Doctoral Thesis

LOW-CARBON WATERSHED MANAGEMENT: INTEGRATION OF RENEWABLE ENERGY SUPPLY AND DECENTRALIZED WASTEWATER TREATMENT - A CASE STUDY IN VIETNAM

（ベトナムにおける再生可能エネルギーと分散型排水処理の組み合わせによる低炭素型流域管理方法の提案）

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ABSTRACT

Vietnam is among the most climate change vulnerable and disaster-prone nations, and water is the first sector to be affected by climate change. Being one of the developing countries launching climate policies, the country has recently announced to strive for a low-carbon economy. Nevertheless, there is a mismatch in the development strategy for the power sector and the climate-related policies which might lead to the ambiguous in the further implementation of climate change mitigation strategies. To achieve sustainable development and green growth, the government goal is to increase renewable energy share to 9.4 % and wastewater treatment to 80 % in the year 2030. However, there are no specific guidelines to accomplish the multiple targets. The research goal is to propose the integrated mechanism of renewable energy supply (run-off-river hydropower) and decentralized wastewater treatment system. The proposed mechanism is expected to reduce greenhouse gas emission from power generation and alleviate environment pollution from domestic wastewater.

The objective of this study has been three-fold. First, to estimate the potential of small hydropower (in the form of run-off-river hydropower) and its contribution to greenhouse gas emission reductions in the representative river basin of Vietnam. Second, to estimate the potential for greenhouse gas emission reductions by providing adequate domestic wastewater treatment facilities. Third, to demonstrate the co-benefits of the integrated mechanism through scenario analysis, considering social, financial feasibility and carbon crediting scheme.

The result of our study highlighted that run-off-river hydropower potential has potential to fulfill the electricity demand for the rural villages in the Vu Gia-Thu Bon

River basin, especially remote communities without access to the grid with the total capacity 277 MW with a capacity factor of 40.2 %. Also, off grid hydropower can serve as alternative electricity source to ensure the reliability of the grid by reducing grid load, prevent from blackout and brownout. Besides, renewable electricity generation from ROR hydropower scheme will provide power for decentralized wastewater treatment facilities within the watersheds.

This study proposes scenario four is the most applicable for the region with the GHG reduction amount of 0.45 mil.tCO_2eq. In this scenario, the Japanese Johkasou system could serve 30 % of the total rural household especially in the mountainous areas in the up and middle stream of the Vu Gia-Thu Bon River basin, where the population density is relatively lower than the downstream. In populated areas downstream, centralized or semi-centralized wastewater treatment system is favored and more efficient.

Full implementation of ROR hydropower generation and wastewater treatment system would reduce the total amount of 0.38 million tCO_2eq per year (on-grid) and 0.60 million tCO_2eq per year (off-grid).

Regarding financial aspect of investment in wastewater treatment facilities, the main budget comes from external assistant Official Development Assistance (ODA) in the form of grants, technical assistance and loans; and the priority is to invest in urban wastewater treatment. Therefore, the obstacle for installation of Johkasou and wastewater treatment system in the rural and less developed area remains as one of the biggest challenges. Nevertheless, this treatment scheme, besides environmental conservation, a substantial amount of GHG emissions can be reduced. With existing Carbon trading schemes, this system has potential to attract carbon finance from Clean Development Mechanism (CDM) or Joint Crediting Mechanism (JCM) projects.

Emissions reduction from wastewater treatment can be credited to existing carbon-trading scheme, to minimize the initial cost of system construction including installation of Johkasou. On the other hand, GHG emissions can also be reduced utilizing renewable energy for wastewater treatment eliminates grid emissions. The high uncertainty of emission calculation can be minimized by the accessibility of local data or existing empirical data.

The research finding indicates government's GHG emissions reduction target in the waste sector can be set up to 16 %. Moreover, a method to develop emission inventory for wastewater treatment in rural areas of developing countries from the watershed approach is proposed. Also, this study raises the potential of utilizing existing carbon emission trading schemes for an initial investment of the wastewater treatment facilities through carbon credit.

