Document No.: 2015P6-THA-APR1
Receiving Date:
(For APFNet Secretariat)

Asia-Pacific Network for Sustainable Forest Management and Rehabilitation

COMPLETION REPORT

To Demonstrate the Development and Application of Standing-Tree Carbon Equations to Improve the Accuracy of Forest-cover Carbon Stock Estimates in Thailand

01 January 2017 to 31 December 2018

Kasetsart University Faculty of Forestry

Bangkok, Thailand

January 2019

BASIC INFORMATION

Project Title(ID)	To Demonstrate the Development and Application of Standing-Tree Carbon Equations to Improve the Accuracy of Forest-cover Carbon Stock Estimates in Thailand (2015P6-THA-APR1)		
Supervisory Agency	Royal Forest Department, Bangkok, Thailand		
Executing Agency	Kasetsart University-Faculty of Forestry (KUFF)		
Implementing Agency	N/A		
Date of Project Agreement: 01/01/2017			
Duration of implementation: [01/2017-12/2018], 24 months			
Total project budget(in USD)	253,345.00	APFNet assured Grant (in USD)	199,045.00
Actual project cost(in USD)	255,486.45	APFNet disbursed Grant (in USD)	181,480.00

Disbursement Status	Date of disbursement	Amount (in USD)
Initial disbursement	03/2017	101,795.00
2nd disbursement	07/2018	79,685.00
Balance to be disbursed (minus cost of 8,000 for evaluation)		9,565.00

Reporting Status	Schedule [1] implementation	Project progress status[2]
First reporting (period covered: 01/2017-06/2017)	on track	satisfactory
Second reporting (period covered: 07/2017-12/2017)	on track	satisfactory
Third reporting (period covered: 01/2018-06/2018)	on track	satisfactory
Fourth report (period covered: 07/2018-12/2018)	on track	satisfactory

[1] Schedule [1]implementation status could be on track/behind/ahead of schedule

[2] Project progress status could be ranked as satisfactory, dissatisfactory, moderately satisfactory, moderately dissatisfactory

List of Project Steering Committee and Project Team

1. Project Steering Committee (PSC)

Name	Organization	Title	Contact information (e-mail)
Mr .Xia Jun	APFNet	Assistant Executive Director	
Mr .Li Zhaochen	APFNet	APFNet representative	
Dr .Nikhom Laemsak	Faculty of Forestry, Kasetsart University (KUFF)	Dean of KUFF, Chairperson of PSC	
Dr .Kobsak Wanthongchai	Faculty of Forestry, Kasetsart University	Associate Dean of KUFF	
Dr .Sakhan Teejuntuk	Faculty of Forestry, Kasetsart University	Associate Dean of KUFF	
Mr .Isoon Rinkome	Department of National Park, Wildlife and Plant Conservation (DNP)	Representative of Director of Protected Area Regional Office (Lampang Branch)	
Mrs .Natcha Visuthitepkul	Department of National Park, Wildlife and Plant Conservation (DNP)	Department of National Park, Wildlife and Plant Conservation Officer	
Mr .Thiti Visaratana	Royal Forest Department (RFD)	Director of Forest Research & Development Bureau, RFD	
Mr .Sapol Boonsermsuk	Royal Forest Department (RFD)	Director of International Forestry Cooperation Office, RFD	
Mr .Preecha Ongprasert	Royal Forest Department (RFD)	Representative of International Convention and Commitment Division	

Executive Summary

This project originated from the Kasetsart University Faculty of Forestry (KUFF), Bangkok, Thailand. The rationale for this project was that there was uncertainty in the accuracy of national estimates of Thailand's forest-cover carbon stocks, incomplete reporting of carbon stocks, and limited knowledge of the methods of carbon stocks assessment among the stakeholders. This, in turn, affects the national planning and other policy decisions that rely on information on national carbon stocks. A new and novel approach has been developed at KUFF to estimate standing tree carbon content as a function of standing tree attributes (total height and DBH), using sample tree increment cores. Through this project, Thailand sought financial assistance and technical support from APFNet to demonstrate this new approach that could be used to develop new national standing-tree carbon equations.

The project overall goal was to provide accurate information on national forest carbon stocks to support informed sustainable forest management policy decision-making and balanced public debate on the benefits of forests in climate change mitigation. The project specific objective was to demonstrate the development of accurate standing-tree carbon equations and their application to the preparation of a forest-cover carbon stock map in the Mae Huad Sector, Ngao Demonstration Forest in Lampang province.

The methodology to construct new tree carbon equations was developed and pilot-tested. An initial inventory was conducted to generate a tree list in the Mae Huad Sector. It was based on 54 point samples located on a uniform fixed 3 x 3 km grid. Tree measurements, including tree species, DBH, total height, and number, as well as topography, were recorded. From these inventory data, three forest types, namely, Mixed Deciduous (MDF), Dry Dipterocarp (DDF) and Dry Evergreen Forests (DEF), along with the Importance Value Index (IVI) and wood density of each tree species, were reported. In each forest type, tree wood density was classified into 10 groups for a total of 30 groups and the species with the highest IVI in each group was selected for data collection. A total of 450 sample trees from 30 major species with 3 DBH classes and 5 replications of each diameter class (i.e., 30 x 3 x 5 = 450 trees in total) were selected. Additional sample tree data of, merchantable height, bark thickness, upper-stem diameters by 2-metre sections up to the first major branch and wood samples for carbon content analysis were collected for the selected sample trees.

The average tree bole carbon contents analyzed using C/N analyzer in the MDF, DDF and DEF were 47.61, 47.50 and 47.17%, respectively. Equations to predict tree bole carbon content were then constructed using the relationship between tree bole carbon content C, and total height and DBH were developed from the collected sample trees. Ten specific equations were constructed for each forest type by wood density ranges and species, and a general equation for all tree species in each forest type. The general equation to evaluate tree bole carbon equation for all forest types at the Mae Huad Sector was $C = 0.012348(D^{2.1676}H^{0.6539})$, where C was carbon storage in tree bole (kg/tree), D was diameter at breast height (cm) and H was total height (m) of the tree. The estimated carbon storage in the tree bole at the project site was 34.66 tons/ha.

