van Canh	Thanh Phu Pig Farm	Pig	2,500	9.50	6.50	94,900	246.0	31.2	233.7

16	Binh Dinh	Phu Cat	Nhat Vinh Pig Farm	Pig	2,200	6.00	6.00	91,250	236.5	30.0	224.7
17	Gia Lai	Dak Po	Hiep Anh Xuan Limited-Liability One-member Trade Services Company	Pig	4,000	5.00	5.00	73,000	189.2	24.0	179.8
18	Dong Nai	Xuan Loc	DOLICO Suoi Cao Pig Farm	Pig	2,400	6.00	4.00	73,000	189.2	24.0	179.8
19	Thai Nguyen	Dong Hy	Phuc Thinh Pig Farm	Pig	4,000	4.00	4.00	73,000	189.2	24.0	179.8
20	Bac Giang	Viet Yen	Pig Farm of Mr. Tho	Pig	2,000	3.60	3.60	65,700	170.3	21.6	161.8
21	Bac Giang	Viet Yen	Pig Farm of Mr. Chu The Van	Pig	1,500	3.30	3.30	60,225	156.1	19.8	148.3
22	Dong Nai	Long Thanh	Nguyen Tan Hau Pig Farm	Pig	1,200	3.00	3.00	54,750	141.9	18.0	134.8
23	Binh Dinh	An Nhon	Thai Nguyen Pig Farm	Pig	1,500	3.50	3.00	43,800	113.5	14.4	107.9
24	Bac Ninh	Thuan Thanh	Nguyen Duc Lua Pig Farm	Pig	1,500	2.00	2.00	36,500	94.6	12.0	89.9
25	Hanoi City	Ung Hoa	Pig Farm of Mr. Nguyen Van Thanh	Pig	16,300	30.00	2.00	36,500	94.6	12.0	89.9
26	Binh Dinh	Hoa An	Huy Tuyet Pig Farm	Pig	600	3.00	2.00	32,850	85.1	10.8	80.9
27	Thai Binh	Hung Ha	Viet Hung Breeding One-Member Co., Ltd.	Cow	7,000	80.00	2.00	21,900	56.8	7.2	53.9
28	Thanh Hoa	Tho Xuan	Thanh Hoa Dairy Farm	Cow	1,600	22.00	2.00	21,900	56.8	7.2	53.9
29	Vinh Phuc	Phuc Yen	Phat Dat Livestock Farm	Pig	2,000	2.25	1.20	21,900	56.8	7.2	53.9
30	Yen Bai	Yen Bai City	Pig Farm of the Dam Mo Co., Ltd.	Pig	2,100	3.00	1.00	18,250	47.3	6.0	44.9
31	Bac Ninh	Tien Du	DABACO Nucleus Breeding Pig Co., Ltd.	Pig	30,000	22.00	1.00	18,250	47.3	6.0	44.9
32	Lam Dong	Don Duong	Da Lat Dairy Farm No. 1 of Vinamilk	Cow	1,000	10.00	1.40	15,330	39.7	5.0	37.7
33	Dong Nai	Bien Hoa	Tam Phuoc Pig Farm	Pig	500	1.20	0.70	14,600	37.8	4.8	36.0
34	Hanoi City	My Duc	Pig Farm of Mr. Nguyen Van The	Pig	5,000	7.50	0.70	12,775	33.1	4.2	31.5
35	Hai Duong	Kim Thanh	Hoang Van Thuan Pig Farm	Pig	1,600	0.90	0.65	11,863	30.7	3.9	29.2
36	Tuyen	Yen Son	Tuyen Quang Dairy	Cow	1,976	33.00	1.50	10,950	28.4	3.6	27.0

	Quang		Farm of Vinamilk								
37	Ha Nam	Kim Bang	Pig Farm of Mr. Nguyen Van Che	Pig	1,800	2.90	0.60	10,950	28.4	3.6	27.0
38	Hanoi City	Ung Hoa	Pig Farm of Mr. Quach Thanh Toan	Pig	2,000	3.00	0.50	9,125	23.7	3.0	22.5
39	Bac Giang	Viet Yen	Thanh Oanh Pig Farm	Pig	3,000	2.50	0.50	9,125	23.7	3.0	22.5
40	Hanoi City	Dong Anh	Hong Nhien Pig Farm	Pig	4,000	4.00	2.00	7,300	18.9	2.4	18.0
41	Hanoi City	Dong Anh	Mr. Khanh Pig Farm	Pig	2,000	2.50	1.00	6,570	17.0	2.2	16.2
42	Hung Yen	My Hao	Pig Farm of Mr. Pham Khac Bo	Pig	1,200	1.60	0.30	5,475	14.2	1.8	13.5
43	Bac Giang	Yen Dung	Pig Farm of Mr. Nhiem (CP Vietnam)	Pig	1,000	2.30	0.30	5,475	14.2	1.8	13.5
44	Bac Giang	Viet Yen	Pig Farm of Mr. Chu Van Oanh	Pig	500	0.45	0.25	4,563	11.8	1.5	11.2
45	Lam Dong	Don Duong	Da Lat Dairy Farm No. 2 of Vinamilk	Cow	400	4.00	0.40	4,380	11.4	1.4	10.8
46	Thai Nguyen	Tan Cuong	Tran Thi Mai Pig Farm	Pig	1,200	0.82	0.22	4,015	10.4	1.3	9.9
47	Bac Giang	Viet Yen	Hung An Pig Farm	Pig	1,200	1.20	0.20	3,650	9.5	1.2	9.0
48	Son La	Moc Chau	Livestock Farm of Mrs. Nguyen Thi Chi	Cow	86	1.12	0.23	3,139	8.1	1.0	7.7
49	Thai Binh	Thai Thuy	Le Van Khoa Pig Farm	Pig	1,700	1.00	0.17	3,103	8.0	1.0	7.6
50	Gia Lai	Mang Yang	Gia Lai Livestock Joint Stock Company	Cow	7,000	180.00	0.00	0	0.0	0.0	0.0
51	Gia Lai	Chuprong	Tay Nguyen Dairy Products Joint Stock Company	Cow	5,000	75.00	0.00	0	0.0	0.0	0.0
52	Gia Lai	Dak Po	Nguyen Van Thanh Super-lean Pig Farm	Pig	1,200	2.40	0.00	0	0.0	0.0	0.0
53	Binh Dinh	Phu Cat	Nguyen Van Thi Pig Farm	Pig	1,700	4.50	0.00	0	0.0	0.0	0.0
54	Nghe An	Quy Hop	Pig Farm of Masan Nutri Co., Ltd.	Pig	2,000	3.60	0.00	0	0.0	0.0	0.0
55	Gia Lai	Pleiku City	Dairy Farm of Gia Lai Livestock JSC	Cow	2,900	37.70	0.00	0	0.0	0.0	0.0
56	Thanh	Nhu	Nhu Thanh Dairy Farm	Cow	2,000	16.00	0.00	0	0.0	0.0	0.0

	Hoa	Thanh									
57	Thanh Hoa	Yen Dinh	Dairy Farm of Thong Nhat Dairy One-Member Co., Ltd.	Cow	2,447	27.00	0.00	0	0.0	0.0	0.0
58	Dak Nong	Cu Jut	Nucleus Breeding Pig Center of Green Farm Asia Co.	Pig	35,000	45.00	0.00	0	0.0	0.0	0.0
59	Lam Dong	Don Duong	Dairy Farm of Da Lat Milk JSC	Cow	1,000	15.00	0.00	0	0.0	0.0	0.0
60	Nghe An	Nghia Dan	Dairy Farm of the TH True Milk (Cluster 1)	Cow	14,900	180.00	0.00	0	0.0	0.0	0.0
61	Nghe An	Nghia Dan	Dairy Farm of the TH True Milk (Cluster 2)	Cow	13,600	157.70	0.00	0	0.0	0.0	0.0
62	Nghe An	Nghia Dan	Dairy Farm of the TH True Milk (Cluster 3)	Cow	6,000	64.80	0.00	0	0.0	0.0	0.0
63	Thanh Hoa	Ngoc Lac	Cow Farm of the Anh Minh Giang Co., Ltd.	Cow	1,000	10.00	0.00	0	0.0	0.0	0.0
64	Bac Ninh	Thuan Thanh	Nguyen Van Hung Pig Farm	Pig	2,000	2.50	0.00	0	0.0	0.0	0.0
65	Thanh Hoa	Ba Thuoc	Ba Thuoc Livestock Breeding JSC	Cow	5,000	50.00	0.00	0	0.0	0.0	0.0
66	Phu Tho	Thanh Thuy	Nucleus Breeding Pig Farm of Tien Hai Co., Ltd.	Pig	2,031	1.52	0.00	0	0.0	0.0	0.0
67	Hanoi City	Ung Hoa	Pig Farm of Mr. Dao Van Quyet	Pig	2,600	3.12	0.00	0	0.0	0.0	0.0
	Total				**343,768**	**2,009.8**	**536.0**	**7,409,538**	**19,205.3**	**2,436**	**18,245.4**

Table 24: Electricity generation potential at the surveyed wood processing mills

(ranked by *Gross Power Output* and *Additional Biomass Feedstock Sourcing Area*)

No.	Province	District	Name of Wood Processing Mill	Wood resdiue generation (t/yr)	Wood residue available for power generation (t/yr	Gross power capacity output (MW)	Electricity export (use of wood residue only) (GWh/yr)	Electricity export (use of wood residue & additional biomass) (GWh/yr)	Additional biomass feedstock sourced (t/yr)	Feedstock sourcing area (km^2/GWh)
1	Bac Giang	Luc Nam	An Lam Co., Ltd.	3,532.0	0.0	3.0	0.00	17.87	30,757.7	0.698
2	Ha Nam	Duy Tien	Sam Lanh Wood Manufacturing and Processing Mill	986.0	0.0	3.0	0.00	17.87	30,814.2	0.752
3	Hanoi City	Gia Lam	Hai Nam Co., Ltd.	460.0	460.0	3.0	0.29	17.87	30,475.3	0.945
4	Dong Nai	Bien Hoa	Dai Phat Hoan Hao Private Enterprise	300.0	250.0	3.0	0.16	17.87	34,480.9	1.125
5	Dong Nai	Bien Hoa	Toan Gia Private Enterprise - Factories II	260.0	200.0	3.0	0.13	17.87	34,543.1	1.125
6	Dong Nai	Bien Hoa	Duc Long Private Enterprise	450.0	380.0	3.0	0.24	17.87	34,319.4	1.125
7	Dong Nai	Bien Hoa	Truong Nga Private Enterprise	460.0	400.0	3.0	0.26	17.87	34,294.6	1.125
8	Dong Nai	Bien Hoa	Hoang De Private Enterprise	750.0	670.0	3.0	0.43	17.87	33,959.1	1.125
9	Dong Nai	Bien Hoa	Thu Trinh Private Enterprise	300.0	240.0	3.0	0.15	17.87	34,514.0	1.131
10	Dong Nai	Bien Hoa	Huy Hoang Phat Trading Service PTE Wood Processing	470.0	430.0	3.0	0.27	17.87	34,277.8	1.131
11	Dong Nai	Bien Hoa	Nhu Y Ngoc Wood Private Enterprise	3,500.0	3,000.0	3.0	1.91	17.87	31,047.9	1.178
12	Dong Nai	Bien Hoa	Minh Nguyet (Moonlight) Co., LTD - Wood Processing	2,200.0	2,000.0	3.0	1.28	17.87	32,289.8	1.178
13	Dong Nai	Bien Hoa	Tan Phu Hoa Private Enterprise	400.0	300.0	3.0	0.19	17.87	34,401.1	1.178
14	Dong Nai	Bien Hoa	Cong Lap Wood Processing	250.0	190.0	3.0	0.12	17.87	34,537.8	1.178
15	Dong Nai	Bien Hoa	Dang Long Co., LTD Processing Export Wooden	3,500.0	3,000.0	3.0	1.91	17.87	31,047.9	1.178

			Product							
16	Dong Nai	Bien Hoa	Thien An Thinh Trading Service PTE Wood Processing	400.0	350.0	3.0	0.22	17.87	34,360.3	1.185
17	Dong Nai	Bien Hoa	Thai An Private Enterprise	250.0	220.0	3.0	0.14	17.87	34,521.9	1.185
18	Bac Giang	Yen The	Bao Lan One-Member Co., Ltd.	2,718.0	2,718.0	3.0	1.73	17.87	27,729.6	1.196
19	Binh Duong	Di An	Cong ty TNHH Che bien Lam san Binh An	1,000.0	900.0	3.0	0.57	17.87	30,733.9	1.319
20	Thai Nguyen	Thai Nguyen City	Viet Bac Plywood JSC	1,872.0	0.0	3.0	0.00	17.87	30,680.0	1.381
21	Binh Duong	Di An	Cong ty TNHH Do go Nguyen Thanh	550.0	480.0	3.0	0.31	17.87	31,208.8	1.383
22	Binh Duong	Di An	Cong ty TN MTV Phu Gia Loc	7,500.0	6,000.0	3.0	3.83	17.87	24,938.8	1.457
23	Dong Nai	Bien Hoa	Phu Thanh Phat Manufacturing and Export Co., Ltd.	1,000.0	800.0	3.0	0.51	17.87	34,257.9	1.463
24	Dong Nai	Bien Hoa	Vuong Thien Nhat One Member Co., Ltd	1,050.0	900.0	3.0	0.57	17.87	34,131.9	1.463
25	Phu Tho	Lam Thao	Glee Wood Processing Company	400.0	400.0	3.0	0.26	17.87	30,753.2	1.497
26	Binh Duong	Thuan An	Cong ty TNHH SX-KD-TM-DV Thien Phat	540.0	375.0	3.0	0.24	17.87	33,431.1	1.504
27	Binh Duong	Thuan An	Cong ty TNHH SX-TM-DV Hiep Sanh	506.0	333.0	3.0	0.21	17.87	33,393.6	1.560
28	Binh Duong	Thuan An	Cong ty TNHH SX-TM-DV Hung Loc Phat	350.0	300.0	3.0	0.19	17.87	33,505.2	1.579
29	Binh Duong	Tan Uyen	Cong ty TNHH Go Lien Phat	1,800.0	1,500.0	3.0	0.96	17.87	32,361.2	1.675
30	Binh Duong	Tan Uyen	Cong ty TNHH Do go Lap Dat	15,000.0	11,000.0	3.0	7.02	17.87	20,759.6	1.675
31	Binh Phuoc	Chon Thanh	MDF VRG DONGWHA Wood JSC	15,000.0	0.0	3.0	0.00	17.87	40,557.5	1.683
32	Gia Lai	Pleiku	Hoang Anh Gia Lai Wood Joint Stock Company	9,270.0	270.0	3.0	0.17	17.87	61,225.1	2.238
33	Gia Lai	Pleiku	Cong ty TNHH MTV Noi	3,000.0	1,560.0	3.0	1.00	17.87	59,254.2	2.310

			That SESAN							
34	Quang Ninh	Cam Pha	Minh Long Trading and Service JSC	124.8	15.6	3.0	0.01	17.87	30,940.2	2.396
35	Gia Lai	Pleiku	Hiep Loi Co., Ltd.	840.0	420.0	3.0	0.27	17.87	63,639.2	2.446
36	Gia Lai	Chu Prong	Tam Phuc Gia Lai Trading Co., Ltd.	9,900.0	8,100.0	3.0	5.17	17.87	43,351.7	2.461
37	Gia Lai	Pleiku	Cong ty TNHH 30/4 Gia Lai	2,159.0	952.0	3.0	0.61	17.87	63,151.9	2.654
38	Dak Nong	Dak Song	MDF Veneer Manufacturing Plant of MDF Bison JSC	630.0	630.0	3.0	0.40	17.87	44,580.0	4.404
39	Binh Dinh	Quy Nhon	PISICO Forestry Export Processing Enterprise	6,030.6	0.0	3.0	0.00	17.87	44,768.1	5.735
40	Quang Nam	Hiep Duc	Quang Nam MDF Manufacturing Mill	1,920.0	788.0	3.0	0.50	17.87	45,212.2	9.507
	Total			**101,628.4**	**50,531.6**	**120.0**	**32.2**	**714.8**	**1,459,208**	

Annex 3: Biomass Atlas Components

The Vietnam Biomass Atlas consists of various maps and datasets. The links for access to these maps and datasets are provided in Tables 25 to 35.

3.1 Survey Data

Table 25: Links for access to the results of survey data

Atlas data	Can be accessed at:
GIS & other datasets:	<URL>
Grid power station data	file: survey\grid_station\Gridstation_3405.shp file content description: survey\metadata\grid_station.txt
Road network density	Data aggregated to districts: file: feedstock\districts\district.shp file content description: feedstock\metadata\districts.txt
District level aggregates of the field survey data	file: feedstock\districts\district.shp file content description: feedstock\metadata\districts.txt
Other datasets:	
Field survey interview data	files: survey\field\ file content description: survey\metadata\field.txt

3.2 Land Use Classification

Table 26: Links for access to the results of land use classification

Atlas data	Can be accessed at:
Map	<URL>
GIS & other datasets:	<URL>
Land use classification	file: vietnam_crop.ers file content description: metadata\land_use.txt

3.3 Biomass Feedstock Data

Table 27: Links for accessing the maps and datasets for the theoretical potential of crop harvesting residues

Atlas data	Can be accessed at:
Map	<URL>
GIS datasets:	<URL>
Theoretical feedstock potential (all crops)	file: feedstock\theoretical_feedstock_per_pixel_all_crops.tif QGIS style: feedstock\styles\theoretical_fs_all_crops.qml file content description: feedstock\metadata\feedstock.txt
Theoretical feedstock potential (single crops)	file: feedstock\theoretical_feedstock_per_pixel.tif QGIS style: feedstock\styles\theoretical_feedstock_blue-red.qml file content description: feedstock\metadata\feedstock.txt
District level crop residue yields (all crops)	file: feedstock\theoretical_fs_per_ha_and_district.tif QGIS style: feedstock\styles\theoretical_feedstock_blue-red.qml file content description: feedstock\metadata\feedstock.txt
Other datasets:	
Crop yield data from the survey aggregated to the district level (min, mean, max yield)	file: feedstock\crop_yield.xlsx

Table 28: Links for access to the maps and datasets of the technical potential of crop harvesting residues

Atlas data	Can be accessed at:
Map, based on existing use of biomass residues only	<URL>
Map, based on both existing use and farmers' willingness to sell	<URL> <to be included or not?>
GIS datasets:	<URL>
Technical feedstock potential, based on existing use only	file: feedstock\technical_feedstock_per_pixel_residue.tif file content description: feedstock\metadata\feedstock.txt
Technical feedstock potential, based on existing use and farmers' willingness to sell	file: feedstock\technical_feedstock_per_pixel_willing.tif file content description: feedstock\metadata\feedstock.txt
District level data on existing use and willingness to sell biomass residues	file: feedstock\districts\district.shp file content description: feedstock\metadata\districts.txt
Other datasets:	
Feedstock summary by country and by district, including sampled district confidence intervals for yearly feedstock amounts	file: feedstock\feedstock.xlsx

3.4 Power Plant Analysis Data

Table 29: Links for access to the results of site suitability analysis of sugar mills

Atlas data	Can be accessed at:
Map	<URL> <Will this be included?>
GIS & other datasets:	<URL>
Sugar mill analysis	file: industrial\sugarmills\sugarmills.shp file content description: industrial\metadata\sugarmills.txt
Other datasets:	
Mill analysis results without the map data	file: output\sugarmills.xlsx
Cogeneration model the analysis results are based on, feedstock to conversion technology suitability mapping	file: data\technology\Tech Suitability Matrix_VN Biomass Mapping_2017-10-28_Final.xlsx
Survey results	file: data\industrial_survey\Industrial survey in Vietnam_18_06_15.xlsx

Table 30: Links for access to the results of site suitability analysis of rice mills

Atlas data	Can be accessed at:
Map	<URL> <Will this be included?>
GIS & other datasets:	<URL>
Rice mill analysis	file: industrial\ricemills\ricemills.shp file content description: industrial\metadata\ricemills.txt
Other datasets:	
Mill analysis results without the map data	file: output\ricemills.xlsx
Cogeneration model the analysis results are based on, feedstock to conversion technology suitability mapping	file: data\technology\Tech Suitability Matrix_VN Biomass Mapping_2017-10-28_Final.xlsx
Survey results	file: data\industrial_survey\Industrial survey in Vietnam_18_06_15.xlsx

Table 31: Links for access to the results of site suitability analysis of MSW landfills

Atlas data	Can be accessed at:
Map	<URL> <Will this be included?>
GIS & other datasets:	<URL>
MSW landfill analysis	file: industrial\MSW\MSW.shp file content description: industrial\metadata\MSW.txt
Other datasets:	
Survey results	file: data\industrial_survey\Industrial survey in Vietnam_18_06_15.xlsx

Table 32: Links for access to the results of site suitability analysis of livestock farms

Atlas data	Can be accessed at:
Map	<URL> <Will this be included?>
GIS & other datasets:	<URL>
Livestock analysis	file: industrial\livestock\livestock.shp file content description: industrial\metadata\livestock.txt
Other datasets:	
Survey results	file: data\industrial_survey\Industrial survey in Vietnam_18_06_15.xlsx

Table 33: Links for access to the results of site suitability analysis of wood processing mills

Atlas data	Can be accessed at:
Map	<URL> <Will this be included?>
GIS & other datasets:	<URL>
Wood processing analysis	file: industrial\wood_processing\wood_processing.shp file content description: industrial\metadata\wood_processing.txt
Other datasets:	
Survey results	file: data\industrial_survey\Industrial survey in Vietnam_18_06_15.xlsx

3.5 Greenfield site suitability analysis data

Table 34: Links for access to the results of site suitability analysis

Atlas data	Can be accessed at:
Map	<URL> <Which combinations will be included?>
GIS & other datasets:	<URL>
Site suitability indicator	files: site_suitability\heatmap_combined_MIXED.tif site_suitability\heatmap_combined_SINGLE.tif site_suitability\heatmap_gs_distance.tif site_suitability\heatmap_r_mixed.tif site_suitability\heatmap_r_single.tif site_suitability\heatmap_rn_density.tif file content description: site_suitability\metadata\site_suitability.txt
Grid power station data	file: data\grid_station\Gridstation_3405.shp
Transport network density	file: data\roads\transport_network_3405.shp
Other datasets:	
Energy conversion model the analysis results are based on	file: data\technology\Tech Suitability Matrix_VN Biomass Mapping_2017-10-28_Final.xlsx

3.6 Biomass Atlas training data

Table 35: Links for access to the Biomass Atlas training data

Atlas data	Can be accessed at:
GIS & other datasets:	<URL>
Training dataset	files: training\
Dataset usage	Annex 4: Instructions to the Vietnam Biomass Atlas Usage
Dataset maintenance	Annex 5: Instructions to the Vietnam Biomass Atlas Maintenance

Annex 4: Instructions to the Vietnam Biomass Atlas Usage

Set-up

For these instructions you need two things, the QGIS software, and the training dataset:

Table 36: Requirements for training on Biomass Atlas Usage

Requirement	Can be accessed at
QGIS	https://www.qgis.org
Training dataset	Included in the Biomass Atlas data package available at http://esmap.org/re_mapping_vietnam

After downloading the training dataset zip-file, unzip it and make a note of the folder where you unzipped it. This is the folder you will find the exercise data referred to below.