Also, the small hydropower system has a lower cost compared with conventional diesel generator based system, and even lower than the retail electricity tariff from the government. The economic advantage can interest private entities to invest in rural electrification even without government subsidies. Therefore, creates advantages for implementing on/off-grid hydropower than other renewable energy such as the wind or solar PV.

The negative abatement cost for small hydropower over conventional diesel generator which is - 195.51 USD/tCO_2 (off grid) or -48.18 USD/ tCO_2 indicates that cost for CO_2 mitigation can be saved. Although this result is vary depending on the fuel price projection as well as plant capacity and discounted value of electricity sold, the similar negative value is observed from Blum et al., (2013).

Finally, the demonstration of co-benefits was performed by scenario-based analysis. The result shows that under domestic conditions the project return period is

18.39 years, and IRR is 8.5 %. The IRR for base case is smaller than the benchmark IRR, which is 10% indicate that this project would likely not happen. If the project is implemented under the integrated mechanism, the project payback periods are from 7.31 years to 18.17 years and IRRs are from 10.04% to 26.57%.

Our study also emphasizes the potential of ROR hydropower development for rural electrification in the context of Vu Gia-Thu Bon River basin. This study employed the holistic approach to providing private entities as well as foreign investors with a comprehensive assessment of demand, supply, and economic values. The results from this study may assist the private sector to make the decision for investment in rural electrification projects.

The study provides quantitative evidences for the government of Vietnam, policy makers as well as developers. There is a potential to establish and implement an integrated mechanism for sustainable energy supply and rural development by utilizing existing emission trading schemes such as CDM co-benefits or JCM

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1 INTRODUCTION

1.1 Background

1.1.1 Problem statement

Sustainable development and climate change are the two biggest challenges that the world is facing today. Climate change influences the natural and living conditions specially to developing countries where the development heavily depends on natural resources. On the other hand, sustainable development can restrict vulnerability to climate change and GHG emissions.

Vietnam economy has recently emerged as one of the most active economies in the world, it also facing challenges relating to climate change and energy security. In particulary, the vulnarablity to climate change, and the coupled between energy sector and climate related policies creates dificulties in implementing climate change mitigation measures.

With current economic development, by the year 2025, the country will need to increase its primary energy supply by at least 3 - 4 times and its electricity generation by 6 - 7 times the level seen in the year 2007 (Dinhlong Do,Il Hwan Ahn, Suduk Kim, 2010). The energy sector in Vietnam is similar in other countries, has the largest share in GHG emission. In 2010, GHG emission proportion from energy sector was 35 %, equivalent to 52.8 $TgCO_2eq$ of total 150.9 $TgCO_2e$ emissions (MONDRE, 2010) and will continue to increase as projection until 2030. Emissions from energy, agriculture, and land use- land use change and forestry sectors are projected to be 169.2, 300.4, and 515.8 $TgCO_2eq$ in 2010, 2020, and 2030, respectively. The energy sector accounts for 91.3 % of projected total emissions for 2030. Although the energy sector puts effort to maintaining the share of renewable energy supply, the main source of electricity generation comes from fossil fuel. Since 2006, carbon emissions from the power sector has been doubled for over four year's period together with the increasing of electricity supply. The emission factor of the national grid is reported to increase from 0.54 to 0.57 tCO_2/MWh in 2011 and 2013 respectively.

Vietnam is one of the most climate change vulnerable and disaster-prone countries (Dasgupta et al,.2007). Latest projection indicates that Vietnam will be especially hard hit by sea level rise, and intense and frequent extreme weather (Chaudhry & Greet, 2007; IPCC, 2007a). Climate change can affect the spatial and temporal distribution of water resource as well as intensity and frequency of the extreme hydrological event (Khoi & Hang, 2014). Consequently, climate change may generate extreme impact on socioeconomic development and challenging the natural resource management system of the country, especially water resource management system (Giang, Toshiki, & Sakata, 2012).