In order to apply tree bole carbon equations to generate a carbon stock map of the project site, remote sensing techniques were used for land use classification and Normalized Difference Vegetation Index (NDVI) generation. About 78.26% of the Mae Huad Sector area was Mixed Deciduous Forest. The NDVI, ranging from -1 0 to +1, was used as an independent parameter in a linear regression equation for predicting the carbon stock (C) in each of the 54 inventory sampling points. The best fit for linear equation was with the January 16, 2017 Landsat imagery, with the highest coefficient of determination (R^2) of 0.2297. The regression model was C = 154.68 NDVI -72.991. The NDVI in all pixels were applied to calculate carbon contents and generate the carbon stock map. The carbon stock map estimate was 36.98 tons/ha or 16.39 million tons for the total area of the Mae Huad Sector, Ngao Demonstration Forest. For quality assessment of the carbon map, a second inventory was conducted based on 45 independent sampling points located on a 3 x 3 km rid and another carbon stock map was re-generated. The ratio between the mean map carbon estimates and mean ground estimates was equal to 1.0768, that is, the map provided 92.87 % of the ground estimate. A statistical test to determine the significance of the differences between the carbon map estimates and the 45 inventory samples was done using a Student's t-test. These differences were not statistically significant.

A focus group meeting with 10 selected experts from the relevant governments and private agencies including the Royal Forest Department (RFD), Department of Wildlife and National Parks (DNP), and Ministry of Natural Resources and Environment (MONRE), was held to review the project results and develop an action plan for the full-scale construction of national standing-tree Carbon equations for the major tree species in Thailand. The experts understood and did not oppose the novel technique to evaluate carbon contents in tree boles and suggested the Project Management Team (PMT) to expand the study sites into all regions and all forest types of Thailand. A draft national action plan was also prepared by the PMT. It included: 1) activities and resources for tree data collection; 2) analysis and tree carbon equation dissemination and promotion; 3) institutional set-up for maintaining and updating the equations; 4) capacity building and resource requirements; 5) priority actions and 6) establish policy brief document for distribution to related government authorities.

To transfer knowledge and information from the project to the relevant stakeholders, a national workshop involving about 40 stakeholder representatives was conducted. The workshop agenda included discussion of the project demonstration results, the draft action plan, and the next steps. Most participants also suggested that the PMT to extend the project area to other forest types. This was consistent with PMT intention to implement the national work plan to develop national standing-tree carbon equations and forest carbon stock map to improve the accuracy of tree-bole carbon stock estimates in Thailand. A workshop report and two technical reports were prepared. A project brochure summarizing the project objectives, methods and results was prepared and also loaded onto the project website, as were the documentation of workshop proceedings and technical reports. A national work plan was prepared to scale up the project methodology to the national level, to develop Thailand national tree carbon equations and carbon stock maps.

Contents

1. BACKGROUND AND INTRODUCTION

1.1 Project context

This project originated from the Kasetsart University Faculty of Forestry (KUFF), Bangkok, Thailand. The rationale for this project was that there was uncertainty in the accuracy of national estimates of Thailand's forest-cover carbon stocks, incomplete reporting of carbon stocks and limited knowledge of the methods of carbon stocks assessment among the stakeholders. This, in turn, affects the national planning and other policy decisions that rely on information on national carbon stocks.

The carbon stock estimates are inaccurate because the commonly used tree volume equations, which are a basis for tree carbon estimation, are biased (over- or under-estimate tree volume). The bias occurs because:

- The sample trees used to develop the equations was small (because of the need to minimize destructive sampling of trees and lack of instruments to accurately measure standing tree upper stem diameters) and, in some cases, not representative of the economy;
- Some of the equations were local volume equations, which used only DBH as the independent variable and did not include tree height;
- The past equations were focused on areas to be logged (mainly big trees), yet, since the national logging ban, the interested has shifted to protected areas that include smaller trees; and
- The species grouping was too broad (e.g., volume equations by tree family).

The commonly used existing equations are the local tree volume equations developed by Pochai and Nanakorn (1992). These equations developed by the RFD based on upper stem diameter measurements of standing trees using a Spiegel Relaskop. However, these equations were developed for one local area in northern Thailand using a small sample of trees. Yet, they are commonly applied nationally.

As well, the specific gravity coefficients used to convert volume to biomass were developed based on a small sample of trees. Finally, the generally assumed carbon/biomass fraction of 0.47 (IPCC 2006), for converting biomass to carbon, is too general. The IPCC indicates that "… higher tier methods may allow for variation with different species, different components of a tree or a stand (stem, roots and leaves) and age of the stand …" (IPCC 2003, page 3.25).

A new and novel approach has been developed at KUFF to estimate standing tree carbon content as a function of standing tree attributes (total height and DBH), using sample tree increment cores or wood samples. Some research has been successfully done by Kasetsart University Faculty of Forestry (KUFF) on ways to directly estimate carbon content on standing trees using wood samples (increment cores)

(Duangsathaporn et al. 2011). Other studies have used wood samples to determine carbon content (e.g., Kraenzel, et al. 2003; Wutzler, et al. 2006). Through this project, Thailand sought financial assistance and technical support from APFNet to demonstrate this new approach that could be used to develop new national standing-tree carbon equations. These equations could be used to estimate carbon stocks in Thailand's natural forests. This project demonstrated this process in Mae Huad sector, Ngao Demonstration Forest in Lampang province.

1.2 Project goal(s) and objectives

1.2.1 The overall goal

The project overall goal was to provide accurate information on national forest carbon stocks to support informed sustainable forest management policy decision-making and balanced public debate on the benefits of forests in climate change mitigation.

1.2.2 The specific objective

The project specific objective was to demonstrate the development of accurate standing-tree carbon equations and their application to the preparation of a forest-cover carbon stock map in the Ngao Demonstration Forest, Lampang Province, Thailand.

1.3 Project expected outputs and outcomes

Expected Outputs were:

Output 1: Methodology to construct new tree carbon equations developed and pilot-tested.

Output 2: Application of tree carbon equation to prepare a carbon cover map demonstrated.

Output 3: Action plan to construct and promote national standing-tree carbon equations prepared.

Output 4: Information and knowledge from the project disseminated among stakeholders

Expected Outcomes were:

1. Methodology to construct and apply tree carbon equations is available, and, as a by-product, accurate tree carbon equations for the major species groups in three natural forest types in the demonstration project area are available.
2. An action plan for the development of national standing-tree carbon equations for all the major tree species groups in Thailand is available.
3. Information and knowledge from the demonstration project disseminated.

2. PROJECT IMPLEMENTATION

2.1 Project schedule and implementation arrangements

A project agreement signed between the Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet) and Kasetsart University in January 2017 to demonstrate the development and application of standing-tree carbon equations to improve the accuracy of forest-cover carbon stock estimates in Thailand. The KUFF was the project Executing Agency and the Thailand Royal Forest Department was the Supervisory Agency. . The project was to be implemented over a two-year period 2017-2018. The implementation of project components and activities was on track and satisfactory as outlined below. More details of the implement status are shown in Annex A.