Task 1: Power Plant Investment Feasibility for a Sugar Mill

Your task is to evaluate the feasibility of switching a sugar mill's power plant into year-round operation using a mixed feedstock from the current status of operating it only during the milling season. For this evaluation, you need to figure out from how far from the sugar mill you would need to source the additional feedstock for the off-season operation of the power plant.

Let's use the An Khe Sugar Mill as an example.

To answer this question, you need to:

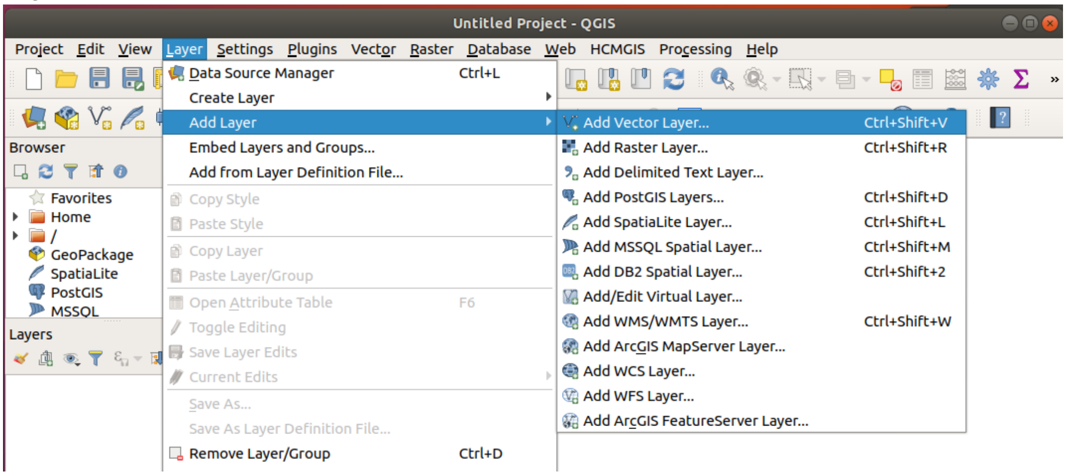
Subtask 1.1: Find out the steam turbine size the mill can have to run it on bagasse for the milling season plus two months

Throughout this workshop manual, steps needed to take are documented in the tables like the one below, please follow the instructions in the tables step-by-step, and keep coming back to this manual for the instructions.

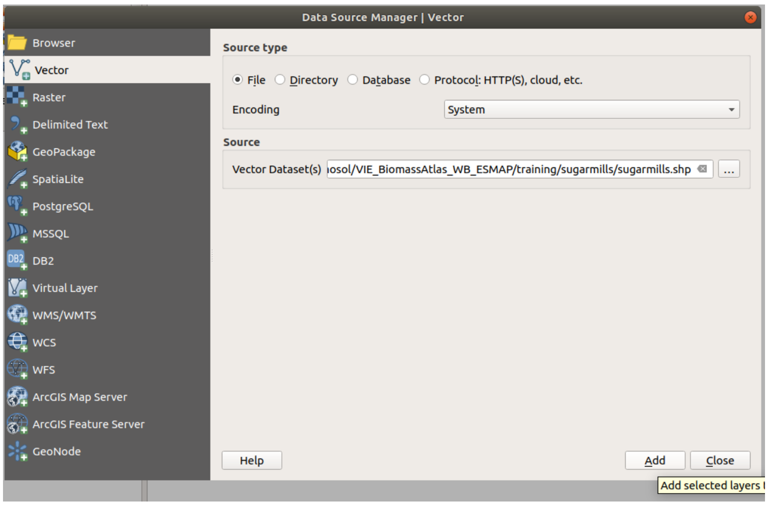
Files needed	power_plant_model.xlsx
In Excel/ OpenOffice	1) With Excel, open power_plant_model.xlsx. It is located in the folder where unzipped the workshop.zip file you downloaded above. The file is within the workshop folder. 2) Go to the "sugarmills" sheet. Find the yearly bagasse production & bagasse-to-sugarcane ratio for the An Khe Sugar Mill. 2) Enter that values in the red cell in the **"MW Cogen-Sugar" sheet**: **Unit** **Value** **Bagasse** tonne/year % 3) Take a note of the value at the yellow cell of the sheet Rated gross power capacity output of cogen system MW It will tell you the "size" of the power plant you use for finding out the sourcing distance for the additional feedstock needed to extend the operation of the power plant year round.

Subtask 1.2: Now you need to find the An Khe Sugar Mill from the Atlas maps. You start by putting the sugar mills on the map in QGIS. Open up QGIS, and then:

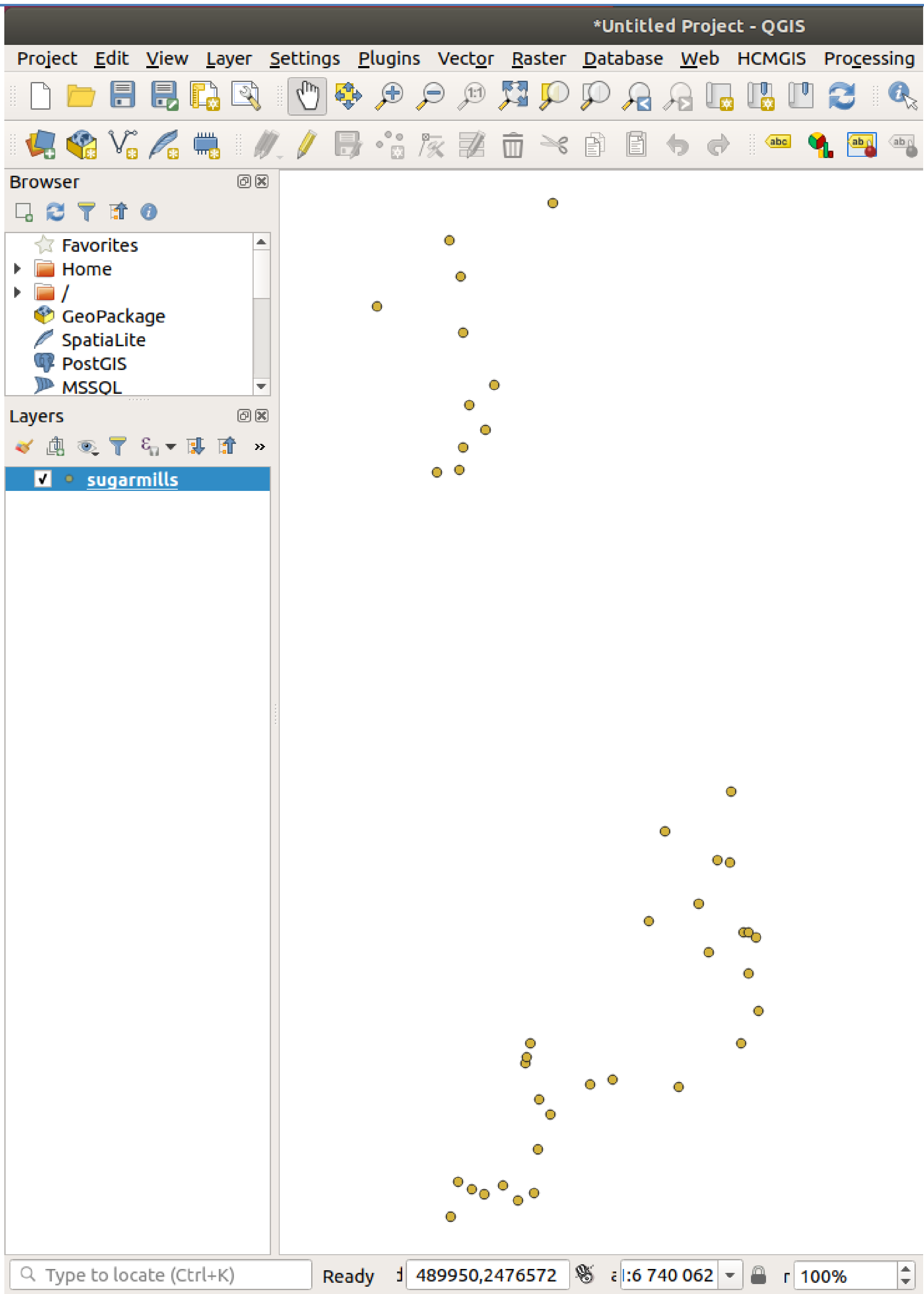
<table>
<tr><td>Files needed</td><td>\industrial\sugarmills\sugarmills.shp
feedstock\districts\districts_3405.shp</td></tr>
<tr><td>In QGIS</td><td>1) Add the sugarmills as a new vector layer to QGIS
Note: As the screenshots were taken on Linux & QGIS 3.2, they will look different to what you might see on Windows or with a different version of QGIS.



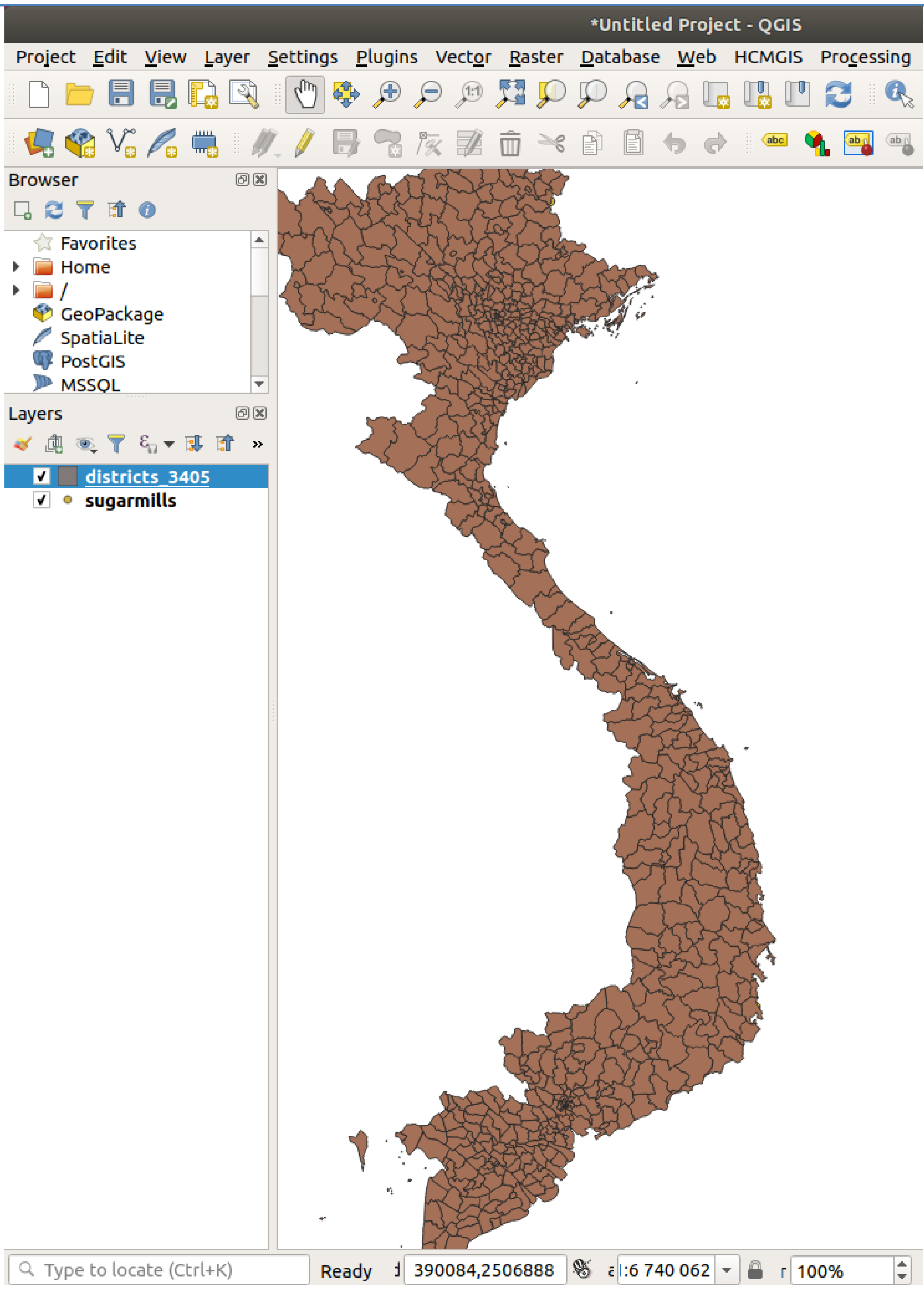
=>



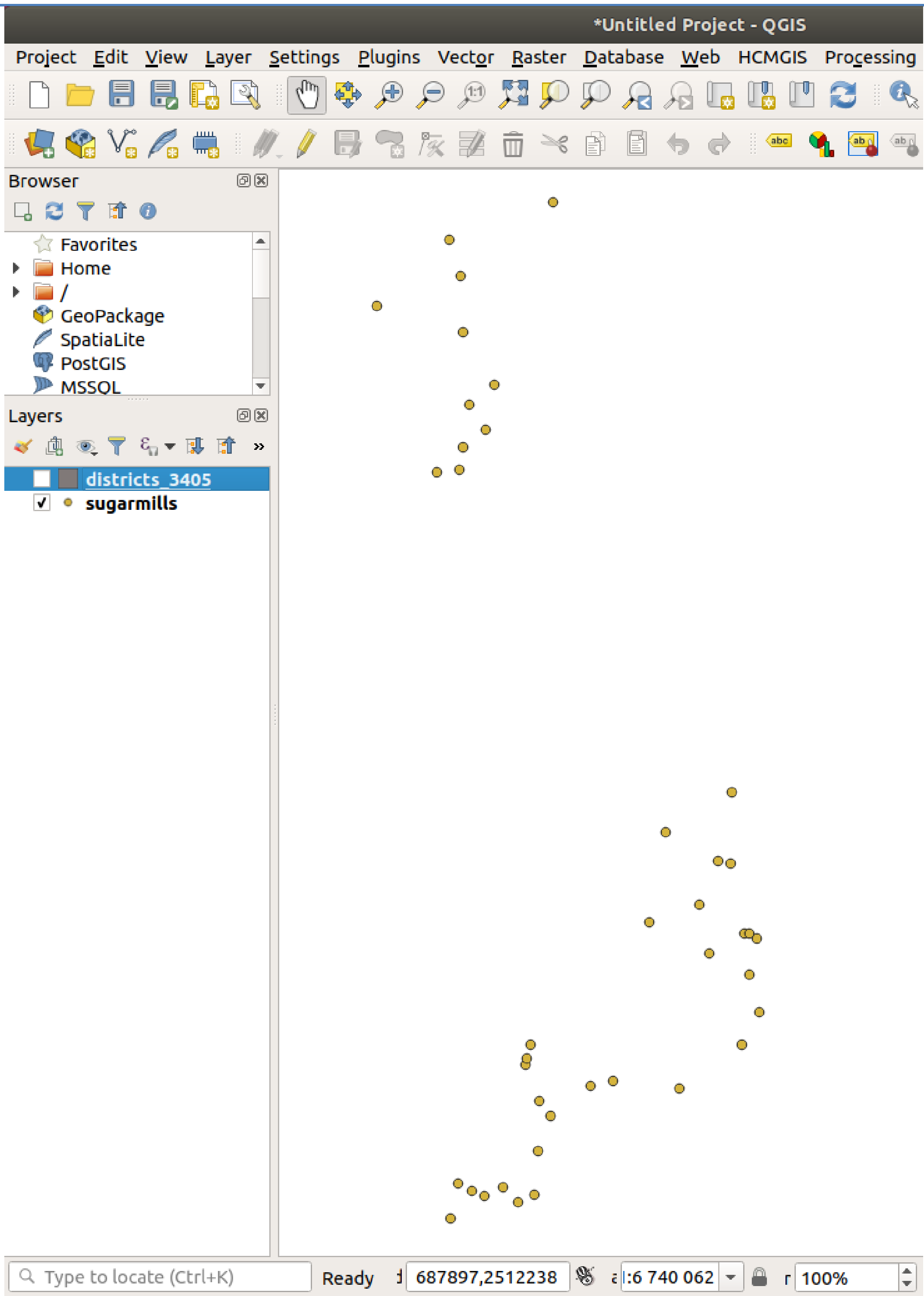
=></td></tr>
</table>



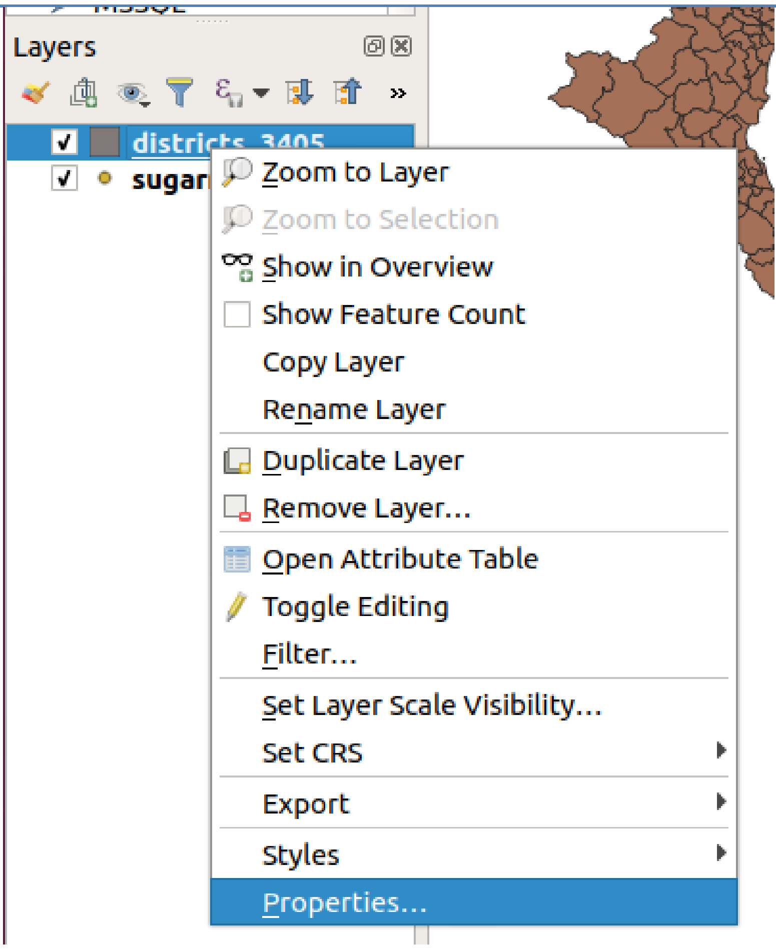
2) To add some context to the map, add another new vector layer to QGIS. Repeat the steps above, and select districts_3405.shp from the folder where you unzipped the workshop data.