Being one of the developing countries launching climate policies, Vietnam has recently announced to strive for a low-carbon economy. The policy shift from pure adaptation towards mitigation was mainly motivated by the restructuring of the economy, strengthening energy security, and attracting international finance (Zimmer, Jakob, & Steckel, 2015). The first only climate change policies which have been entered the national policymaking agenda is known as the National Target Program to Respond to Climate Change (NTP-RCC) approved in 2008, and later the National Climate Change Strategy (NCCS) approved in 2011. The second policy that directly addresses climate change mitigation issues aiming at restructuring the economy is the Vietnam National Green Growth Strategy (VGGS) approved in 2012. Both of this policy targeting to reduce

GHG emissions, however, while NTP-RCC solely address to adaptation measure, the NCCS states that adaptation and mitigation should be carried out in parallel (NCCS, 2011), and the VGGS define explicit emission reduction targets, especially the energy sector. The VGGS commits itself to reduce GHG emissions from energy activities by 10 % in 2020 and 20 % in 2030 (VGGS, 2012). The VGGS target seems ambitious when compared with the latest Power Master Plan VII in July 2011. Power Master Plan VII targeting the increasing the share of the coal-fired power plant to 48.0 % in 2020, and 51.65 % in 2030 while renewable energy (include small hydropower) to 5.6 % of total electricity production in 2020, and 9.4 % in 2030. As a result, emission factor from electricity grid will increase to 0.67 in 2020 and 0.72 tCO_2 per MWh (Power Master Plan VII, 2011). This mismatch in the development strategy for the power sector and the climate-related policies might lead to the ambiguous in further implementation.

1.1.2 Rural electrification and small hydropower development in Vietnam

Rural electrification in Vietnam is seen as a successful story when the electrification rate increases from 2.5 % to 96 % for just over 30 years from 1975 to 2000 (Gencer et al., 2011). The high electrification rate is comparable to other developing countries with higher GDP such as China or Thailand (Asian Development Bank, 2011). However, the challenges of rural electrification remain with the 4 % household lacking of access to electricity and the reliability of electricity provision including prevention of blackout and brownout (Bjorn Linnemann, 2011).

In much low population density areas where the cost of grid extension is too costly or too difficult to access due to geographical conditions, the off-grid system is chosen. According to the latest data from the Vietnam Institute of Energy, the total of 169 off-grid renewable electricity projects was built, mostly located at the north mountain region of the countries. In a study by ADB (2011), small hydropower off-grid is mostly suitable for the northern mountainous, northwest, central north and central south of the countries. These regions have favorable conditions for developing hydropower schemes such as water resources, and geographical conditions. For instance the Vu Gia- Thu Bon river basin in the central south is the major water resource for the region especially high potential for hydropower development. The area with 75 % of hills and mountains are favored for small and medium hydropower projects. This river basin locates within the tropical monsoon climate region and influenced by the Truong Son mountain range with relatively high precipitation but unevenly distributed over the basin regarding spatial and temporary.

Small hydropower is amongst renewable energy sources that have the high potential not only to supply for the local communities living in rural and remote areas but also to increase renewable energy share, hence reduce the grid emission factor. Unfortunately, the potential of small, medium hydropower has not been studied in the country although there were some different official numbers between 2925 MW and 4015 MW (PECC1, 2005). Besides social and economic assessment of the development of small hydropower projects has not been developed, therefore it is difficult to project as well as implement feasible strategies in the power sector to address climate change and restructure the economy towards low carbon economy. Also, hydropower is water resource dependence sector which is highly likely to be affected by climate change; thus the medium and long-term projection of small medium hydropower development is needed.

1.1.3 The state of wastewater discharge and treatment of the country

Currently, the urban population is 28 %, and the proportion of population have access to drainage and wastewater treatment facilities is still too low comparing to the proportion have access to drinking water supply services. There is only 40 % to 50 % of the urban population served by sewage system, in which only 10 % of the wastewater collected is treated with adequate treatment technology before entering the environment (WHO, IHEMA, & Unicef, 2012). The rest of urban wastewater is discharged into natural water bodies. Under tropical climate with relatively high temperature throughout the year, anaerobic processes take place to different extents and methane is released into the atmosphere (IPCC, 2006).