Year 1 (2017): Key project milestone in Year 1 mainly involved field data collection and included the following:

- Established 54 point sampling plots on a systematic 3x3 km grid over the project demonstration area of the Mae Huad Sector, Ngao Demonstration Forest, and recorded sample tree species, DBH, total height and wood density.
- Summarized sample tree data into average and per-hectare statistics including basal area, number of species, wood density by species, and Importance Value Index (IVI).
- Grouped the sample trees into DBH classes, wood density classes, forest types and species groups.
- Selected 450 sample trees from which 900 wood samples were extracted (two wood samples each tree). Upper stem diameters of the sample trees were also measured to calculate tree whole-bole wet volume.
- Conducted land-use classification of the project area using the colour ortho-aerial photograph taken in 2002 and updated with the newest Landsat-8 satellite data acquired in 2017.

Year 2 (2018): Key project milestone in Year 2 mainly involved the construction of standing-tree carbon equations and the forest-cover carbon stock map, and transfer these knowledge to the related users and organizations via the workshop meeting, brochure and website. The activities were included the following:

- Determined carbon contents from the 900 collected wood core samples.
- Constructed standing-tree carbon equations.
- Acquired and classified remote sensing data to construct NDVI map.
- Model relationship between NDVI and carbon stocks in all sampling points to generate carbon stock map.
- Established new 54 point sampling plots on a systematic 3x3 km grid over the pilot project area of the Mae Huad Sector, Ngao Demonstration Forest and recorded sample tree species, DBH and total height.
- Calculated carbon stocks of new 54 point sampling plots by using the standing-

tree carbon equations and NDVI map

- Determined the differences in carbon stock between the carbon stock map and the ground plot estimates
- Conducted a focus group and workshop meeting and established project website and brochure in order to transfer the knowledge.

2.2 Project resources and costs

The total budget for the project was 253,345 USD, which APFNet assured grant was 199,045 USD and the counterpart contribution was 54,300 USD. The APFNet assured grant was disbursed in three times by 101,795 USD; 79,685 USD and 17,565 USD, respectively. The initial and second disbursements of 181,480 USD were completed, and the third disbursement of 9,565 USD (minus cost of 8,000 USD for evaluation) will be disbursed after all required documents specified in the agreements were proposed to APFNet. The actual expenditure of 255,486.45 USD was composed of APFNet disbursed grant for 200,468.67 USD, counterpart contribution for 55,017.78 USD, and self-expenditure for 2,141.45 USD. The project financial details are shown in Annex B. The project director worked closely with the project management team to monitor the expenditure and disburse the project budget according to the Annual Working Plans (AWP), for smooth project progress and achievement of the project goals and objectives.

2.3 Procurement and consultant recruitment

A notebook computer was the only asset purchased to use under the project.
The list of consultants with their types of tasks and outputs are shown in the table below.

No.	Consultant	Task	Output
1	Project Director	Project design, management, monitoring and reporting	The project documents including: 1) Focus Group meeting minutes; 2) National Workshop report; 3) Two technical reports; 4) Project brochure and 5) Project website.
2	Tree ID Expert	Tree species identification	Identified tree species for IVI and individual tree species carbon calculation
3	Remote Sensing Expert	NDVI and carbon stock map construction	Carbon stock map

No.	Consultant	Task	Output
4	Biometrician	Standing tree carbon equation construction	Standing tree carbon equations
5	Data Analysts	Estimate the ratios of tree carbon content to wet volume with individual standing tree and research site carbon stocks	Carbon stocks from standing tree carbon equations
6	Technical Assistants	Support the experts for forest inventory, tree growth measurement and sample wood collection	Tree growth data and sample wood for carbon content analysis
7	The Soil Analyzed Laboratory, Department of Silviculture, KU	Carbon analysis in wood samples	Carbon content (%) in wood samples
8	Ms. Ladda Harnpichitchai, Lockton Wattana Insurance Broker (Thailand) Ltd.	Financial audit and report preparation	Financial audit report
9	Mr. Jaturawit Jantarasriwongs, Plaping Holding Co., Ltd.	Website design and construction	Project website
10	Mr. Pornarong Surangkan, DD Media Plus Co., Ltd.	Brochure design and printing	Project brochure

2.4 Monitoring & evaluation and reporting

The project quality monitoring and evaluation were conducted in both of internal and external processes. A Project Steering Committee (PSC) meeting, together with the Project Management Team (PMT), was held at the beginning of the project to understand the project methodology and visit the study site at the Ngao Demonstration Forest, Lampang province, Thailand. During the data collection and analysis, several meetings of the PMT were often held to track the progress of the project and reduce errors from work and report activities that might not be completed on time. A focus group meeting, involving independent experts from relevant organizations, was held to evaluate the methodology and the results. The documents of the project, annual work plan and progress reports were prepared and submitted

to APFNet on time. The PMT responded to all recommendations and suggestions from APFNet and addressed any issues to achieve high-quality reports.

2.5 Dissemination and knowledge sharing

The outputs of the project including the knowledge of methodologies to construct carbon equations and carbon stock map, and the constructed standing-tree carbon equations were provided to the relevant organizations and interested persons by conducting a national workshop. The objectives of the workshop were to provide a better understanding and transfer knowledge of carbon estimation in a standing tree and forest stand using novel carbon equations and remote sensing techniques, and to discuss a national work plan on the development of national standing-tree carbon equations and forest carbon stock map to improve the accuracy of tree-bole carbon stock estimates in Thailand.

Forty-two participants, including those from primary and secondary stakeholders, attended the workshop. The primary stakeholders consisted of representatives from the Royal Forest Department (RFD: 8 persons) and the Department of National Parks, Wildlife and Plant Conservation (DNP: 8 persons). The secondary stakeholders included representative from the Department of Marine and Coastal Resources (DMCR: 2 persons), the Geo-Informatics and Space Technology Development Agency (GISTDA: 1 person), the Office of National Resources and Environmental Policy and Planning (ONEP: 1 person), the Forest Industry Organization (FIO: 1 person), the Food and Agriculture Organization of the United Nations (FAO: 3 persons), the Thailand Environmental Institute (TEI: 3 persons), the Thailand Greenhouse Gas Management Organization (TGO: 1 person), the Biodiversity-based Economy Development Office (BEDO: 1 person) and the University members from Mahidol University, Chiang Mai University and Kasetsart University (13 persons).

The two technical reports and brochure from the project were printed and distributed to the relevant organizations. Project website (http://www.apfnet-kuff.com/) was also developed and easily accessible worldwide. The technical reports and brochure can be downloaded from the website.

3. PROJECT PARTNERES' PERFORMANCE

3.1 Performance of Supervisory Agency

The Supervisory Agency (SA) (the Royal Forest Department) performed well. It acted as a national focal point to fully support the project executing agency by facilitating and coordinating with APFNet. The RFD sent the relevant experts to attend and give advice to the project focus group meeting. The RFD also sent the operational staff who worked relating to forest inventory to attend the workshop held in order to transfer technology and knowledge derived from the project.