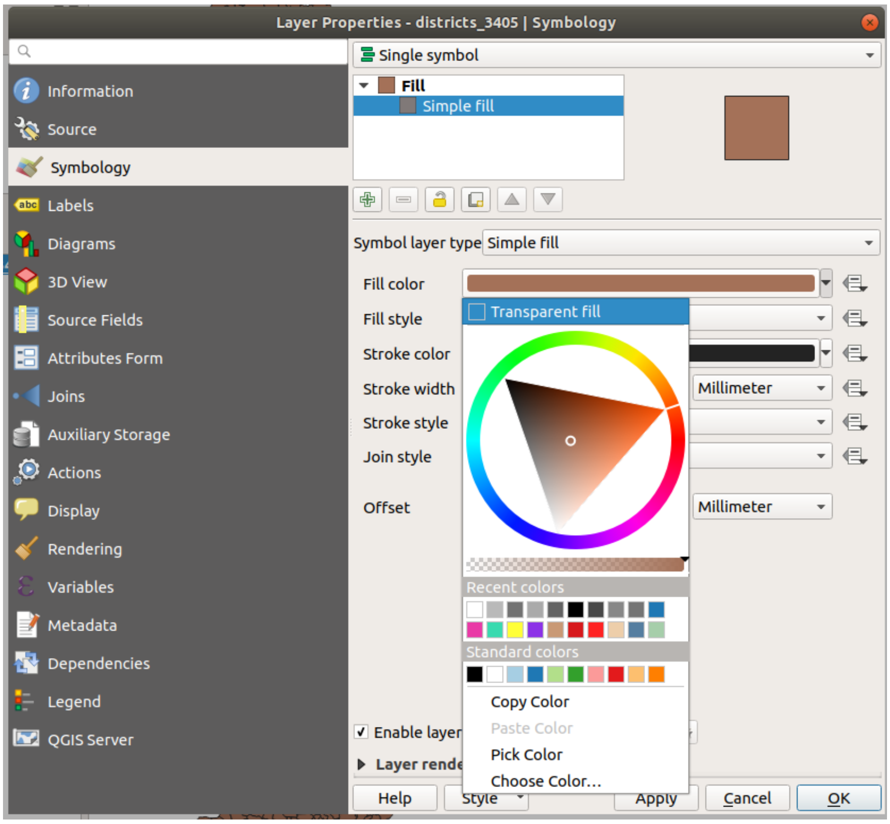
The problem now is that the sugar mills disappeared! (Note: the colour the district polygons have, will be random)
You can make the districts disappear too, by unchecking the checkbox in front of them in the "Layers Panel" list:



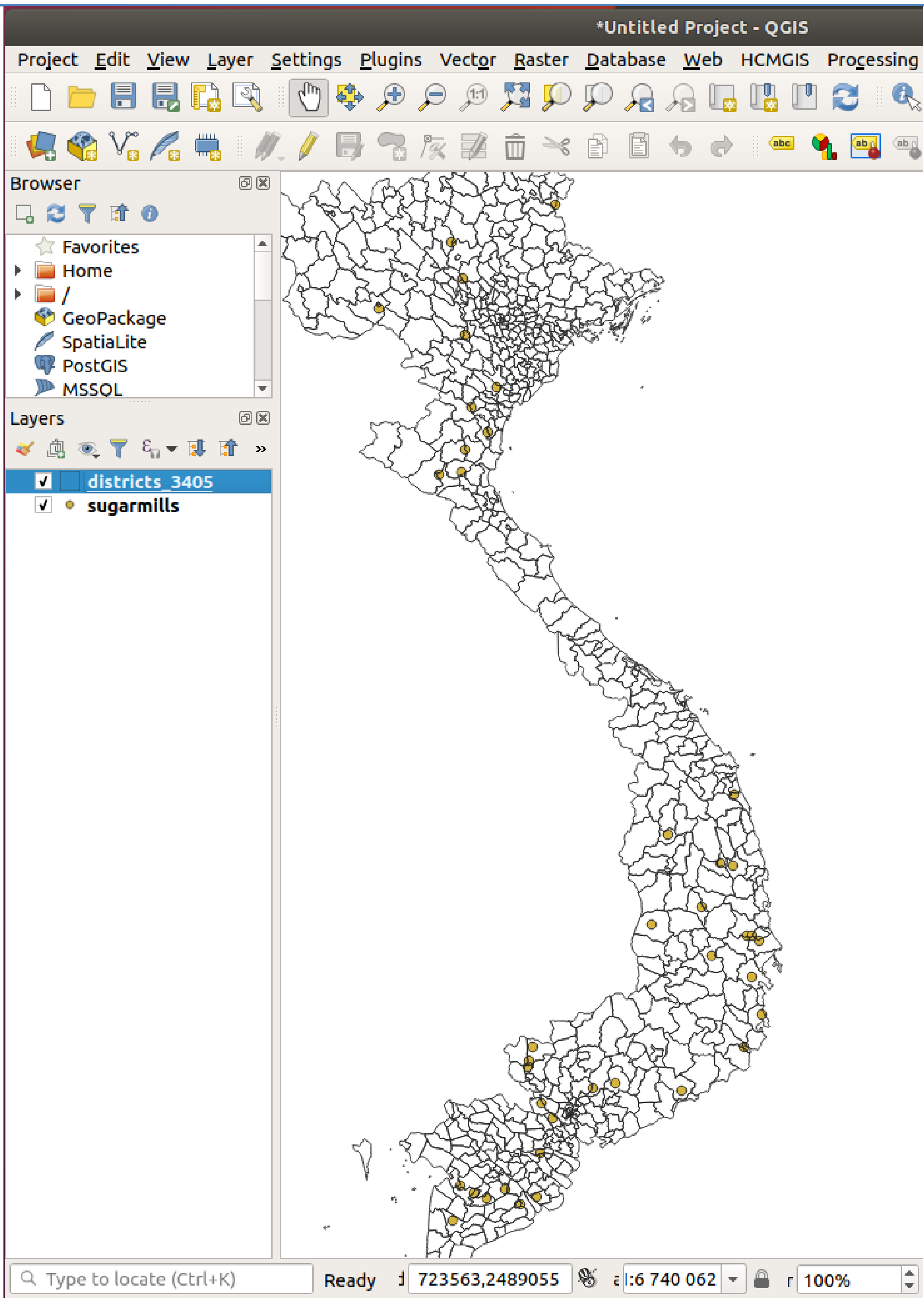
3) But let's make the district polygons transparent, so that we can see both the location of the sugar mills and the district borders on the map. Right-click on the districts layer in the "Layer Panel", and choose Properties (alternatively, you can just double click on the layer name)



=>



=> Click OK at the bottom right corner of the dialog

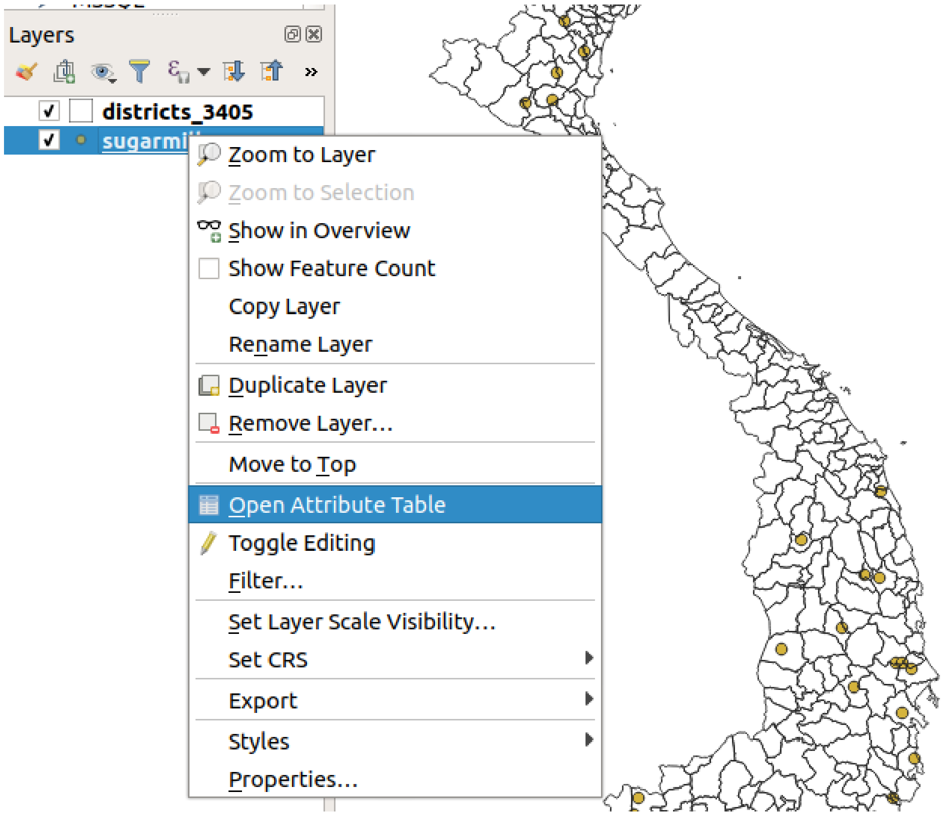


*Untitled Project - QGIS
Project
Edit
View
Layer
Settings
Plugins
Vector
Raster
Database
Web
HCMGIS
Processing
Browser
Favorites
Home
/
GeoPackage
SpatiaLite
PostGIS
MSSQL
Layers
districts_3405
sugarmills
Type to locate (Ctrl+K)
Ready
723563,2489055
1:6 740 062
100%

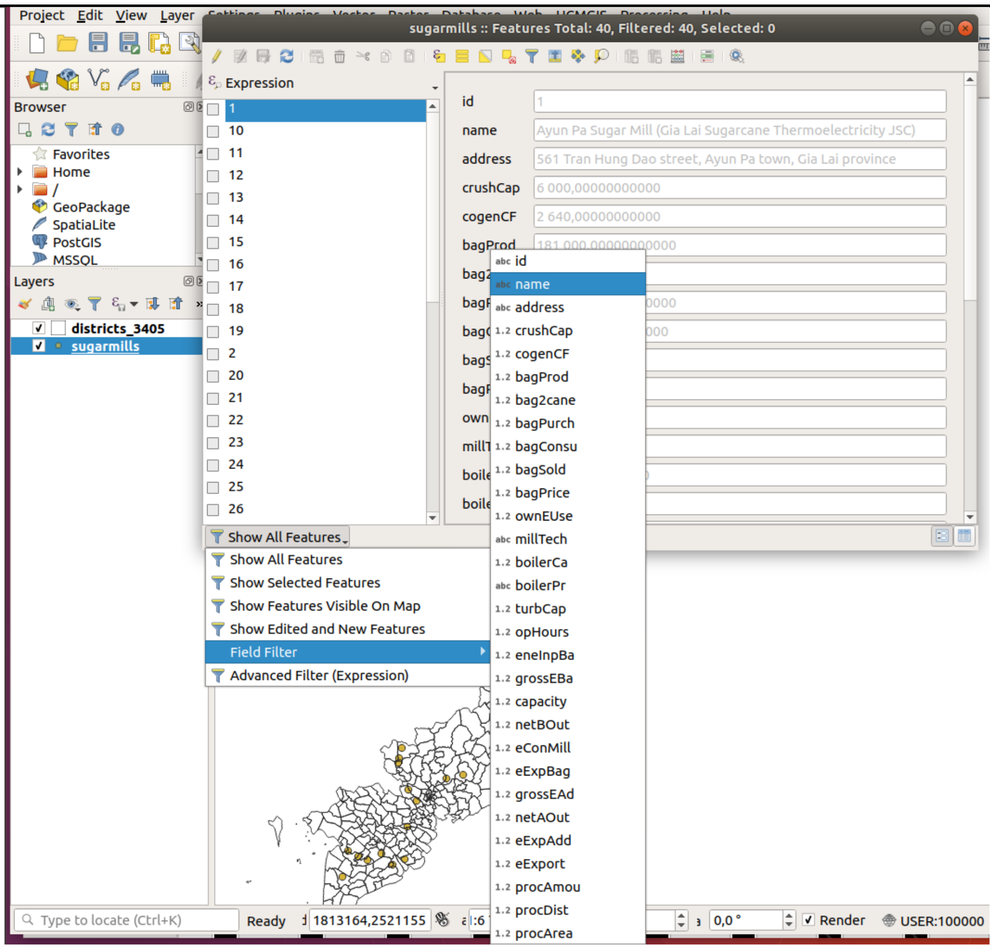
Subtask 1.3: Find the An Khe Sugar Mill site in QGIS

<table>
<tr>
<td>In QGIS</td>
<td>

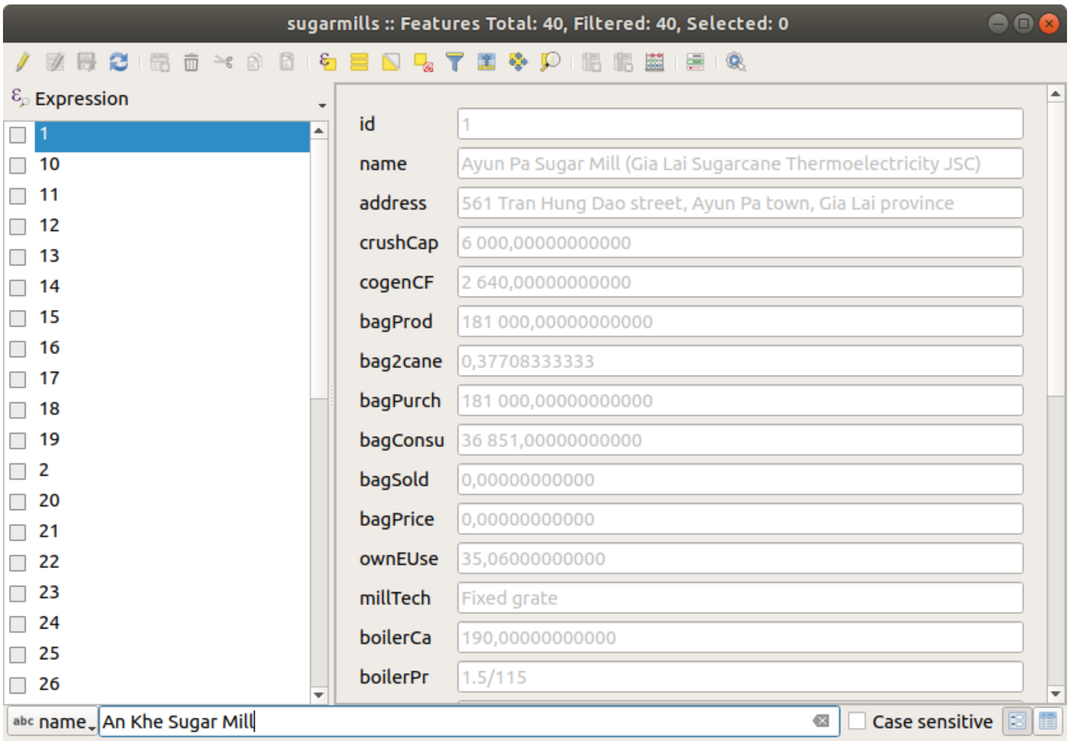
1) Open up the attribute table for the sugarmills layer. Right click on the layer name in the Layer Panel:



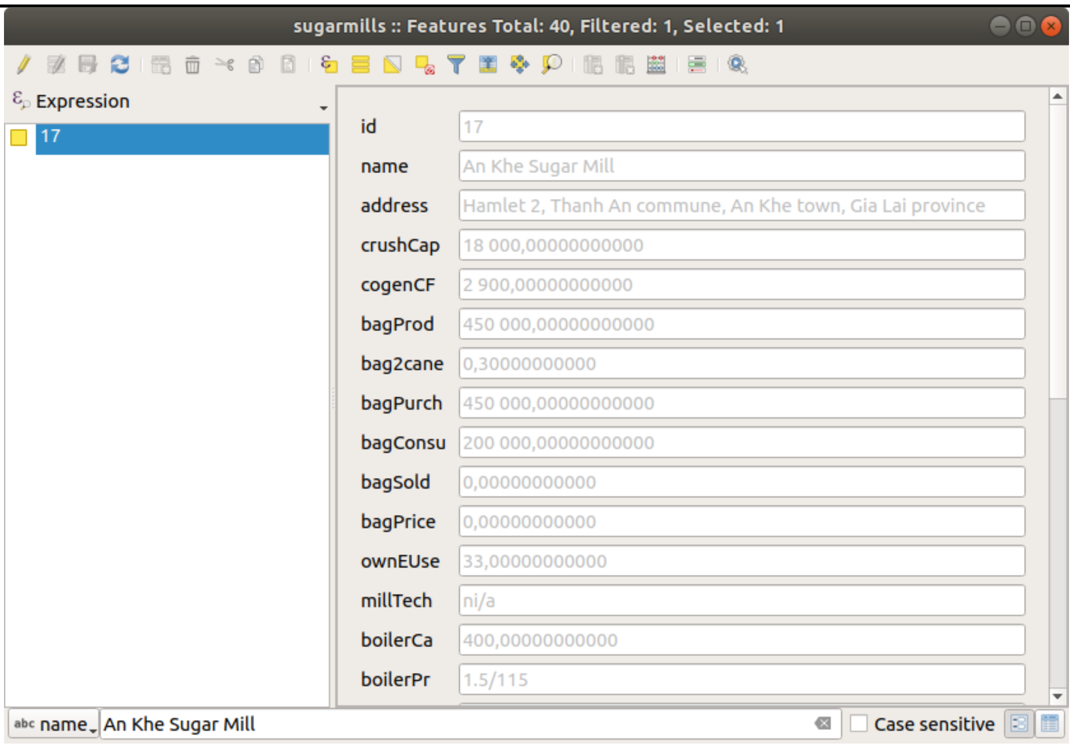
=>
</td>
</tr>
</table>



=>



=> Press Enter and select the sugar mill (tick the box) & press zoom map to selected rows tool.

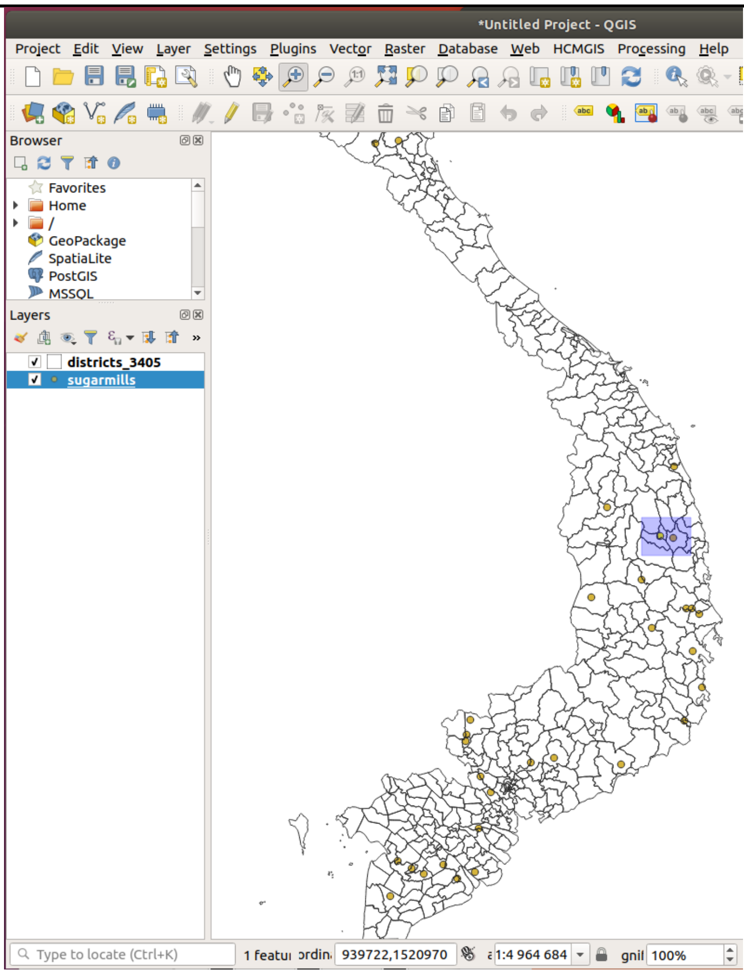


(zoom map to selected row)

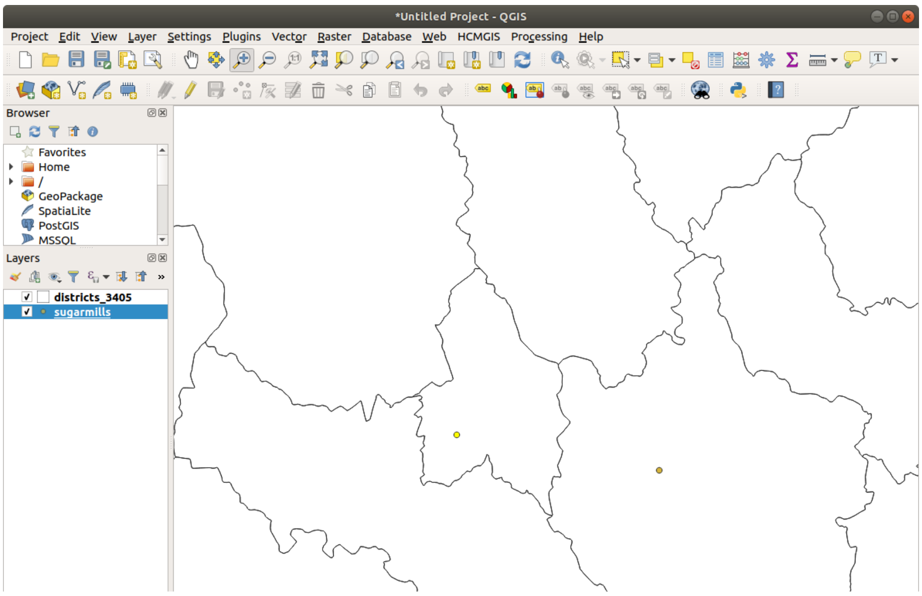
You can close the Attribute table - sugarmills window now.

2) Zoom the map closer to the An Khe Sugar Mill site

=>


*Untitled Project - QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web HCMGIS Processing Help
Browser
Favorites
Home
/
GeoPackage
SpatiaLite
PostGIS
MSSQL
Layers
districts_3405
sugarmills
Type to locate (Ctrl+K)
939722,1520970
1:4 964 684
100%

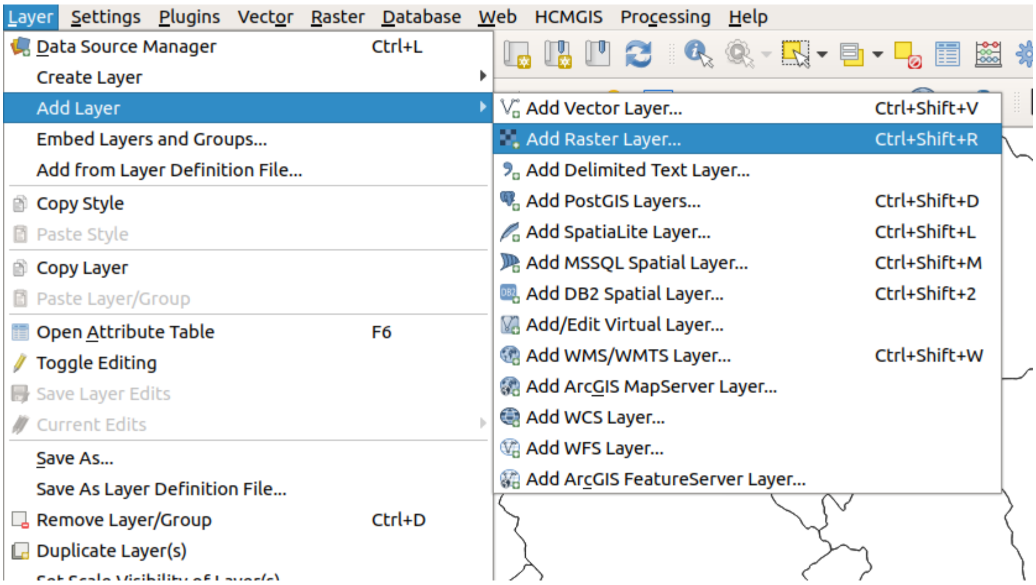
=>


*Untitled Project - QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web HCMGIS Processing Help
Browser
Favorites
Home
/
GeoPackage
SpatiaLite
PostGIS
MSSQL
Layers
districts_3405
sugarmills

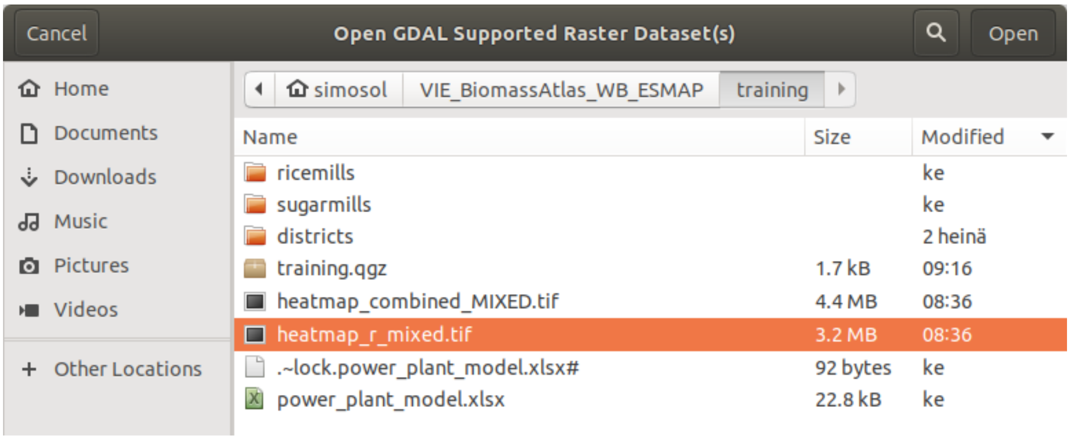
Subtask 1.4: Find the sourcing distance for the additional feedstock needed for the An Khe Sugar Mill site

<table>
<tr><td>Files needed</td><td>heatmap_r_mixed.tif</td></tr>
<tr><td>In QGIS</td><td>

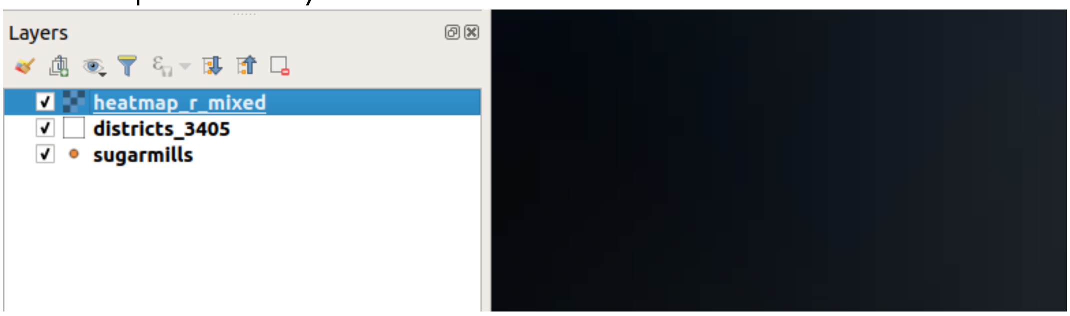
1) Add the heatmap_r_mixed.tif raster layer to QGIS



=>



=> Your map will most likely turn to black

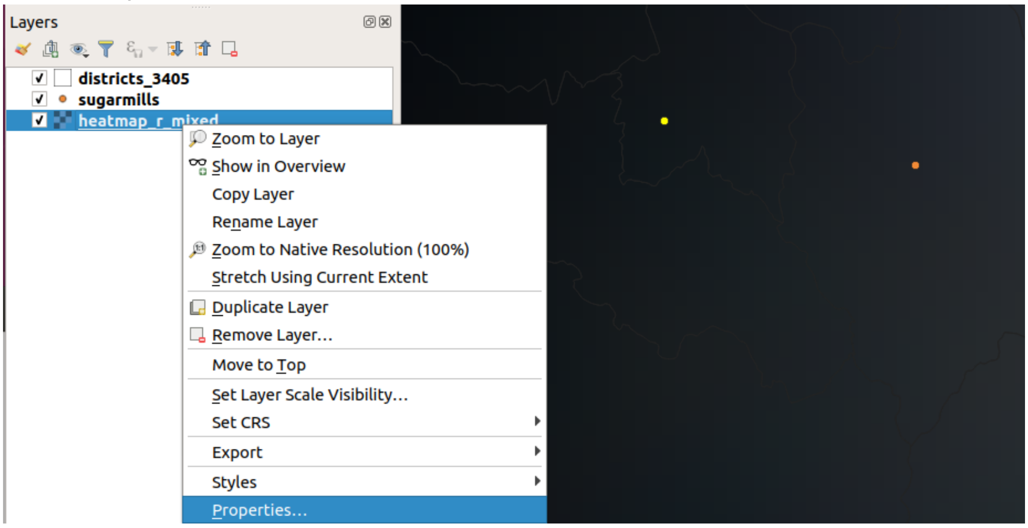


2) Move the heatmap_r_mixed layer to the bottom of the Layer Panel list by pressing & holding left mouse button and dragging heatmap_r_mixed layer to bottom

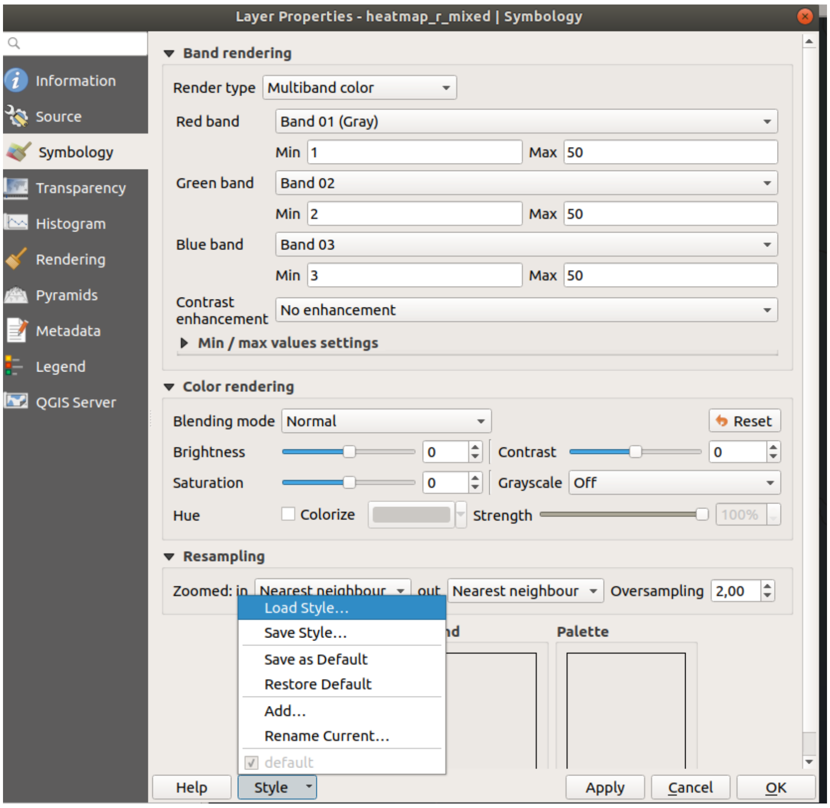
</td></tr>
</table>

=> You should now see the yellow dot for the An Khe sugar mill site:

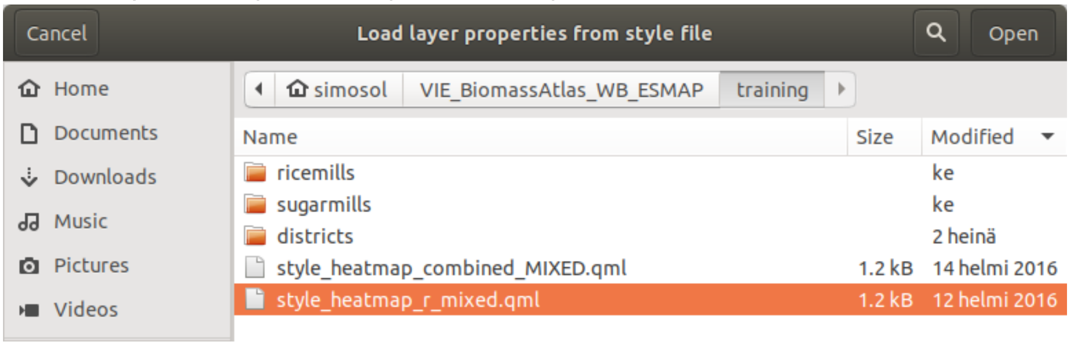
3) Let's make the heatmap_r_mixed raster look a bit nicer. Right-click the heatmap_r_mixed, choose Properties



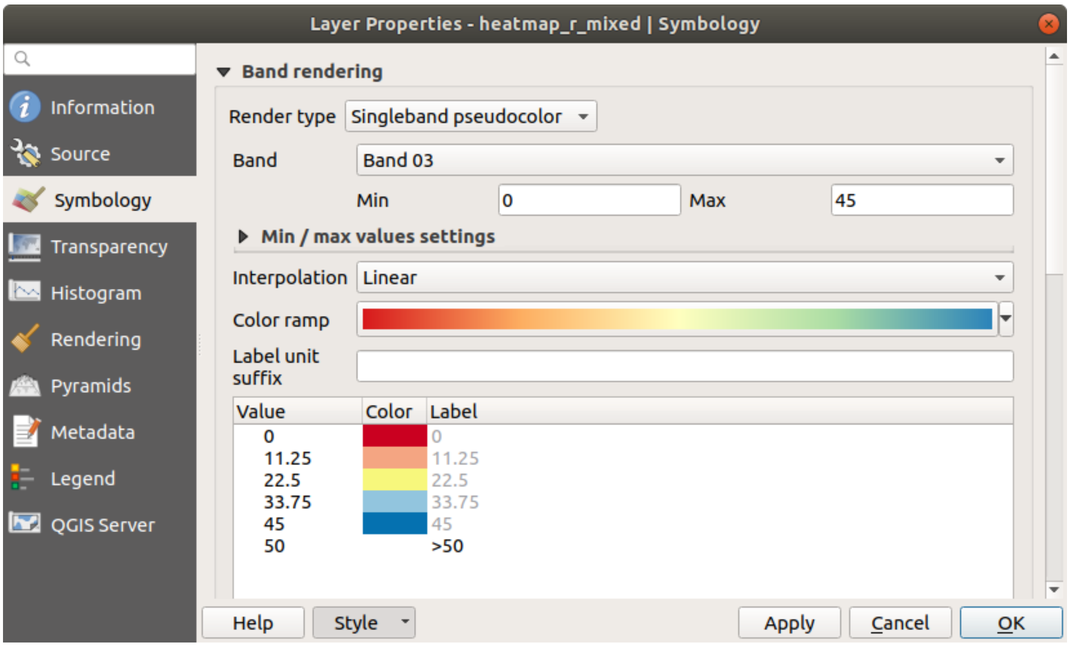
=>



=> Select style_heatmap_r_mixed.qml and click Open

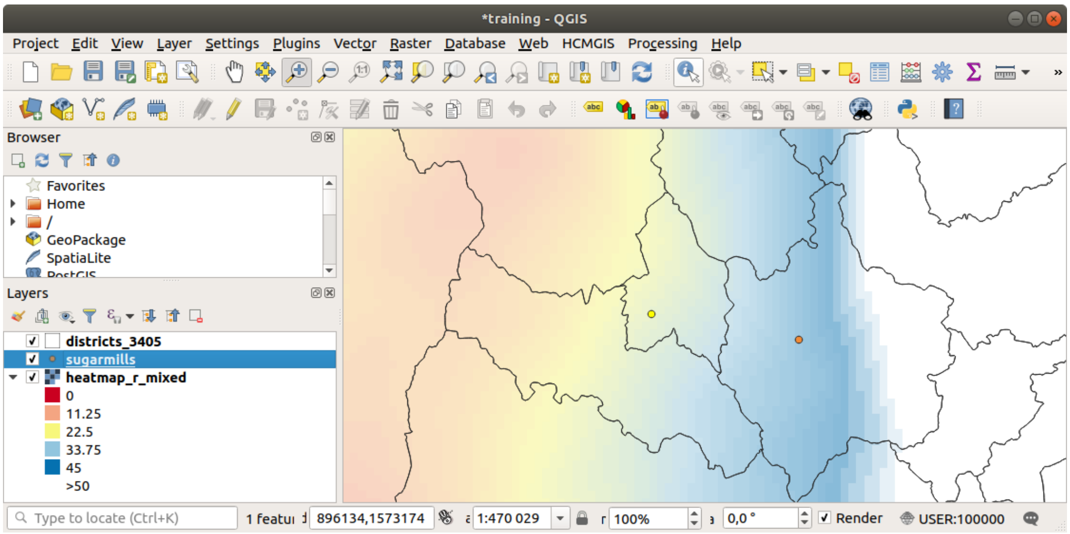


=> Click OK to close the Layer Properties dialogue

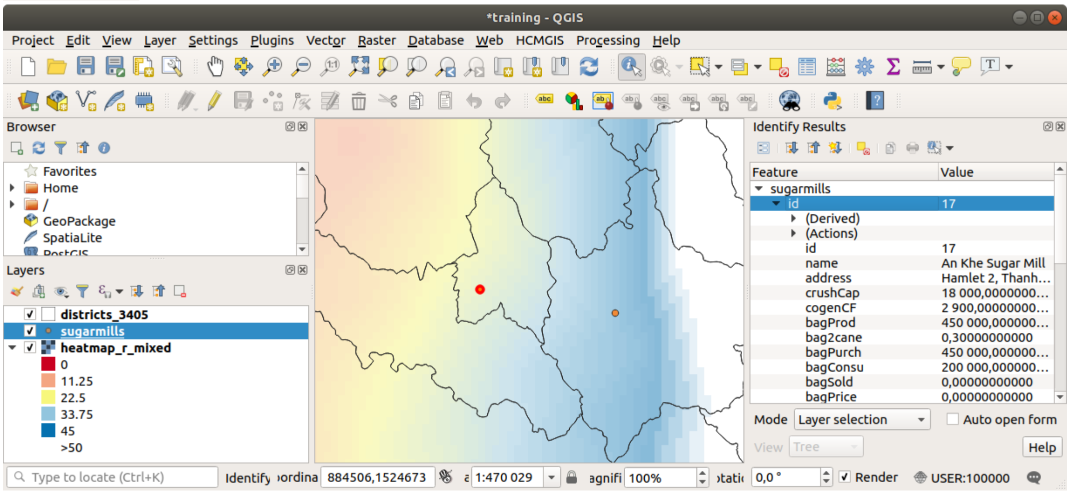


4) Find the exact sourcing distance value for the An Khe sugar mill site

First make sure you're still looking at the right sugar mill

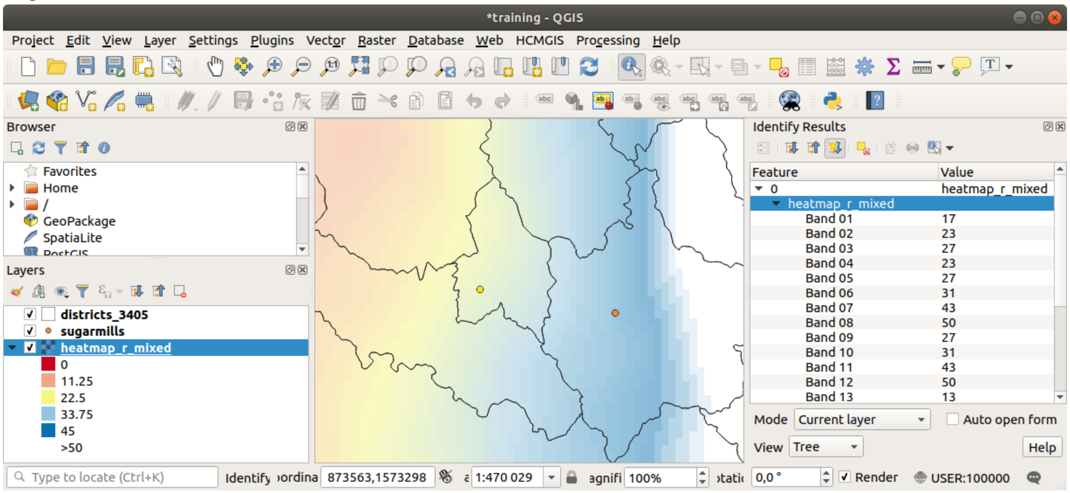


=> Click on the yellow dot on the map with info tool (which then turns the dot red)



If you need to, you can pan and zoom the map with these tools:

=> Now change the active layer to the heatmap_r_mixed layer, and again click on the An Khe sugar mill site dot.



=> In the Identify Results panel you now have the sourcing distances for different types and size categories of power plants given as the **sourcing area radius in km**. The radius is the direct "as crow flies" distance, not the road transport distance.