3.2 Performance of Executing Agency

The Executing Agency (EA), which was Kasetsart University – Faculty of Forestry (KUFF), performed well. It had responsibility to regularly prepare and get approved all documents of the annual work plans, progress reports, financial report, technical reports and completion report before proposing to APFNet to meet the specified schedule.

The project implementation involved mainly the KUFF. Other organizations and their relevant staff were invited to attend the project focus group meeting and national workshop. The project was successful as a result of colleagues with expertise in various fields such as the tree species ID expert, biometrician, remote sensing expert, data analysts and technical assistants who are faculty members, as well as doctoral and master degree students under the Laboratory of Tropical Dendrochronology, KUFF. The information technology and knowledge derived from the project were provided by the Plaping Holding Co., Ltd. and DD Media Plus Co., Ltd. working on website and brochure development, respectively, to design and distribute these information to other interested people. Website and brochure design was carried out smoothly with close coordination between the Project Management Team and these two companies.

3.3 Performance of APFNet

APFNet spared valuable time to provide: i) timely support and clear guidance for project planning, implementation and management; ii) timely disbursement of project grant; iii) effective communication with project executing agency and partners in proper facilitation in undertaking project activities and project dissemination; and iv) external monitoring and evaluation during the project implementation and shared swift feedbacks accordingly.

4. PROJECT PERFORMANCE

4.1 Project achievements

The Project rationale and problem were properly defined, as were the objectives and choice of implementation strategy. The project specific objective was achieved: demonstrated the development of accurate standing-tree carbon equations and their application to the preparation of a forest-cover carbon stock map in the Ngao Demonstration Forest.

The project was well implemented and the outputs achieved were:

1. Methodology to construct and apply tree carbon equations was demonstrated, and, as a by-product, accurate tree carbon equations for the major species groups in three natural forest types in the project demonstration area were available.

2. An accurate forest-cover carbon stock map of the Mae Huad Sector of Ngao Demonstration forest was prepared.

3. A national action plan for the development of national standing-tree carbon equations for all the major tree species groups in Thailand was prepared. The plan shall be proposed to the Ministry of Natural Resources and Environment to create awareness and publicize to interested agencies.

4. A workshop on the project results was held to transfer knowledge to potential users of the carbon equations. As well, two technical reports, a project brochure and a website were prepared.

The methodology to construct new tree carbon equations was developed and was demonstrated in three forest types of Mixed Deciduous (MDF), Dry Dipterocarp (DDF) and Dry Evergreen Forests (DEF) at the Mae Huad Sector, Ngao Demonstration Forest, Lampang province in the northern Thailand. The analysis of wood carbon contents using C/N analyzer indicated the average tree bole carbon contents in MDF, DDF and DEF for 47.61, 47.50 and 47.17%, respectively. The 10 specific carbon equations covered wood density ranges in each forest type, and a general equation for all tree species in each forest type, were constructed. The general equation to evaluate tree bole carbon equation for all forest types at the Mae Huad Sector was $C = 0.012348(D^{2.1676} H^{0.6539})$ where C was carbon storage in stem bole (kg/tree), D was diameter at breath height of tree (cm) and H was total height of tree (m). The estimated carbon storage in tree bole at the project site was 34.66 tons/ha.

In order to apply tree bole carbon equations to generate a carbon stock map of the project site, remote sensing techniques were used for land use classification and Normalized Difference Vegetation Index (NDVI) generation. The NDVI, ranging from -1 0 to +1, was used as an independent parameter in a linear regression equation for predicting the carbon stock (C) in each sampling point. The regression model in the form of linear equation was $C = 154.68\ NDVI - 72.991$ ($R^2 = 0.2297$). The NDVI in all pixels were applied to calculate carbon contents and generate the carbon stock map for 36.98 tons/ha or 16.39 million tons for the total area of the Mae Huad Sector, Ngao Demonstration Forest. For quality assessment, forest inventory in 45 independent sampling points was done and another carbon stock map was re-generated. The ratio between the mean map carbon estimates and mean ground estimates was equal 1.0768 or the map provided 92.87 % of the ground estimate. A statistical test to determine the statistically significant differences between the carbon map estimates and the 54 inventory samples was done using a Student's t-test. These differences were not statistically significant.

A focus group meeting with 10 selected experts from the relevant governments and private agencies including RFD, DNP, and MONRE, was held to review project results and develop an action plan for the full-scale construction of national standing-tree Carbon

equations for the major tree species in Thailand. The experts understood and did not oppose the novel technique to evaluate carbon contents in tree boles and suggested the Project Management Team (PMT) to expand the study sites into all regions and all forest types of Thailand. A draft national action plan was also prepared by the PMT. It included: 1) activities and resources for tree data collection; 2) analysis and tree carbon equation dissemination and promotion; 3) institutional set-up for maintaining and updating the equations; 4) capacity building and resource requirements; 5) priority actions and 6) establish policy brief document for distribution to related government authorities such as MONRE, DNP, RFD, NESDP, TGO, MCRD and FIO.

To transfer knowledge and information from the project to the relevant stakeholders, a national workshop involving about 40 stakeholder representatives was conducted. The workshop agenda were included discussion of the project demonstration results, the draft action plan and the next steps. Many participants also suggested PMT to extend the project area to other forest types. It was consistent with PMT intention to implement the national work plan to develop national standing-tree carbon equations and forest carbon stock map to improve the accuracy of tree-bole carbon stock estimates in Thailand. The workshop report and two technical reports were prepared. A project brochure summarizing the project objectives, methods and results was prepared and also loaded onto the project website, as were the documentation of workshop proceedings and technical reports.

4.2 Project Impacts

The project has created awareness of the weaknesses of the existing carbon estimating systems. In particular, the project has demonstrated that in Thailand, the normally used IPCC factor of 0.47 used to convert tree biomass to carbon content should be slightly higher (up to 0.48, in most forest types in this project demonstration area). Thus, the Thailand Greenhouse Gas Management Organization (TGO) and the Government of Thailand can consider to inform the IPCC of the higher carbon/biomass fraction when reporting carbon sequestration in Thailand.

The project has highlighted the need to develop new accurate national tree carbon estimating equations. It has developed a national work plan to construct new standing-tree carbon equations and carbon stock maps. If this plan is implemented and the resulting new tree carbon equations are adopted nationally, this will have economic and environmental impacts. The new tree carbon equations for calculating carbon stock in forest stands will be more representative and reflect actual, but likely slightly lower estimated, carbon content accumulated in the forest sector of Thailand. They will also contribute to more accurate estimation of carbon credit and monetary compensation from forest conservation for carbon sequestration.

4.3 Sustainability

Tree carbon equations and stock map from the demonstration area shall be widely publicized by KUFF to the relevant organizations. The KUFF shall also seek local and international funding to implement the national project plan to cover the main species in all forest types and regions of Thailand. In case funding support is received to scale up the project results to all regions of the country, the final report will be proposed to the Government of Thailand to consider and announce to the local and international organizations to use the new national carbon equations for calculating forest carbon sequestration in Thailand. On the other hand, in case of no funding support, the completion report with two technical reports, brochure and project website will be proposed to the Ministry of National Resources and Environment in order to transfer knowledge of the new technique for demonstrating the development and application of standing-tree carbon equations to improve the accuracy of forest-cover carbon stock estimates to the relevant organizations and the interested people. The KUFF is well positioned to maintain and update the carbon equations, since it has a critical mass of professors and graduate students qualified in this field.

5. CONCLUSION, LESSONS LEARNED AND RECOMMENDATIONS

5.1 Conclusion

The overall conclusion is that the Project was a success. A major achievement of the project has been the creation of awareness of new methodologies of preparing tree carbon equations and carbon stock maps that can be implemented nationally. The project has also developed a national action plan to scale-up the project methodologies to the national level, to produce tree carbon equations and stock maps for major forest types and regions of Thailand.

5.2 Lessons learned and recommendations

The project Overall Goal could not be attained during the term of this project. This project demonstrated the methodology for developing tree carbon equations, however, until these techniques are scaled-up to the national level, the Overall Goal cannot be achieved. The project management team encountered a problem of currency exchange rate fluctuation causing deviations in the budget originally specified in the Project Document for some activities. The PMT took steps to solve this problem by re-allocating the remaining money from some activities to complete the project as planned. Perhaps these monetary fluctuations should be built into the budget during the project planning.

The project start date should have been extended to the date the first installment of the APFNet grant was deposited into the project bank account, from the date of the documents contract signing. In the case of this project, the bank deposit occurred two months after the contract signing, which delayed start of project activities by the same

period.

6. REFERENCES

Duangsathaporn, K., P. Sangunthum and P. Prasomsin. 2011. **Carbon sequestration of timber product in teak plantation.** Kasetsart University, Bangkok. (in Thai).

IPCC. 2003. Good practice guidelines for land use, land-use change and forestry. International on Climate Change. **IGES**, Japan.

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories. International on Climate Change. **IGES**, Japan.

Issare. M. 1982. **Primary Production of plant Communities in old Clearing Arears at Sakearat Environmental Research Station, Pakthongchai, Nakhon ratchasema**. M.S.thesis. Kasetsart University. Bankok. Thailand (in Thai)

Kajornsrichon S. 1988. **Some Ecological Characteristics of Natural Pine Stands at Ban Wat Chan Royal Project, Amphoe Mae Chaem, Changwat Chiang Mai.** M.S.thesis. Kasetsart University. Bankok.Thailand (in Thai)

Kraenzel, M., A. Castill., T. Moore and C. Potvin. 2003. Carbon storage of harvest-age Teak (*Tectona grandis*) plantations, Panama. For. Ecol. Manage. 173, 213-225.

Ogawa, H., K. Yoda, K. Ogino and T. Kira. 1965. Comparative ecological studies onthree main types of forest vegetation in Thailand. II. Plant Biomass. **Nature and Life in Southeast Asia** 4 : 49-80.

Ogino, K. et al. (1967) The primary production of tropical forests in Thailand. Tonan Ajia Kenkyu. **Jpn. J. Southeast Asia Stud.** 5: 121-154 (In Japanese).

Sahunalu P. 1981. **Primary production of pine plantations I. Net primary production of various age plantations of *Pinus kesiya* royle ex gordon at hod Chiang Mai. Forestry reseach report Volume 77.** Faculty of forestry. Kasetsart University.Bankok.Thailand (in Thai)

Tsutsumi T., K. Yoda, P. Sahunalu, P. Dhanmanonda and B. Prachaiyo. 1983. Forest: Felling, Burning and Regeneration. In Shifting cultivation. An experiment at NamPhrom, Thailand and its implications for upland farming in the monsoon Tropics. Edited by K. kyuma and C. Pairintra. p. 13-62.

US Geological Survey; https://earthexplorer.usgs.gov/

Weier, J., and Herring, D., 2008. Measuring vegetation (NDVI & EVI). [Online] Available URL: http://earthobservatory.nasa.gov/Library/MeasuringVegetation/July 22

Wutzler, T., B. Kostner and C. Bernhofer. 2007. Spatially explicit assessment of carbon stocks of a managed forest area in eastern Germany. **Eu J Fo Res.** 126: 371-383.

ANNEXES

ANNEX A: Project Implementation Status

Project Objective/Outputs/Activities(in line with PD/AWPs)	Indicators (in line with PD/AWPs)	Baseline of activities	Progress made(%completion of activities and degree of output/objective achievement)	Appraisal time	Actual time
Objective 1. Methodology to construct and apply tree carbon equations is available, and, as a by-product, accurate tree carbon equations for the major species groups in three natural forest types in the demonstration project area are available.					
Output 1: Methodology to construct new tree carbon equations developed and pilot-tested.					
Activity 1.1: Collect sample tree field data	Sample tree field data	NA	100%	7/2017	9/2017
Activity 1.2: Analyze sample core sample	Sample core carbon content	NA	100%	10/2017	12/2017
Activity 1.3: Construct tree carbon equations	Tree carbon equations	NA	100%	11/2017	2/2018
Activity 1.4: Prepare a technical report	Technical Report No. 1	NA	100%	12/2017	3/2018
Output 2: Application of tree carbon equation to prepare a carbon cover map demonstrated					
Activity 2.1: Acquire and classify remote sensing data	Classified remote sensing data and NDVI map	NA	100%	6/2017	9/2017
Activity 2.2: Model relationships between the ground and remote sensing data	Carbon - NDVI Modelling	NA	100%	5/2018	5/2018
Activity 2.3: Collect and compile ground mapping data	Compiled ground mapping data	NA	100%	7/2018	7/2018

Project Objective/Outputs/Activities(in line with PD/AWPs)	Indicators (in line with PD/AWPs)	Baseline of activities	Progress made(%completion of activities and degree of output/objective achievement)	Appraisal time	Actual time
Activity 2.4: Prepare final carbon stock map and technical report	Final carbon stock map and technical report No. 2	NA	100%	8/2018	9/2018
Objective 2. An action plan for the development of national standing-tree carbon equations for all the major tree species groups in Thailand is available					
Output 3: Action plan to construct and promote national tree carbon equations prepared					
Activity 3.1 Select Focus Group (FG) members	List of FG members	NA	100%	8/2018	9/2018
Activity 3.2 Conduct a one-day FG meeting	One-day FG meeting and Minutes	NA	100%	8/2018	9/2018
Activity 3.3. Prepare draft national Action Plan	National Action Plan	NA	100%	9/2018	10/2018
Objective 3. Information and knowledge from the demonstration project disseminated					
Output 4: Information and knowledge from the project disseminated among stakeholders					
Activity 4.1. Prepare workshop materials	Workshop PPT slides	NA	100%	9/2018	10/2018
Activity 4.2. Conduct workshop	Workshop	NA	100%	10/2018	11/2018
Activity 4.3. Prepare workshop proceedings (report)	Workshop proceeding (report)	NA	100%	12/2018	12/2018
Activity 4.4. Prepare project completion report, website and brochure.	Project completion report, website and brochure	NA	100%	12/2018	12/2018