The band number interpretations are:

Band	Power plant
	Horizontal grate combustion steam boiler + steam turbine (GC)
1	3 MW
2	8 MW
3	15 MW

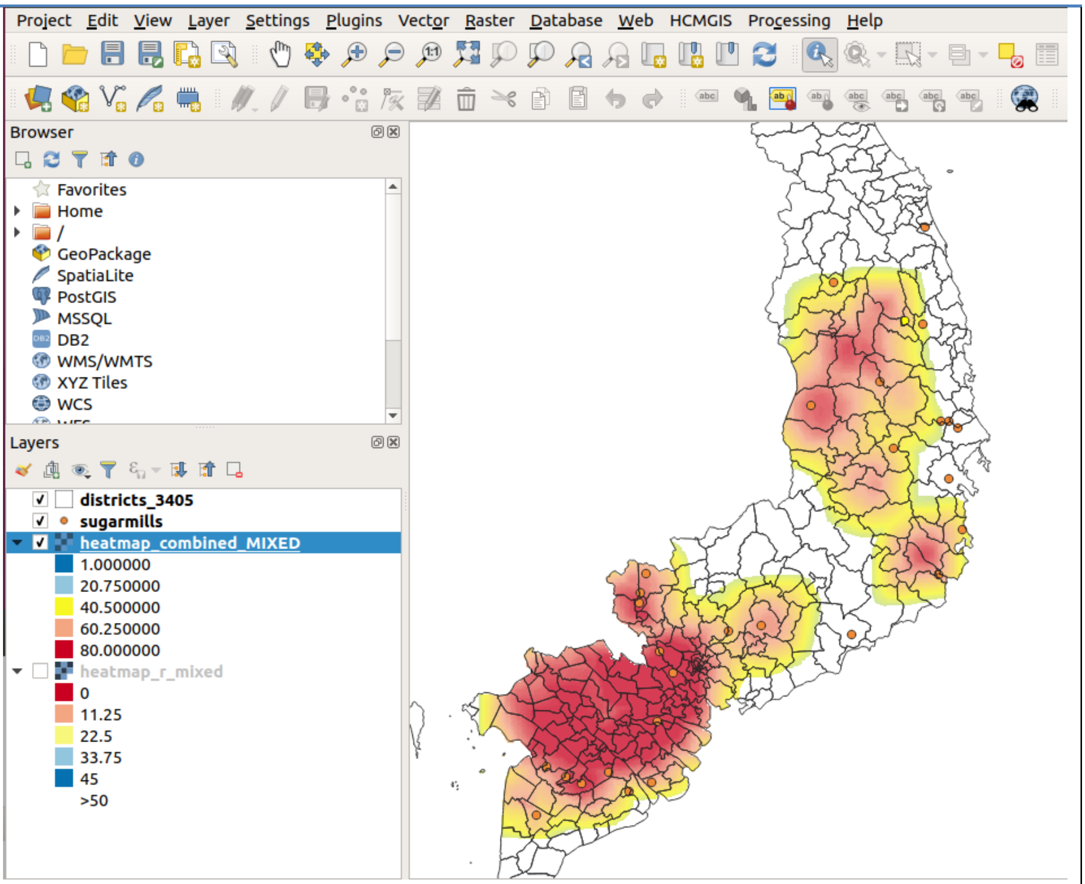
		Bubbling fluidized bed combustion steam boiler + steam turbine
	4	8 MW
	5	15 MW
	6	25 MW
	7	50 MW
	8	100 MW
		Circulating fluidized bed combustion steam boiler + steam turbine
	9	15 MW
	10	25 MW
	11	50 MW
	12	100 MW
		Gasifier + syngas engine/turbine
	13	0.5 MW
	14	1.5 MW
		Anaerobic digester + biogas engine/turbine
	15	0.5 MW
	16	1.5 MW
	17	3 MW
	18	8 MW
		Pick the values closest to the capacity you defined at the beginning with the Excel sheet (the yellow cell on the sheet). Extrapolate or interpolate the sourcing distance value for the capacity you got from Excel. This number will tell you from how far from the sugar mill you'd need to purchase all the available field harvest residue to run the power plant all year. "All available" is here defined to mean harvest residue currently being burned on the fields by the farmers that are willing to participate in a commercial supply chain for power generation.

Task 2: Identifying and Evaluating a Greenfield Investment Opportunity

Your task is to find a potential site for a power plant that uses harvest residues collected from fields, and evaluate how much harvest residue, and of what kind is available within a 15 km radius from that site.
To answer the question, you need to

<u>Subtask 2.1: Open the site index raster that is part of the Atlas, and decide on the site you want to analyse</u>

Files needed	heatmap_combined_MIXED.tif
In QGIS	1) Open the heatmap_combined_MIXED.tif raster in QGIS the same way you opened heatmap_r_mixed.tif in the previous exercise, see step 4 above. Apply the style style_heatmap_combined_MIXED.qml on the layer, again see step 4 for instructions The end result should look like this:

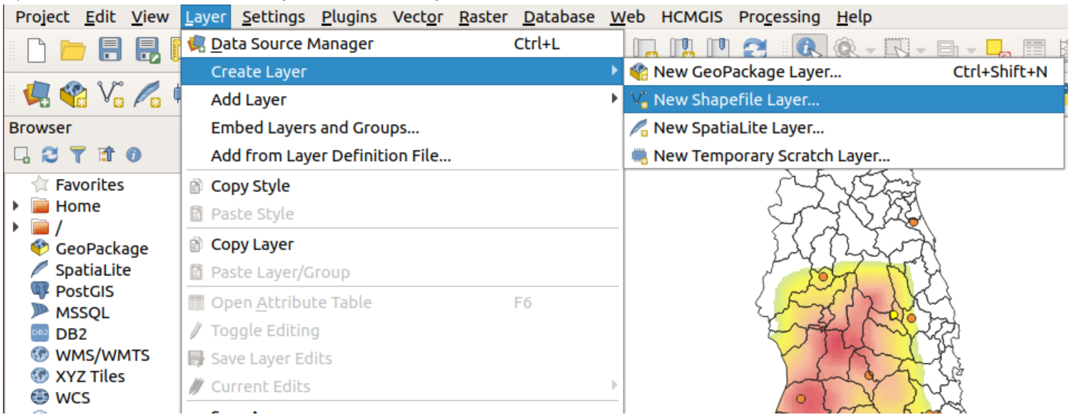


Locate a place that has high site index values, indicated by red colour, and preferably does not have sugar mills right next to it (to avoid competition for harvest residues).

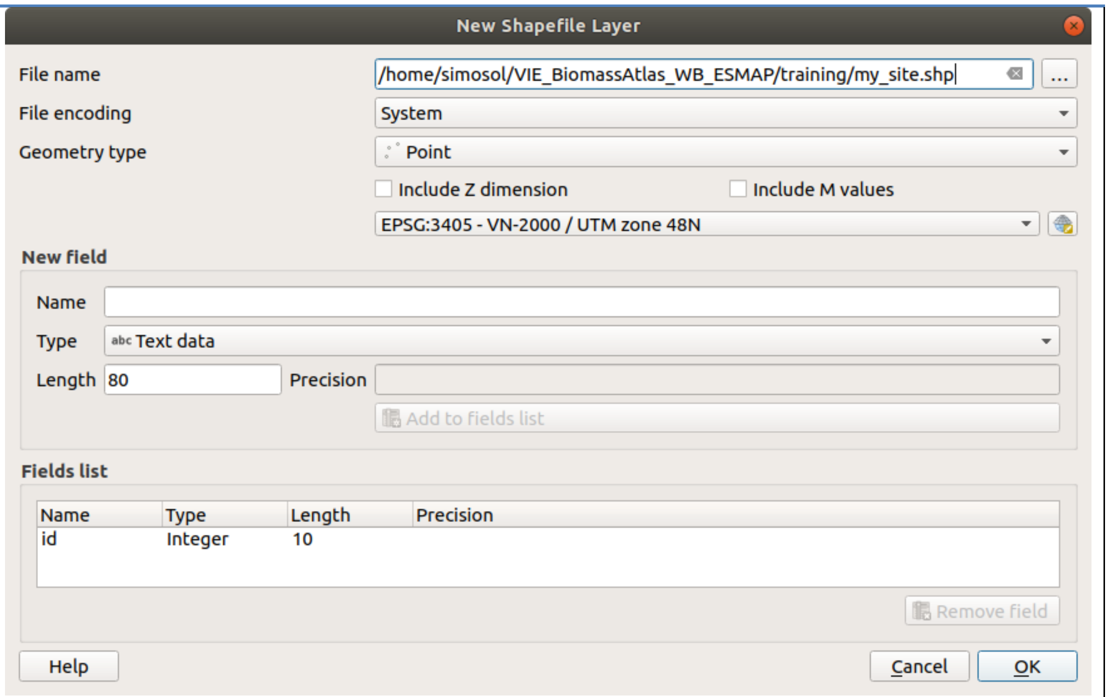
Subtask 2.2: Next we mark that location with a point on the map and create the 15 km radius sourcing area around it.

In QGIS

1) Create a new vector layer on the map

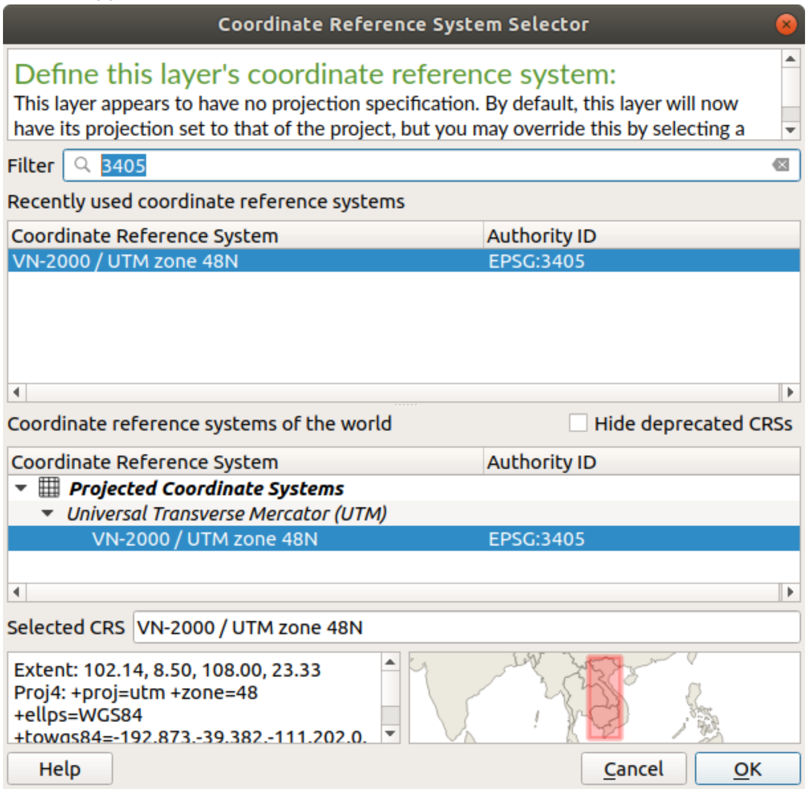


=>



=> If right coordinate system (In our case EPSG:3405) cannot be found from the drop menu in Geometry type section, then look for it from the icon on right side of the menu,

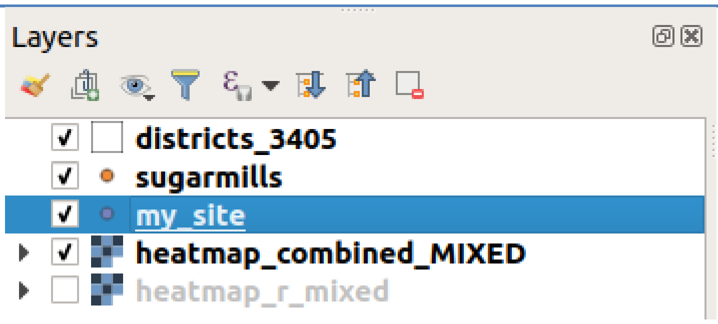
=> and type 3405 to filter field,



=> press OK

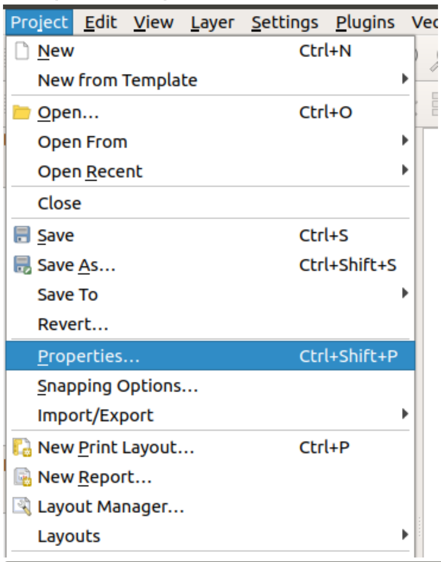
=> give the new layer a name, and save it

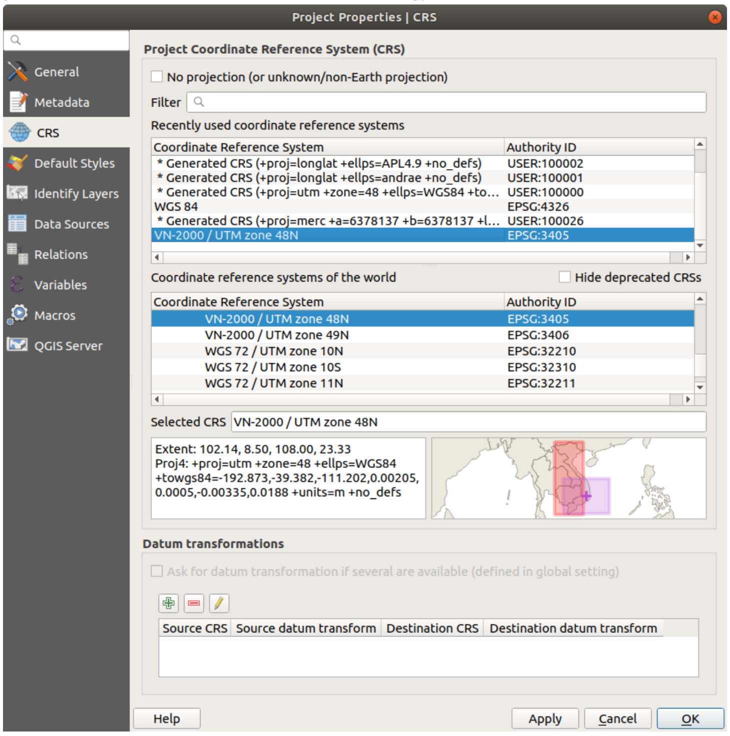
=> You will have a new layer on the Layers Panel



=>

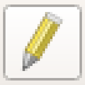
Check that also the QGIS project you are working with has the same coordinate system as the newly added layer:

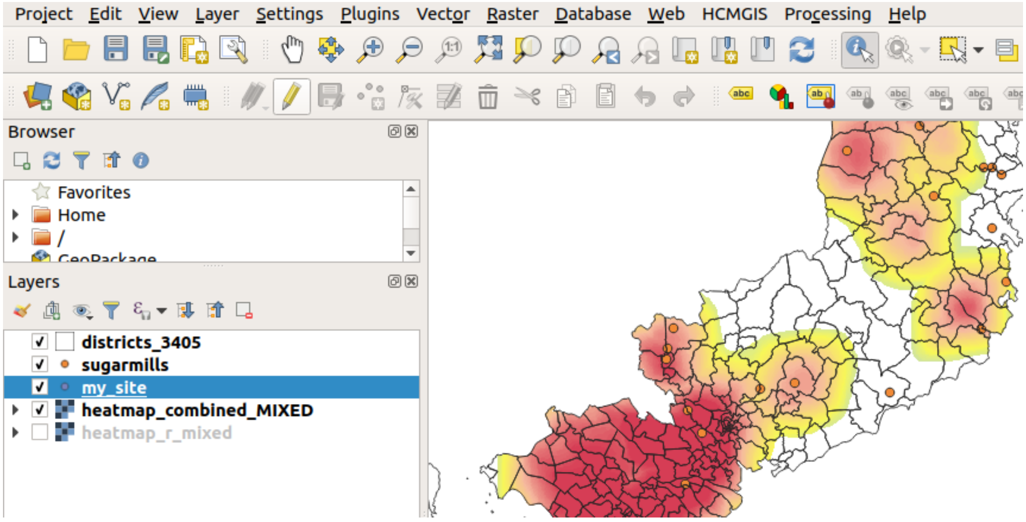




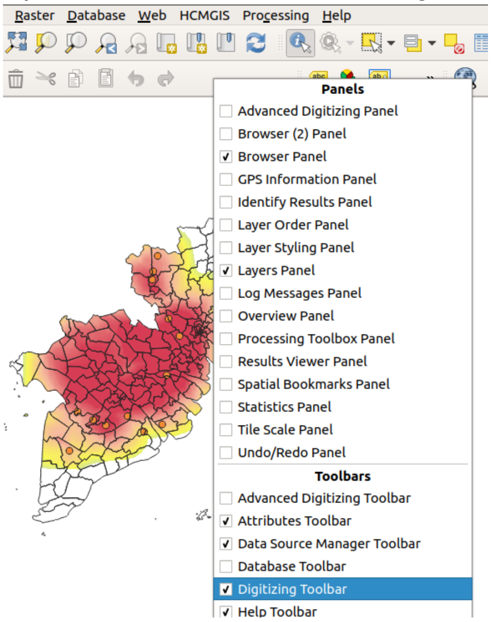
2) Add a new point to the new layer to the place you picked for analysis

While your new layer is highlighted on the Layer's Panel, click Toggle Editing tool



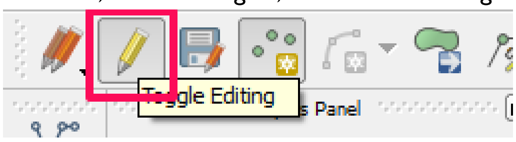


If you don't see that toolbar button, right click over an empty spot on the toolbar, and select:

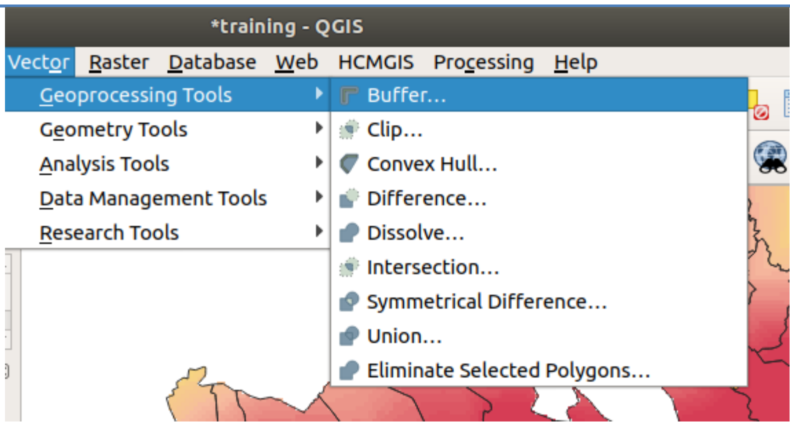


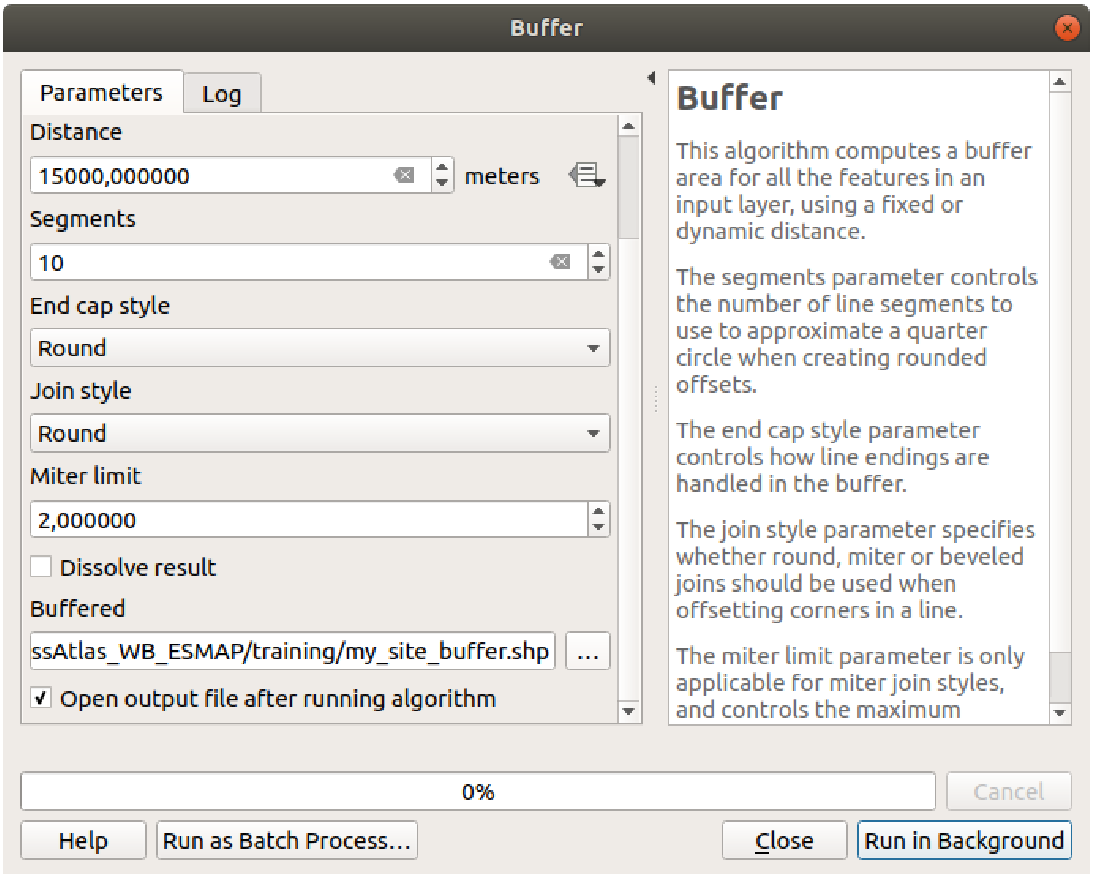
=> Zoom the map to the place where you want to add the point, and then:

=> click on the place on the map you selected for analysis, give an ID for the new point (e.g. 1) and then, click here again, and save the changes when prompted:

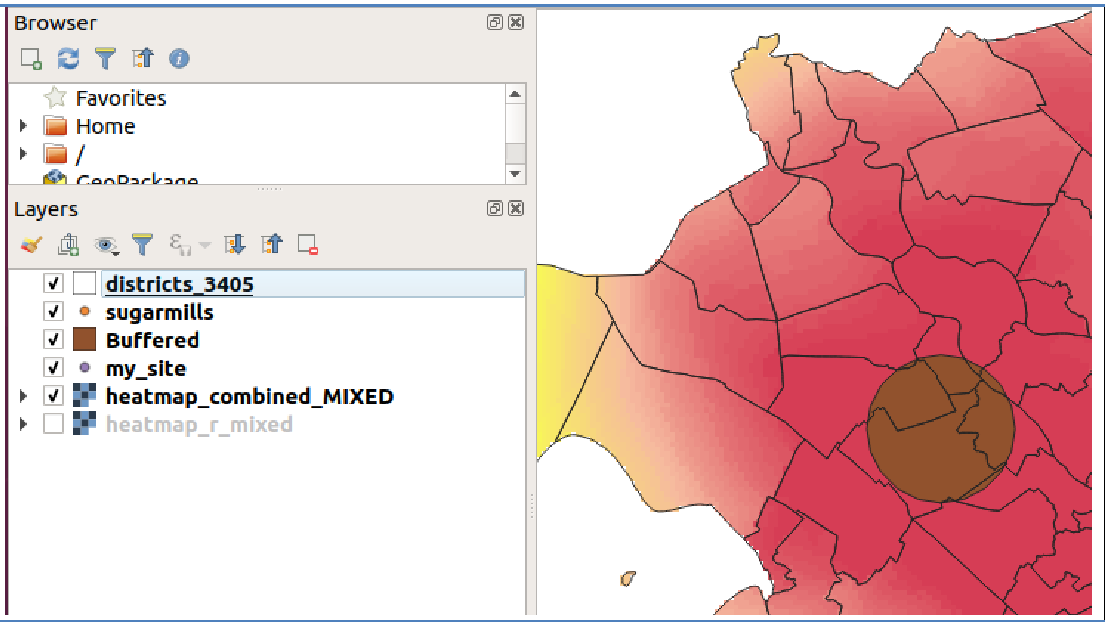


3) Create a 15 km radius buffer around the site marked with the point

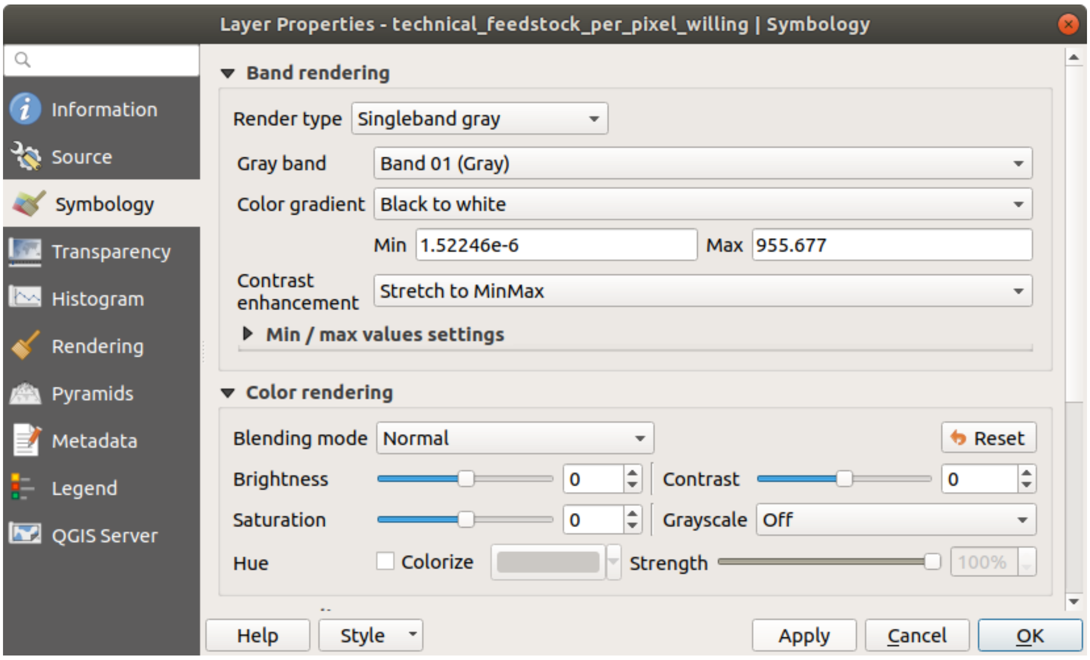




=> Qgis will automatically open my_site_buffer.shp with layer name Buffered



Subtask 2.3: Next you calculate how much and what type of harvest residue is available from that 15 km radius circle.

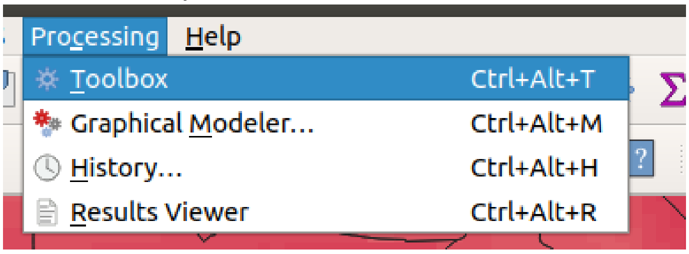
Files needed	technical_feedstock_per_pixel_willing.tif power_plant_model.xlsx
In QGIS	1) Add the rasters technical_feedstock_per_pixel_willing.tif to your map. See instructions for step 4 for the previous exercise for adding raster layers to the map. Note: since these rasters are 28 band rasters, each band containing the available biomass for each pixel, there is no obvious way of styling the layer for display. If you want, you can show the values for a single band (i.e. single harvest residue) for example by right clicking the layer name in the Layers Panel, and then:  2) For each band that has the biomass for a field based harvest residue, calculate the total amount

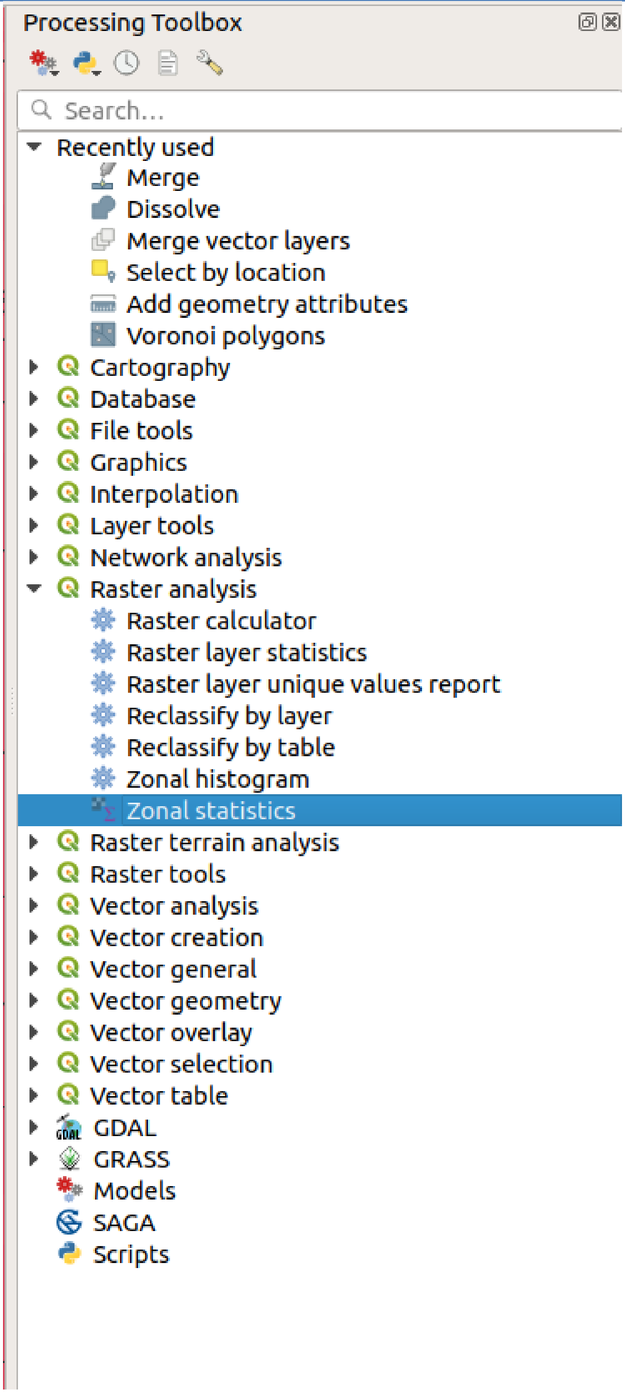
within the 15 km radius circle.

The bands in the raster are:

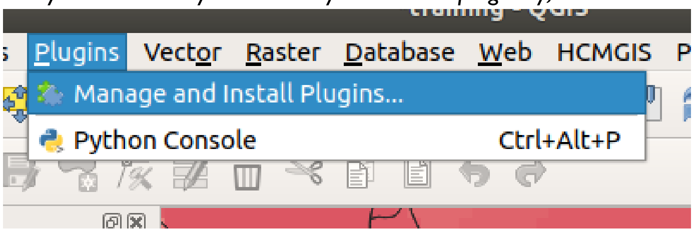
Band	Feedstock, short	Feedstock, long
1	RicStr	Rice straw
2	MaiTra	Maize straw
3	SugTra	Sugar trash
4	PeaStr	Peanut straw
5	SoyStr	Soy straw
6	CasSta	Cassava stalks
7	CshWoo	Cashew wood
8	RubWoo	Rubber wood
9	CofWoo	Coffee wood
10	TeaWoo	Tea wood
11	PepWoo	Pepper wood
12	CocWoo	Coconut wood
13	MngWoo	Mango wood
14	OraWoo	Orange wood
15	ManWoo	Mandarin wood
16	LonWoo	Longan wood
17	LitWoo	Litchi wood
18	RamWoo	Rambutan wood
19	RicHus	Rice husk
20	MaiCob	Maize cobs
21	MaiShe	Maize shells
22	SugBag	Sugarcane bagasse
23	PeaShe	Peanut shells
24	CasPee	Cassava peel
25	CasShe	Cashew nut shells
26	CofHus	Coffee husk
27	CocHus	Coconut husk
28	CocShe	Coconut shells

=> For this task you will use the Zonal statistics tool of QGIS from Toolbox in Processing tab,



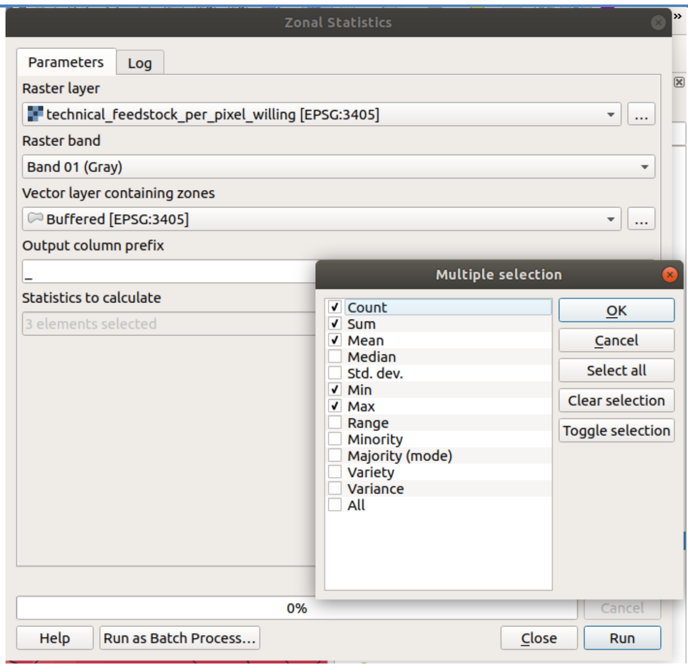


In case you are using some version of Qgis not having zonal statistics as ready installed tool you can easily add it as a plugin by,



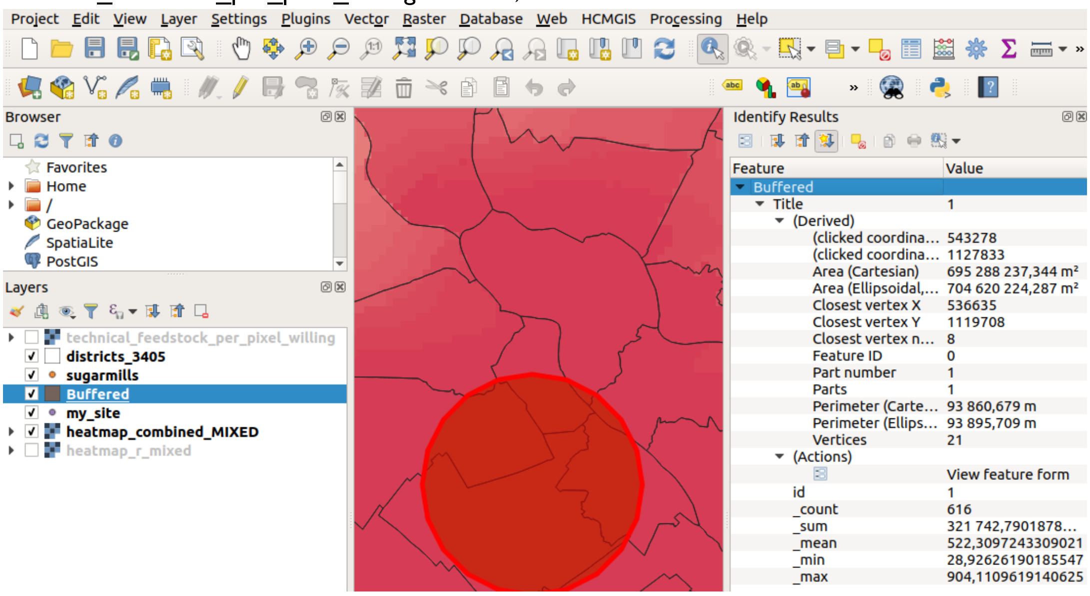
=> *and typing zonal statistics to search bar.*

=> Once Zonal Statistics tool is opened



=> After running the Zonal Statistics like this, you will have the raster statistics in the buffered point layer attributes. You can use the Identify features-tool to have a look at the numbers.

Select the Identify Features tool  and while the Buffered layer is selected in the Layers Panel, click on the 15 km circle. The Identify Results panel will show statistics for that area based on the technical_feedstock_per_pixel_willing.tif raster,



You will want the _sum and _count values; _sum is the sum of pixel values for band 1 for the raster, i.e. tonnes of rice straw available. The _count value is the number of pixels from which this amount comes from. The size of a single pixel is 1000 m x 1000 m. You can check that value to validate that the sum is for the area under the circle.

Write down the sum in the appropriate green cell in the "MW Power" sheet of the power_plant_model.xlsx

Biomass fuels used	Low Heating Value (LHV)[3]		Amounts of biomass fuels used	Fuel share	Energy input from fuels
	MJ/kg	MWh/t	t/yr	%	GWh/yr
RicStr	***12.60***	3.50	***322***	100.0%	1.1
MaiTra	***12.50***	3.47	***0***	0.0%	0.0
SugTra	***12.50***	3.47	***0***	0.0%	0.0
PeaStr	***15.00***	4.17	***0***	0.0%	0.0
SoyStr	***12.40***	3.44	***0***	0.0%	0.0
CasSta	***17.00***	4.72	***0***	0.0%	0.0

Repeat this step for all the relevant bands as well. After that, you have the your power plant model primed with feedstock data, and can see for example the gross power capacity of the power plant, (below shown with fuel contribution of rice straw only):

Calculation results:		
Rated gross power capacity output:	**0.03**	MWe
Gross electricity output:	**227.7**	MWh/yr
Electricity own-consumption by the power plant[4]	***15.0%***	% of gross electricity output
Net electricity output	**193.5**	MWh/yr

Of course it's not realistic to assume that you can source 100% of the available feedstock, but now you are able to create a baseline, and can start playing with the sourcing assumptions.

Annex 5: Instructions to the Vietnam Biomass Atlas Maintenance

UPDATING OF THE BIOMASS ATLAS DATA

The purpose of this document is to introduce the structure and the parameterization of the Biomass Atlas Model so that in the event of updates to some of the input data for the Biomass Atlas, new versions of the Atlas datasets can be generated.

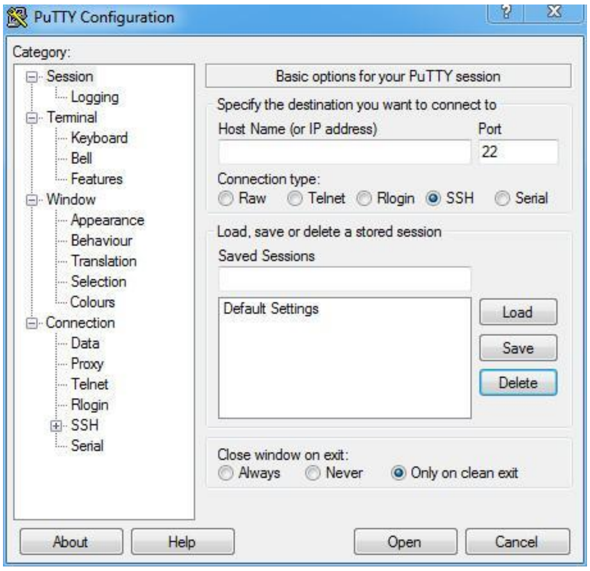
The exercises in this chapter rely on a sample of the original Atlas data to keep the runtime for the exercises at a reasonable level.

Setting up remote Biomass Atlas environment using SSH client (PuTTy)

These instructions have been written by bearing in mind that the Biomass Atlas model is executed on a remote Linux server accessed using an SSH client on a Windows desktop. If you are running the whole exercise locally on a Windows desktop, you can skip these remote access instructions.

In order to install PuTTy SHH client needed for remote access, go to http://www.putty.org and follow the "Download PuTTy link" and from there, download the "putty.exe" to your computer. A detailed PuTTy documentation can be found from http://the.earth.li/~sgtatham/putty/0.66/htmldoc/

To sign in to the remote server, write the server address in the text field under "Host Name (or IP address). Click "Open". The first time you log on the server you are shown a pop-up "PuTTY Security Alert"; click "Yes". More detailed instructions on logging in to remote server using PuTTY can be found here: http://the.earth.li/~sgtatham/putty/0.66/htmldoc/Chapter2.html#gs



Set-up

The Biomass Atlas model, used to generate the Biomass Atlas datasets, is implemented with the Python programming language. It also relies on several Python modules that need to be installed together with Python.

We begin the atlas setup by preparing a Python environment that has required Python modules for Biomass Atlas model. To keep this environment separate from other Python environments on the same system we encapsulate our working environment using a virtual environment.

To be able to generate a virtual environment in our Biomass Atlas main directory, we need to install virtualenv & virtualenvwrapper, by running commands:

    $ pip install virtualenv and
    $ pip install virtualenvwrapper.

See more details on how to use *virtualenvwrapper* on
https://virtualenvwrapper.readthedocs.io/en/latest/

Now let's create a virtual environment called "atlas". Then with "atlas" activated, we are going to install required modules and run the actual tasks. With *virtualenvwrapper* properly set up, execute the command:

    $ mkvirtualenv atlas

After executing that command your terminal prompt should start with the string:

    (atlas)

That is an indication that you have now successfully created and activated the virtual environment and we can start installing required modules.