ANNEX D: Project Audit Report

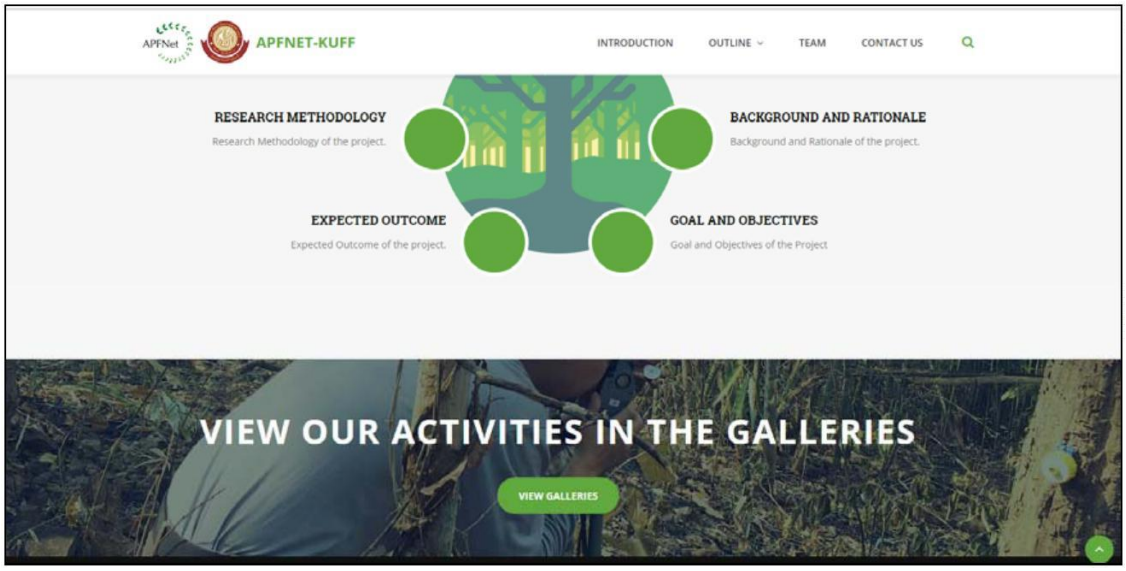
The audit report has been submitted to APFNet separately for financial checking.

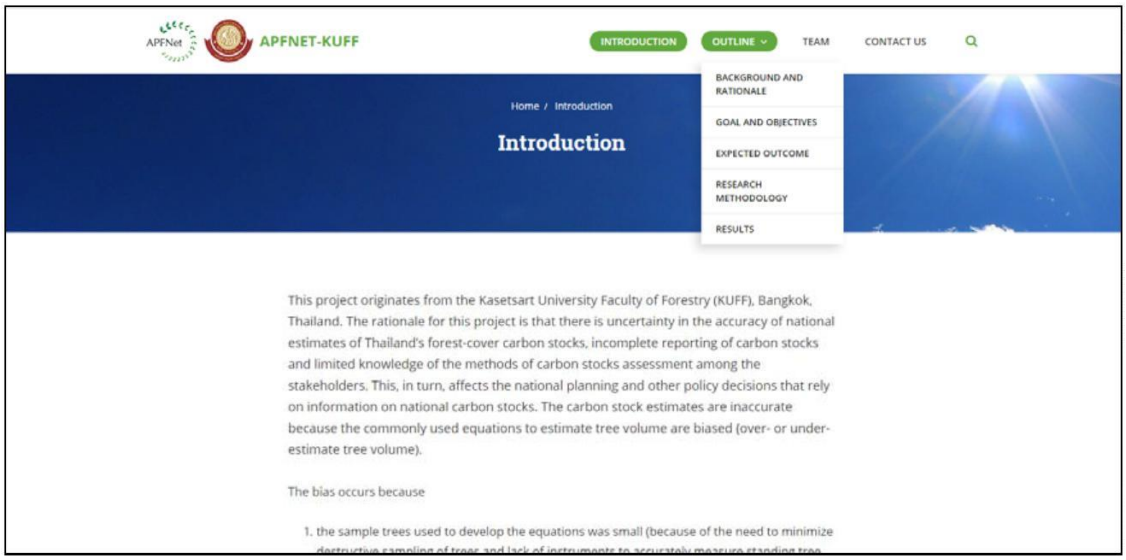
ANNEX E: Project Outputs

The project outputs were:

1. Focus Group meeting minutes
2. National Workshop report
3. Two technical reports
4. Project brochure
5. Project website

The Focus Group and workshop reports and two technical reports have been separately submitted to APFNet. What follows is an illustration of only the project brochure and website.





The Project Website: http://www.apfnet-kuff.com/home/

TO DEMONSTRATE THE DEVELOPMENT AND APPLICATION OF STANDING-TREE CARBON EQUATIONS TO IMPORVE THE ACCURACY OF FOREST-COVER CARBON STOCK ESTIMATES IN THAILAND

Project Management Team

Kasetsart University Faculty of Forestry (KUFF)
Bangkok Thailand
Contact us: fforkcd@ku.ac.th

Problems to be Addressed

This project originates from the Kasetsart University, Faculty of Forestry (KUFF), Bangkok, Thailand. The rationale for this project is that there is uncertainty in the accuracy of national estimates of Thailand's forest-cover carbon stocks, incomplete reporting of carbon stocks and limited knowledge of the methods of carbon stocks assessment among the stakeholders. This, in turn, affects the national planning and other policy decisions that rely on information on national carbon stocks.

A new and novel approach has been developed at KUFF to estimate standing tree carbon content as a function of standing tree attributes (total height and DBH), using sample tree increment cores. Through this project, Thailand sought incremental financial assistance and limited technical support from Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet) to demonstrate this new approach that could be used to develop new national standing-tree carbon equations. These equations could be used to estimate carbon stocks in Thailand's natural forests.

Goal and Objectives

The overall goal is to provide accurate information on national forest carbon stocks to support informed sustainable forest management policy decision-making and balanced public debate on the benefits of forests in climate change mitigation.