Table 33 lists the required modules, and the easiest way to get them installed on Linux. On Windows, a good source for installation files of the needed modules is
http://www.lfd.uci.edu/~gohlke/pythonlibs/.

Table 37: Requirements for generating the Biomass Atlas with the Biomass Atlas model

Requirement	Can be accessed at
Python 2.7	https://www.python.org/downloads/
pip	https://pip.pypa.io/en/stable/installing/
Python modules, installed with pip:	Execute on command line
rasterio	pip install rasterio
shapely	pip install shapely
fiona	pip install fiona
xlrd	pip install xlrd
xlsxwriter	pip install xlsxwriter
rtree	pip install rtree
numpy	pip install numpy
pyproj	pip install pyproj
affine	pip install affine
scipy	pip install scipy
futures	pip install futures
Biomass Atlas Model	Included in the the Biomass Atlas data package available at http://esmap.org/re_mapping_vietnam see folder atlas_model
Training dataset	Included in the the Biomass Atlas data package available at http://esmap.org/re_mapping_vietnam see folder training

After downloading the Biomass Atlas data package, unzip it and make a note of the folder where you did the unzipping. This is the folder you will find the model and the exercise data referred to below.

Also, if you start a new SSH session to the server, make sure you activate the "atlas" virtual environment before executing the commands listed in the task instructions.

Task 1: Changing How the Atlas Is Generated

Overview of the Biomass Atlas model

The Biomass Atlas Model consists of two main scripts: feedstock.py module and heatmap.py module (located in <*unzipping location*>/atlas_model/src directory). Both of the modules are controlled by a number of settings in constants.py file, which is located in <*unzipping location*>/atlas_model/src/utils directory. The steps in running the whole Biomass Atlas model are:

1. Set the run parameters by editing the constants.py file
2. Run the feedstock.py module
3. Run the heatmap.py module

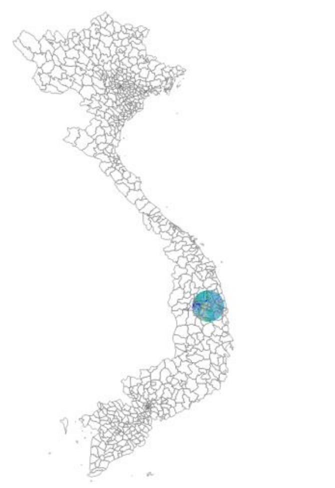
Detailed instructions for doing this are below.

Before running the Biomass Atlas, you must change the current working directory to the Biomass Atlas main directory, by running a command:

$ cd <*unzipping location*>/atlas_model

Here <*unzipping location*> is the folder in which you unzipped the model and training data. Note that these instructions are written for Linux, so you need to adapt them for Windows (e.g. \ instead of / as the directory separator in path names).

Above the "$" marks the "command prompt" in your PuTTy window, i.e. you're meant to type the text following the $-sign and press Enter/Return key. On Windows this would be your Command Line window.



Modifying Biomass Atlas settings in the constants.py

In this example, we will be running the Biomass Atlas model for only a small subset of the whole country, as running the model for the whole of Vietnam would take a considerable time. To do this, we need to set the model land use classification to layer named An_Khe_55km.ers (land use classification within 55 km of An Khe sugar mill) by modifying the constants.py file. The area is shown in the left image as the bluish colored area in central Vietnam.

Note that this is also how you would assign a completely new land use classification to the Atlas.

The constants.py module can be modified using nano editor by running the following command (here we assume that you successfully changed your working directory to <unzipping location>/atlas_model in the previous step above):

$ nano src/utils/constants.py

(on Windows, use e.g. Notepad to open the file)

After starting the nano editor, your screen should look like this:

```
  GNU nano 2.2.6                File: constants.py

Biomass Atlas Model is distributed in the hope that it will be useful,
but WITHOUT ANY WARRANTY; without even the implied warranty of
MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
GNU Affero General Public License for more details.

You should have received a copy of the GNU Affero General Public License
along with Biomass Atlas Model.  If not, see <http://www.gnu.org/licenses/>.
'''
import os


# -----------------------------------------------------------------------
# PROCESSING PARAMETERS
#
# General processing parameters
PIXEL_SIZE = 1000  # Feedstock aviability raster pixel size in meters
# Pixel are to field area conversion factor; i.e. 'mixel' reduction from
# pixel classified as field total area to real field area under that pixel
EFFECTIVE_PIXEL_SIZE = 0.9
# maximum road network density value (km/km²), can be used to scale down
# high density urban areas, which would otherwise drive the road density
# part of the suitability index creation completely
CAP_ROAD_DENSITY_TO = 1.5
# nodata value to use for the raster output
NODATA = 0

# Settings for running the different subtasks in the feedstock analysis
FEEDSTOCK_RUN_SURVEY_ANALYSIS = True  # Process the field survey data?
FEEDSTOCK_RUN_FEEDSTOCK_MAPS = True  # Generate the feedstock maps?
FEEDSTOCK_RUN_DISTRICT_LANDUSE = True  # Run district-level landuse analysis
FEEDSTOCK_RUN_CROP_STATISTICS = False  # Compare the results to the stats

# Settings for running the different subtasks in the heatmap analysis
HEATMAP_RUN_HEATMAP_ANALYSIS = True
HEATMAP_RUN_PROCUREMENT_DISTANCE = True
HEATMAP_RUN_GRID_STATION_DISTANCE = True
HEATMAP_RUN_ROAD_NETWORK_DENSITY = True
HEATMAP_RUN_COGEN_ANALYSIS = True
HEATMAP_RUN_IN_DEBUG_MODE = False
HEATMAP_SUBTASK_SIZE = 5  # n for n x n window in concurrent processing
```

Subtask 1.1: Changing the model inputs - land use classification file

Using the nano editor, find a row that contains a text *LANDUSE_CLASSIFICATION*. You can do this either by moving down using arrows, or by searching for the text using "Where Is" command (press ctrl + w). After finding the correct row, change the row contents into the following:

LANDUSE_CLASSIFICATION = os.path.join('..', 'training', 'An_Khe_55km.ers')
After the change, the constants.py should look like this in nano editor.

***NB**: `..´ is used to move one level up in the directory hierarchy, i.e. to the <unzipping location> directory*

```
# PATHS TO MODEL INPUTS
#
# Land use classification
LANDUSE_CLASSIFICATION = os.path.join('..','training',
                                      'An_Khe_55km.ers')
```

Save the changes (press ctrl + o), and now the land use classification will be read from a An_Khe_55km.ers instead of the mosaic that combines a large number of Sentinel images to cover the whole Vietnam.

Subtask 1.2: Changing the model parameters - maximum biomass sourcing distance

Before running the Biomass Atlas model, we should still edit some of the input parameters of the Biomass Atlas model. In this example we will modify the maximum biomass sourcing distance. By default, the maximum sourcing distance is 50 km, but you should change it to 25 km. This means that the maximum allowed distance, from which biomass can be transported to a power plant, will be 25 km.

To modify the maximum sourcing distance, search for the text *MAX_DISTANCE* from the constants.py using the nano editor and change its value to 25. After the edit, the constants.py should look like this.

```
#
# Maximum feedstock procurement distance (km)
MAX_DISTANCE = 25
```

Subtask 1.3: Changing the model outputs - result heatmap file names

Another thing we want to change, are the names of the output files that will be generated when running the Biomass Atlas model. The names of the output files, and other model outputs are also defined in the constants.py file. The Biomass Atlas model will generate a number of raster files during the processing, but the most relevant outputs are the so-called *combined heatmaps*, which represent the potential for biomass power plants of different types and capacities.

In order to compare model outputs with different input parameters, we want to save the outputs from separate model runs with separate names. Using the nano editor, search for the text *PATH_TO_COMBINED_HM_SINGLE* from the constants.py file. Change the name of the file to heatmap_combined_SINGLE_run1.tif. Do the same for the *PATH_TO_COMBINED_HM_MIXED* and change the output file name to heatmap_combined_MIXED_run1.tif.

The "SINGLE" refers to heatmap for a single fuel power plant and "MIXED" refers to a heatmap for a mixed fuel power plant.

After these changes, the constants.py file should look like this:

```
PATH_TO_ROAD_NETWORK_HM = os.path.join('..', 'site_suitability', 'heatmap_rn_density.tif')

# Combined heatmaps, both for single fuel and mixed fuel cases
# 16 channels, one per each power plant type and capacity class combination.
# These classes are defined in constants.TECHNOLOGY_TYPES
# Unit: "goodness" index, 0..100
PATH_TO_COMBINED_HM_SINGLE = os.path.join('..', 'site_suitability',
                                          'heatmap_combined_SINGLE_run1.tif')
PATH_TO_COMBINED_HM_MIXED = os.path.join('..', 'site_suitability',
                                         'heatmap_combined_MIXED_run1.tif')
```

Now, make sure you save your edits (ctrl + o), exit the nano editor (ctrl + x) and we're ready to run the model!

Subtask 1.4: Running the Biomass Atlas model

The Biomass Atlas model should be run in two steps: first the feedstock.py module and then the heatmap.py module.

Run the feedstock.py module with the following command:

```
$ python src/feedstock.py
```

The server logs will show messages about the execution of the model, and in case anything goes wrong, the error messages. If you did the edits in the previous steps following the instructions, then there should be no error messages.

After the feedstock.py module has been run successfully, the next step is to run the heatmap.py module. This is done with the following command:

```
$ python src/heatmap.py
```

Running the heatmap.py module will take a while, as it will run a spatial analysis for the biomass potential for 18 power plant type and capacity combinations. The heatmap.py module will generate the power plant potential heatmaps and after the model run has ended, we're ready to analyse the results.

Subtask 1.5: Re-running the Biomass Atlas model with alternative parameters

In this example, we want to run the model twice with different parameters in order to see how the parameters affect the model outputs.

In subtask 1.2, we changed the maximum sourcing distance to 25 km. Now, edit the constants.py and change the maximum sourcing distance back to 50 km.

In subtask 1.3, we change the output filenames by adding "_run1" to the end of the output heatmap file names. For the model re-run, we want to change the output file names so that we will have two alternative sets of result files to compare. Follow the instructions of subtask 1.3, but now the filenames, so that you change the "_run1" into "_run2".

After finishing the above edits, save your changes (ctrl + o) and exit nano editor (ctrl + x). Then, re-run the heatmap.py model. Notice that you don't need to re-run the feedstock.py again as you didn't change any parameters that affect the feedstock.py module.

Task 2: Checking the Results with QGIS. Did the Atlas Change?

Subtask 2.1: Loading the results from remote server to desktop computer

In order to view the Biomass Atlas model results, you need to first load the model outputs (the raster files) from the remote server to your desktop computer.
You can download files from the server using a program called PSCP, which you can download from the same web page as PuTTy.

PSCP download: http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html

Copy the downloaded pscp.exe to the folder of where you want to copy the files. For these instructions, we assume the desired location for downloading the heatmaps is "C:\Atlas", so the pscp.exe should be saved to the folder "C:\Atlas".

PSCP is a command-line tool and should be run from the command-line prompt. To start the prompt, click the Windows icon at the bottom of the screen, and type "cmd" and press Enter in the "Search for programs and files" text box at the bottom of the menu.

In the prompt, change to the folder by typing

C: (and Enter)

followed by

cd \Atlas

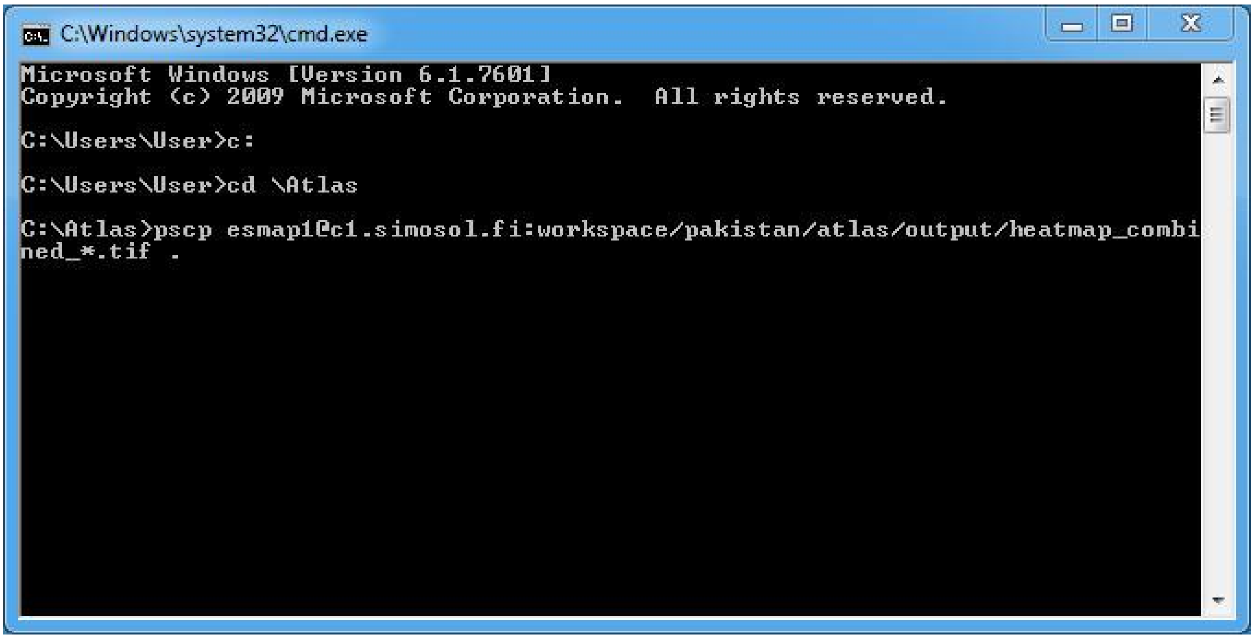
Again, assuming that you want to work in the C:\Atlas folder. Change this according to the folder in which you want to have the data.

To copy the output files to C:\Atlas use the following command, but replace the user name and the server name with those you used when logging on with PuTTY to run Atlas:

pscp <username>@<your server>:<unzipping folder>/atlas_model/output/tt_cap/heatmap_combined_*.tif .

Make sure to include the last point in the command.

After pressing Enter, the program will ask for the same password it did when logging in with PuTTY.



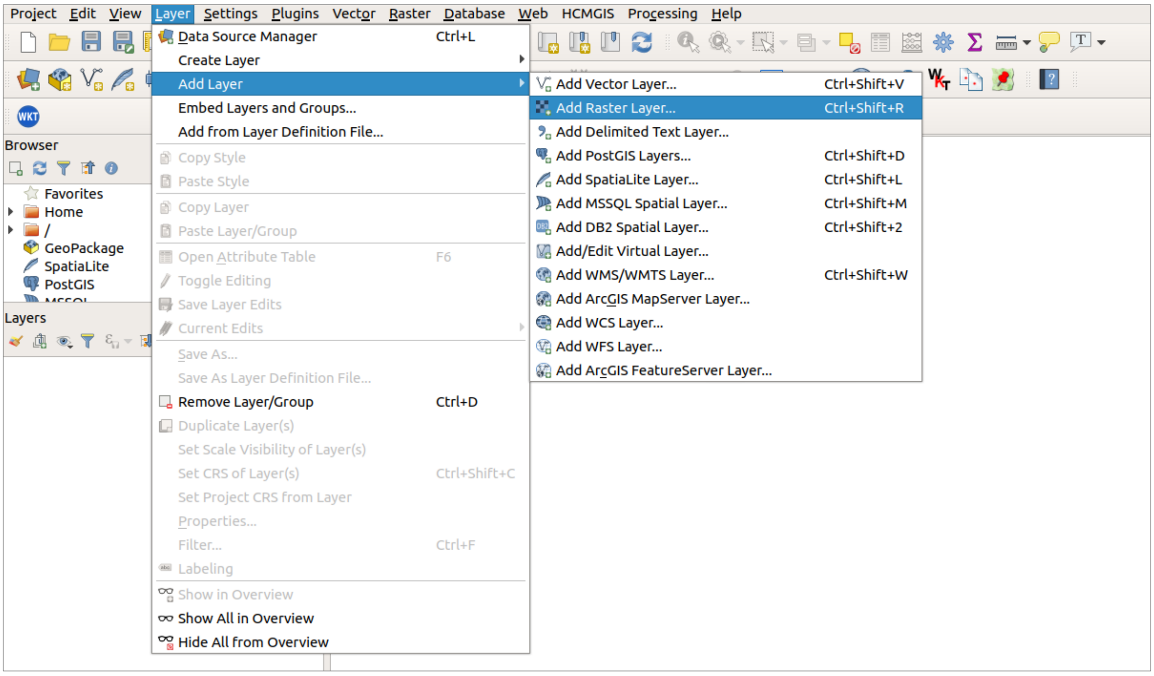
If everything worked OK, you should have now downloaded all four combined heatmaps you just generated in the two model runs.

heatmap_combined_SINGLE_run1.tif
heatmap_combined_MIXED_run1.tif
heatmap_combined_SINGLE_run2.tif
heatmap_combined_MIXED_run2.tif

To copy only one single file, replace "heatmap_combined_*.tif" with the name of the desired file.

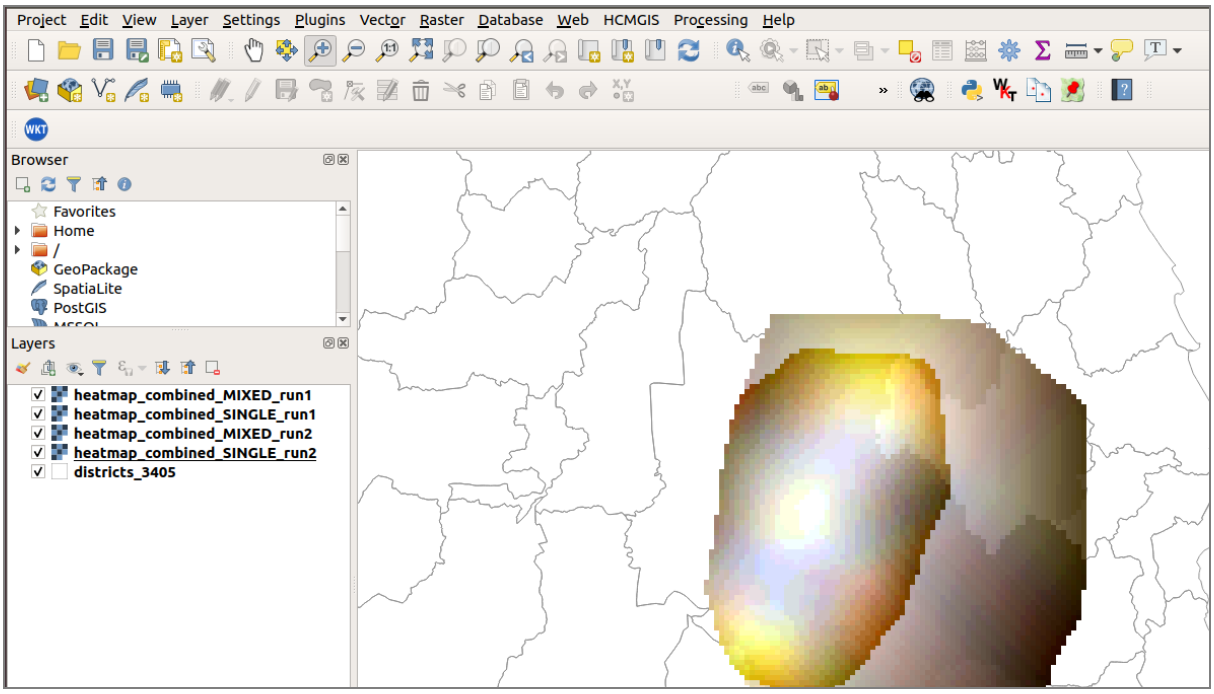
Subtask 2.2: Loading the heatmaps into QGIS

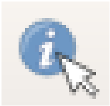
After downloading the generated heatmaps to your desktop computer, you can view them in QGIS. To do this, first start QGIS and create a new project. Next, add the rasters to QGIS by selecting "Layer" from the top menu, select "Add Layer" and finally "Add Raster Layer...".