The specific objective is to pilot-test the development of accurate standing-tree carbon equations and their application to the preparation of a forest-cover carbon stock map in the Ngao Demonstration Forest, Lampang Province.

Project Site

The project target area for the demonstration project is the Mae Huad Sector, Ngao Demonstration Forest (NDF) locate in the north-west of Lampang Province in northern Thailand. The Mae Huad Sector covers an area of 43,431.75 hectares, including several forest types.

Figure 1 The area of Ngao Demonstration Forest (NDF) (left) and the layout and boundary of Mae Huad Sector (right)

Project Methodology and Results

❶ Field sample tree data were collected using technique of Forest Inventory, Point sampling, Tree identification and Forest mensuration. The result found that the 45 tree species in 3 forest types are including the mixed deciduous forest (MDF), the dry evergreen forest (DEF) and the dry dipterocarp forest (DDF).

Figure 2 Field sample tree data collection

❷ The groups of tree species were classified using the list of wood density and Importance Value Index (IVI) for 10 groups in each forest type, for a total of 30 groups.

❸ Sample tree collections for tree volume and wood carbon fraction analysis were done by using the technique of Forest Inventory, Forest Mensuration and Dendrochronology. A total of 30 major tree species from 3 forest types (10 species each forest type) were selected. In each tree species, wood samples from 15 sample trees with small, medium and large size classes were collected using an increment borer.

Figure 3 Sample tree collections

❹ Wood carbon fraction was analyzed using the Combustion Technique. The fresh and dry weights of wood samples were measured. These samples were pulverized to analyze the carbon fraction in the laboratory using the C/N analyzer. It was found that the average of carbon fraction in wood sample was 47.43 %.

Figure 4 Wood carbon fraction analysis

❺ The standing tree bole carbon equations were constructed using the Regression Analysis as a function of total height and DBH. The resulting carbon equations were constructed by forest type: mixed deciduous forest (Table 1), dry dipterocarp forest (Table 2) and dry evergreen forest (Table 3). Additionally, the general tree carbon equation of the Mae Huad Sector is as follows:

$$C = 0.012348\, D^{2.1636}\, H^{0.6589}$$

Where: C = Carbon sequestration in stem bole, kg/tree
D = Diameter at breath height of the tree, cm
H = Total height of the tree, m

Table 1 The carbon equations classified by wood density of tree species in the mixed deciduous forest

No.	Sample Species	Carbon Equations	DBH Range (cm)
1	*Ficus var.pubescens* *Canarga latifolia* *Bombax insulare*	$C = 0.008730\ D^{2.355}\ H^{0.550}$	13.2-43
2	*Tetrameles nudiflora* *Elaeocarpus stipularis* *Croton roxburghii* *Grewia elastica* *Litsea ghatensa* *Sterculia pexa* *Atlanthus triplyna*	$C = 0.019454\ D^{2.223}\ H^{0.328}$	16.2-63
3	*Cleidion spiciflorum* *Lannea coromandelica* *Canarium subulatum* *Miliusa velutina*	$C = 0.001538\ D^{3.014}\ H^{0.432}$	11.8-58
4	*Radermachera pierrei* *Tectona grandis* *Lagerstroemia duperreana* *Terminalia nigrovenulosa*	$C = 0.018836\ D^{2.503}\ H^{0.886}$	8.7-71
5	*Buchanania latifolia* *Spondias bipinnata* *Dipterocarpus turbinatus* *Dipterocarpus costatus* *Albizia odoratissima* *Terminalia bellerica* *Lagerstroemia macrocarpa* *Dillenia obovata*	$C = 0.011350\ D^{2.569}\ H^{0.958}$	11.0-29
6	*Stereospermum neuranthum* *Anogeissus acuminata* *Terminalia nigrovenulosa* *Vitex canescens* *Chukrasia velutina* *Eugenia cumini* *Vitex pubescularis*	$C = 0.067764\ D^{2.051}\ H^{0.255}$	15-69
7	*Pterocarpus macrocarpus* *Madhuca thorelii* *Diospyros ehretioides*	$C = 0.014093\ D^{2.668}\ H^{0.773}$	11.5-61.5
8	*Xylia xylocarpa* *Millettia brandisiana* *Irvingia malayana* *Terminalia alata* *Schleichera oleosa*	$C = 0.011967\ D^{2.947}\ H^{0.757}$	13.2-68.8
9	*Butea monosperma* *Dalbergia oliveri*	$C = 0.017539\ D^{2.576}\ H^{0.545}$	11.1-42.8
10	*Quercus kerrii* *Terminalia corticosa* *Diospyros mollis*	$C = 0.005957\ D^{2.996}\ H^{0.919}$	13.2-66.5
11	General Equation for all species/wood density groups	$C = 0.018155\ D^{2.7554}\ H^{0.890}$	8.7-71

Table 2 The carbon equations classified by wood density of tree species in the dry dipterocarp forest

No.	Sample Species	Carbon Equations	DBH Range (cm)
1	*Mitragyna brunonis*	$C = 0.006353\ D^{2.227}\ H^{0.835}$	13-44.1
2	*Bridelia pierrei*	$C = 0.004887\ D^{2.648}\ H^{0.738}$	10-28.6
3	*Gardenia sootepensis*	$C = 0.020417\ D^{2.355}\ H^{0.496}$	11-2.4
4	*Haldina cordifolia* *Buchanania latifolia*	$C = 0.001928\ D^{2.854}\ H^{0.819}$	10.2-41.9
5	*Dipterocarpus obtusifolius.*	$C = 0.000975\ D^{2.981}\ H^{1.277}$	13.1-42.5
6		N/A	
7	*Dalbergia assamica* *Pterocarpus macrocarpus*	$C = 0.014093\ D^{2.668}\ H^{0.773}$	11.5-61.5
8	*Shorea siamensis* *Millettia brandisiana* *Shorea obtusa* *Terminalia alata* *Irvingia malayana* *Quercus kerrii*	$C = 0.022751\ D^{2.286}\ H^{0.458}$	11.2-58.2
9	*Xylia xylocarpa* *Dalbergia oliveri*	$C = 0.017539\ D^{2.576}\ H^{0.545}$	13.2-66.8
10	*Quercus SP.* *Terminalia corticosa*	$C = 0.005957\ D^{2.996}\ H^{0.919}$	13.2-66.5
11	General Equation for all species/ wood density groups	$C = 0.009462\ D^{2.828}\ H^{0.802}$	10-66.8

Table 3 The carbon equations classified by wood density of tree species in dry evergreen forest

No.	Sample Species	Carbon Equations	DBH Range (cm)
1	*Parkia leiophylla* *Tetrameles nudiflora* *Duabanga grandiflora*	$C = 0.049317\ D^{2.397}\ H^{0.397}$	18-147
2	*Adenanthera pavonina* *Cleidion spiciflorum* *Croton roxburghii* *Podocarpus neriifolius* *Bischofia javanica*	$C = 0.019498\ D^{2.393}\ H^{0.393}$	12.5-42
3	*Hiliocarpus annamensis* *Castanopsis acuminatissima* *Harpullia arborea* *Careya sphaerica*	$C = 0.012134\ D^{2.476}\ H^{0.668}$	12.0-3830
4	*Artocarpus lakoocha* *Terminalia nigrovenulosa* *Dipterocarpus costatus* *Eugenia aequea* *Lagerstroemia tomentosa*	$C = 0.001549\ D^{2.958}\ H^{0.851}$	11.10-47.30
5	*Dillenia obovata* *Cratoxylum formosum* *Hopea odorata* *Schima wallichii*	$C = 0.003192\ D^{2.587}\ H^{0.876}$	9.7-26.2
6	*Anogeissus acuminata*	$C = 0.015560\ D^{2.389}\ H^{0.629}$	18.6-71.7
7	*Pterocarpus macrocarpus*	$C = 0.014093\ D^{2.668}\ H^{0.773}$	11.5-61.5
8	*Terminalia alata*	$C = 0.062624\ D^{2.503}\ H^{1.086}$	12.8-52.7
9	*Xylia xylocarpa* *Dalbergia cultrata* *Dalbergia oliveri* *Terminalia nigrovenulosa*	$C = 0.049317\ D^{2.397}\ H^{0.397}$	13.2-66.8
10	*Quercus SP.* *Quercus lamellosa* *Quercus kerrii* *Terminalia corticosa*	$C = 0.006353\ D^{2.482}\ H^{0.668}$	10.9-43.7
11	General Equation for all species/ wood density groups	$C = 0.011803\ D^{2.3944}\ H^{0.3171}$	9.7-147

6 The estimation of carbon sequestration in each sample point using the statistical analysis indicated carbon sequestration in Mae Huad Sector was 41.04 ton/ha.

7 The carbon stock map was constructed using the technique of Remote Sensing and Regression Analysis. The satellite data of two image bands (red and near-infrared bands) derived from Landsat 8 with a spatial resolution of 30 meters was used to generate the Normalized Difference Vegetation Index (NDVI). Carbon contents and the NDVI values in all sampling points were related by using Regression Analysis. The related pattern was applied to construct the carbon stock map. It was found that the total carbon stock in the form of living standing trees (boles) in the Mae Huad Sector, Ngao Demonstration Forest was estimated at 1,638,729 Tons.

8 The quality assessment (QA) of the carbon stock map using techniques of Land-use cartography, Forest Inventory, Forest Mensuration, Tree Identification, Remote Sensing and QA analysis indicated the relative difference of the carbon stock was only 11.40%.

Acknowledgement

The project was partly funded by a grant from the Asia-Pacific Network for Sustainable Forest Management and Rehabilitation (APFNet).

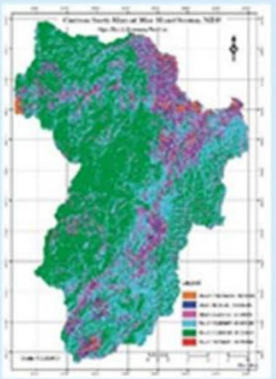


Figure 5 Carbon Stock Map of Mae Huad Sector, Ngao Demonstration Forest, Lampang Province

ANNEX F: Feature Stories from the Project for Promotion

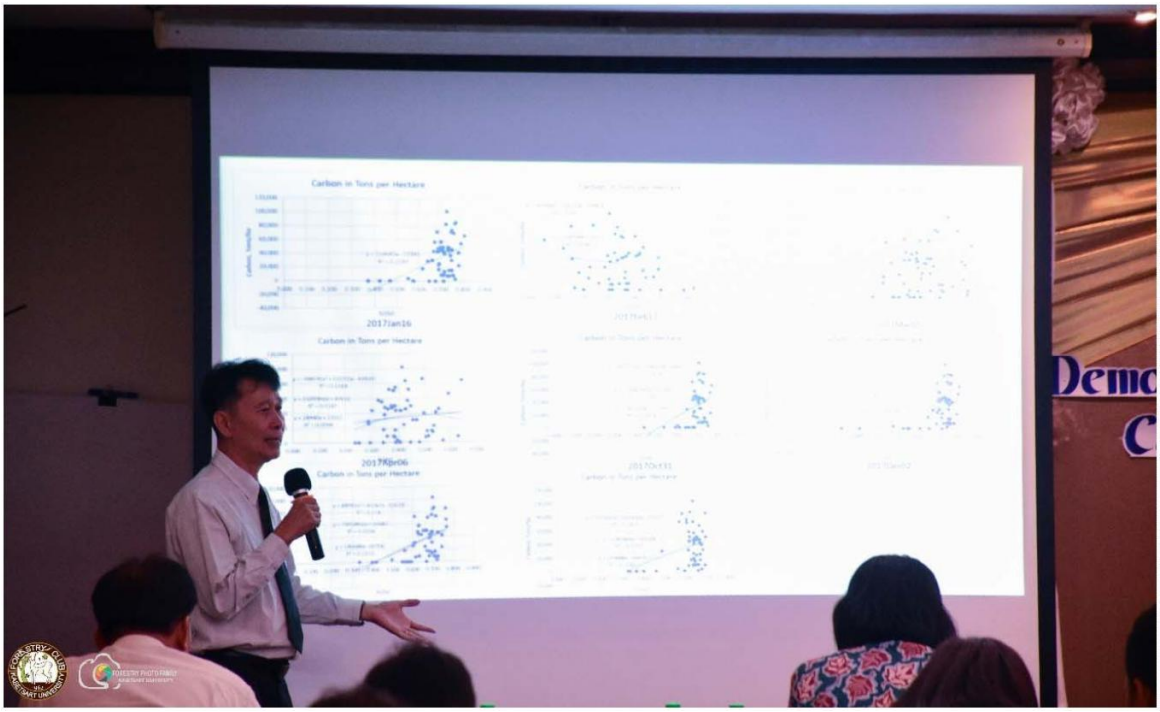
1. The Focus Group Meeting

Project Management Team informed the project results

Project Management Team lead the discussion of national action plan

2. The National Workshop

Project overview by Assist. Prof. Dr. Khwanchai Duangsathaporn, Thailand Project Director



The presentation by Assoc. Prof. Prasong Saguantam

The workshop discussion

The workshop discussion (Cont.)

The workshop discussion (Cont.)

ANNEX F: Photos, media cliffs and other materials Used/Available for Project Outreach

Project photos during implementation are available in the project website and https://drive.google.com/drive/folders/1TVTO2jimTDkvMe3q13mNK-8z6SdzF4JQ?usp=sharing