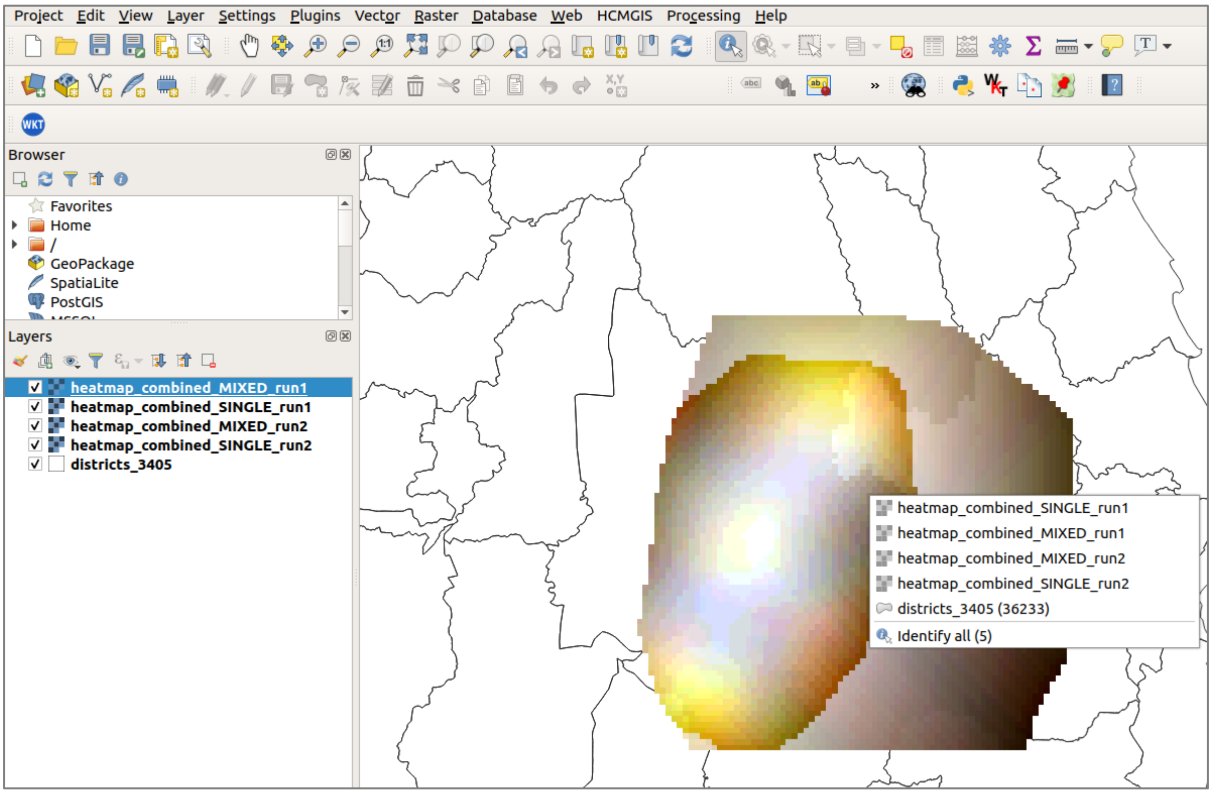
From the file selector, select the four combined heatmaps you generated and downloaded from the server: heatmap_combined_SINGLE_run1.tif, heatmap_combined_MIXED_run1.tif, heatmap_combined_SINGLE_run2.tif and heatmap_combined_MIXED_run2.tif.

After loading the heatmaps to QGIS, each of the heatmaps should show as a separate *layer* in the layer listing on the left side of your QGIS application (see the following image).

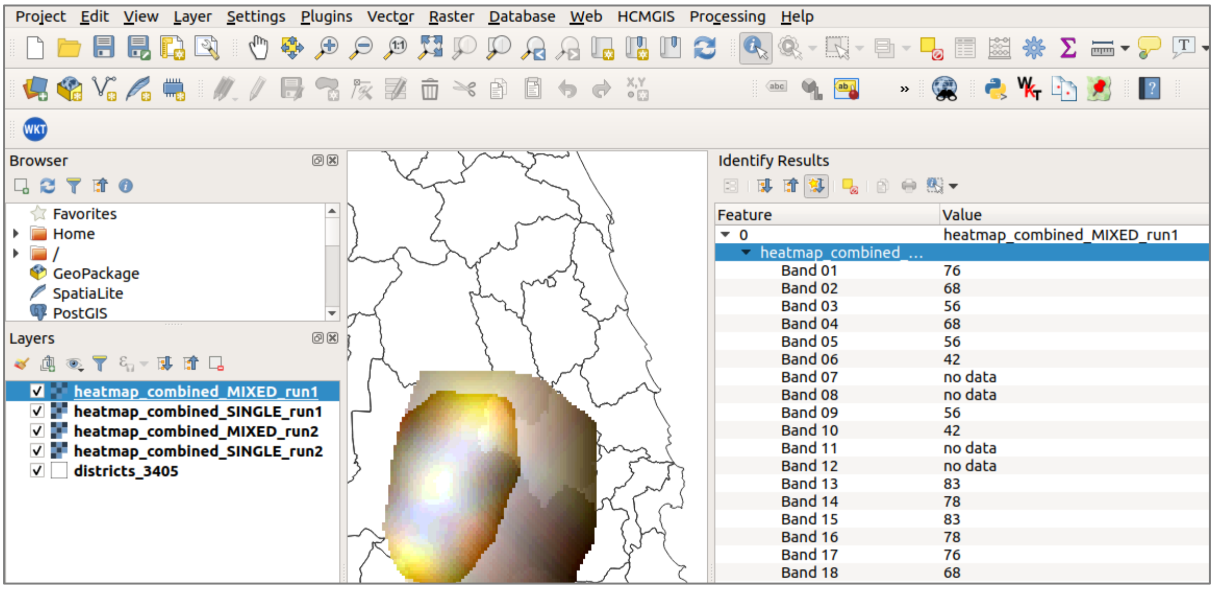




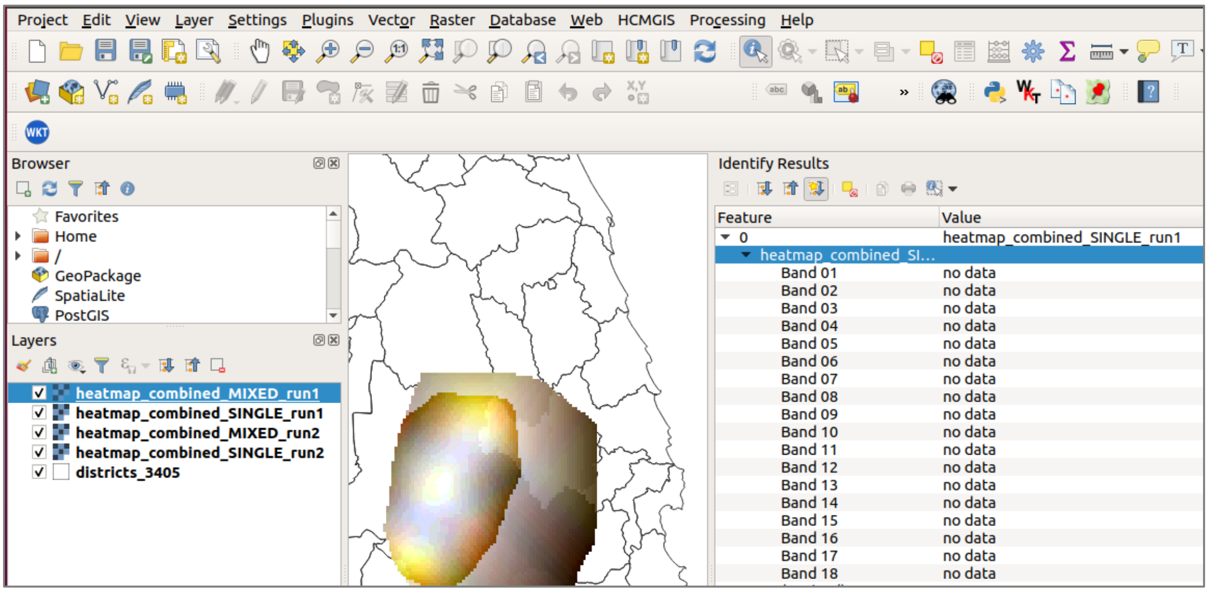
Let's check the layers with the info tool more closely. Left click one of the visible heatmaps with info tool and it should give you a selection of layers which you can take look of more closely.

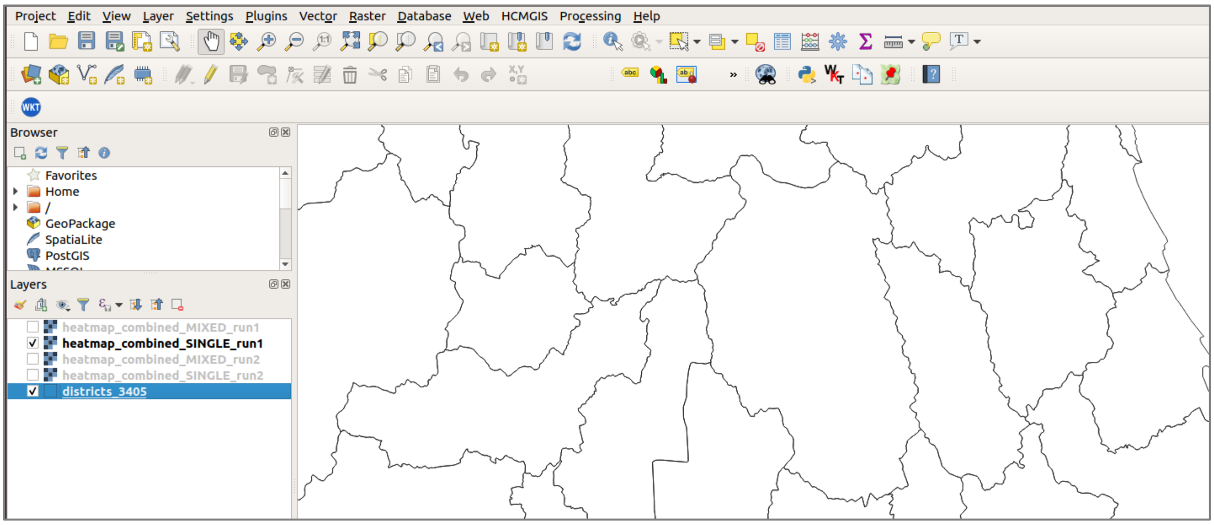


You can first select heatmap_combined_MIXED_run1 (the one we see here as golden brown). Info tool should give you information on all the separate bands off heatmap_combined_MIXED_run1 layer,



Now under the Identify Results panel on the right side, you see different suitability values between 0 to 100 for different power plants described earlier. No data values in some bands indicate that there is not enough feedstock available within the maximum sourcing distance to support year-round operation of the power plant designated at that band. As an example, no data value for Band 07 seems to mean that 50 MW Bubbling fluidized bed combustion steam boiler + steam turbine combo is not feasible at the location for whole year operation. If we click again the visible heatmaps and select heatmap_combined_SINGLE_run1 layer for closer look, we realize that there are no data values at clicked location. It means that with 25 km procurement distance (run1) and by only using a single feedstock type, we are not able to supply any type of power plant the whole year round. And if we check the info for heatmap_combined_SINGLE_run2, we notice that the situation is the same even with 50 km procurement distance. We can confirm this by visualizing only heatmap_combined_SINGLE_run1 or run2 layer.



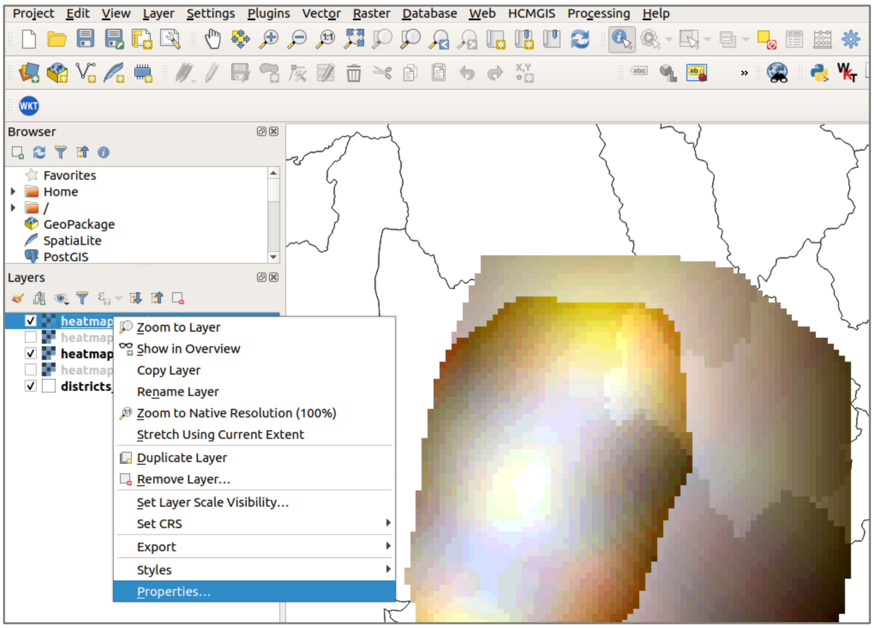


Blank view (even when heatmap_combined_SINGLE_run1 is checked) indicates that it is not feasible to run any of the power plant types the whole year round using single fuel, even with 50 km procurement distance.

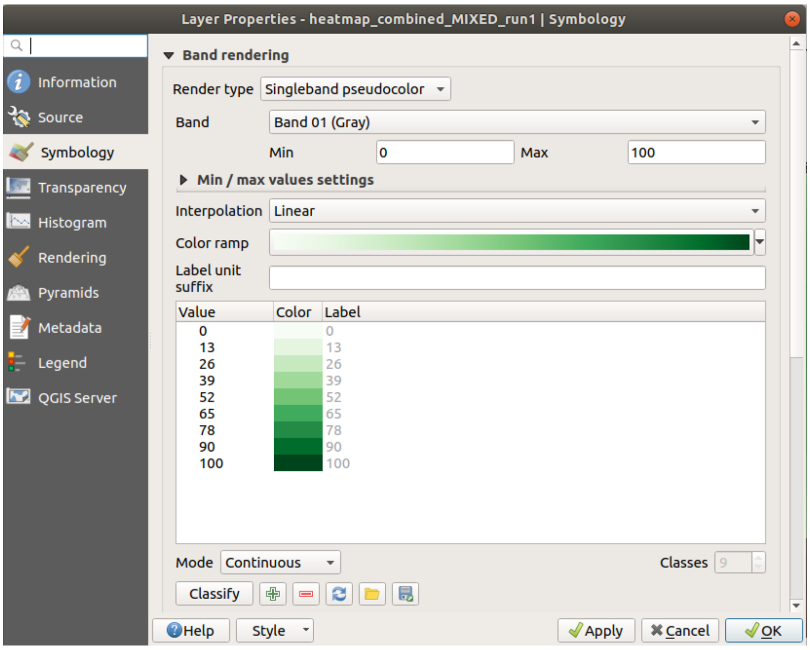
Subtask 2.3: Setting the layer style of the heatmaps in QGIS

The visual representation of the layers in QGIS are controlled by layer *style*. In order to compare the alternative heatmaps, we want to set their visual properties to represent the potential for biomass-based power plants.

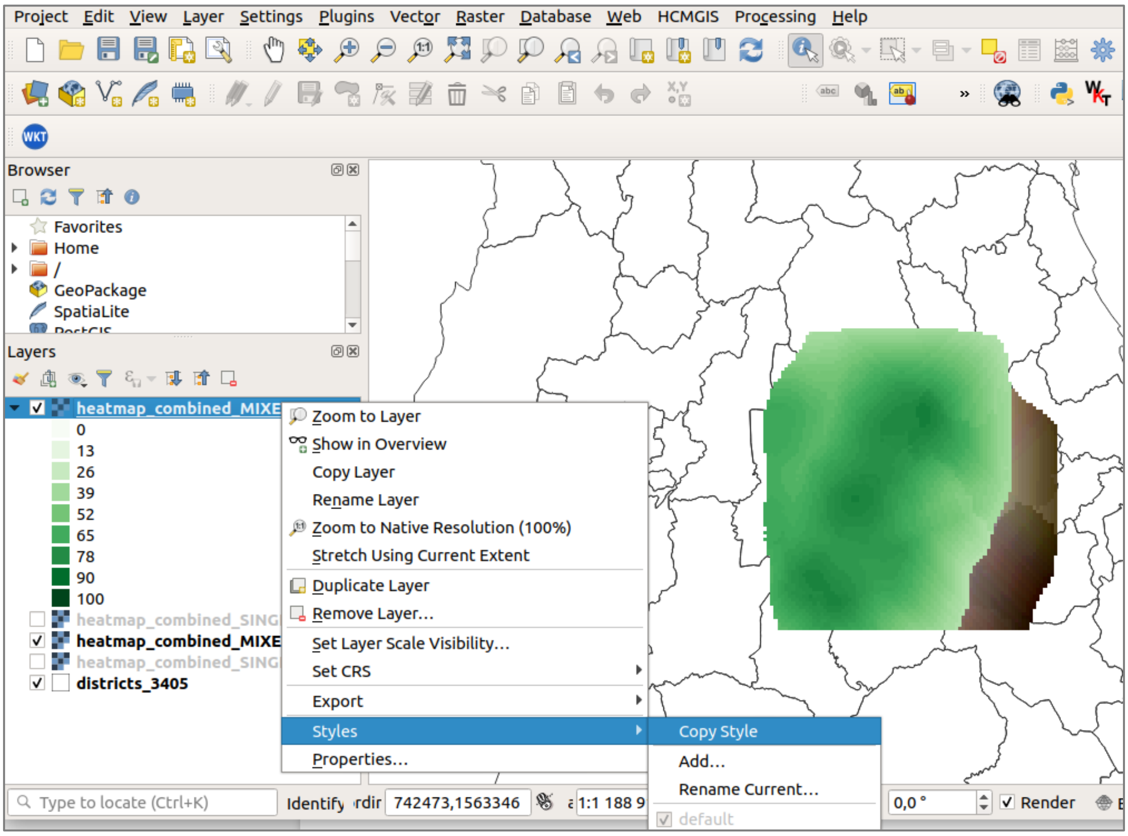
To do this, first select the heatmap_combined_MIXED_run1 layer, press the right button of your mouse and select "Properties" from the pop-up menu (see the following image).



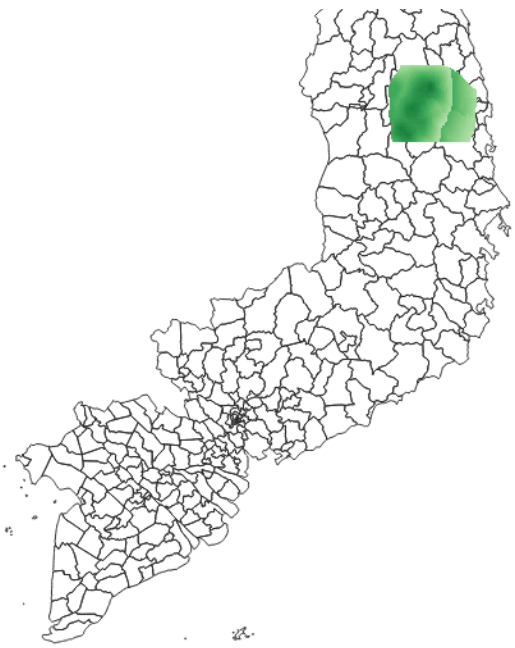
In the layer properties, select "Style", from there set Render type as "Singleband pseudocolor", set the Band as "Band 01", select green color map, set minimum value to 0 and maximum to 100 and click "Classify" button. After this, the layer style settings should look similar to the following image. Make sure that your layer style settings are ok, then click "Apply" and "OK".



The above steps changed the style of one of the two layers visible. Next, you should copy the same style for the other layer. This can be done by selecting the layer that you just modified, opening the pop-up menu by right clicking, and selecting "Style" and "Copy style". Then, select one of the other three layers and do the same steps, except that in the end, select "Paste style".



Subtask 2.4: Comparing the layers from alternative runs

After setting the styles to same, you can start comparing the heatmaps from the alternative model runs. In the image left, you can see the heatmaps for single stock power plants from runs 1 and 2 (25 km and 50 km maximum sourcing distance). The raster band 1 is for 3 MW horizontal grate combustion steam boiler + steam turbine (GC). So, in the current settings, the raster displays the potential, or goodness, of each 1 x 1 km cell for a 3 MW HGC power plant, so that dark green means high potential and light green low potential. The white areas are outside the maximum sourcing distance.	

Task 3: Changing the weights of different factors affecting the heatmap

Besides the maximum sourcing distance, there are also other factors that affect what the site suitability index heatmaps end up looking like. These are "nearest grid station distance factor" and "road network density factor". Find out where these are in **constants.py**, change them so that the weight of the sourcing distance is 80%, the weight for the grid station distance is 20%, and the road network distance has no weight at all (0%).

Rename the output rasters from having the "_run2" to have "_run3" ending.

Compare the results of this model run to the previous ones in QGIS.

FINAL WORDS ABOUT UPDATING THE ATLAS

The key to successful Atlas maintenance is understanding the different settings in
atlas_model/src/utils/constants.py
The file is documented with comments outlining the purpose of each setting. When new input data for atlas generation is available, of particular interest are the settings in section
PATHS TO MODEL INPUTS,
i.e. the new data should be entered into the files pointed to by the settings in that section of constants.py

For help with troubleshooting, please contact Simosol Oy at info@simosol.fi