Meanwhile in rural areas, the most common sanitation practice is household latrines. Household wastewater (including gray water and black water) is collected in underground chambers and leached to ground or discharged directly to farmland or gardens, eventually entering open water bodies. The high methane conversion factor (MCF) value of household latrines (Doorn, Liles, & Thorneloe, 2000; IPCC, 2006) indicates a significance amount of methane emission from this treatment facility. Thus, having a proper wastewater treatment facility would reduce GHG emissions from domestic wastewater discharge and handling. However, the inventory of GHG emission from wastewater sector as well as options to reduce GHG emission in the sector was not described in any of Climate Change mitigation policies of the country. Also, taking the sectoral approach by targeting each sector (i.e. emissions targeted in VGGS (2012)) in the economy might result in unbalance of development in the sector because many of the sectors are highly independent on each other especially the nexus of water, energy sector.

Methane emission from wastewater treatment is among the major sources of GHG emissions besides CO_2 and N_2O. Methane emission results from the two main routes: the decomposition of degradable organic under anaerobic condition and the air exposure of flow containing dissolved CH_4.Under anaerobic condition, organic matters contain in wastewater are decomposed by anaerobic bacteria (e.g. the enitrification or dephosphorization process) results in the generation of CH_4. Also, CH_4 dissolved in wastewater could be released into atmosphere via surface exposure. Recent research on GHG emissions from domestic wastewater was seen mostly in small scale or some specific treatment processes. Work conducted by Ma et al., (2015) is among few studies that focus on the general condition of domestic wastewater using the IPCC methods for GHG emissions inventory for wastewater discharge and handling (hereafter called IPCC methods). This study found that the emissions from domestic wastewater treatment could be reduced by 10 % or 0.0763 Mt in the year 2020 scenarios. However this study as well as IPCC method is significant regarding trend and peak of GHG emissions, the allocation of GHG from spatial dimension was not considered especially from emissions from the watershed. In a study by Galloway et al., (1996), emission from watershed was analyzed because watersheds have structural and functional characteristics that can reflect and influence how human interacting within the watershed system. In this analysis, the watershed is considered as one of the four major reservoirs, namely: atmosphere, watershed, coastal and shelf region, and open oceans. The result of this study shows the major source of N is from N-fertilizer input. However, this study did not include inputs from sewage discharge to the watershed. Another related study from (B. Liu, Wei, Zhang, & Bi, 2013) examined the life cycle GHG emissions from sewage sludge treatment in the Tai Lake Watershed in China. This study selects different sludge treatment and disposal processes to reduce emissions in the watershed and suggests the optimum choice for the Tai Lake Watershed. The proportion of GHG emission from this process calculates about 40% of total emission from sewage treatment and handling (Brown, Beecher, & Carpenter, 2010; Siddiqi & Anadon, 2011). The case of Tai Lake is much different from other developing countries, where sewage discharged without proper treatment and became the major source of GHG emissions from rivers and streams. Therefore, it is important to study the GHG emissions from wastewater discharge and handling in the watershed to provide the optimum solution of the wastewater system for the river basin.

1.1.4 The Co-benefits Approach to Climate Change Mitigation

a. Emission Trading Schemes

Carbon Emission Trading Schemes are considered as the cornerstone to facilitate climate change mitigation.

The Kyoto Protocol is the largest ETS up to now. This is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. The protocol offer 3 market based mechanisms including Emission Trading (ET), Clean Development Mechanism (CDM) and Joint Implementation (JI)

Although Japan is abandoning the Kyoto protocol mechanism after March 11 incident, the nation is establishing a bilateral offset scheme that appears to be modeled on the CDM. The Japanese bilateral offset credit mechanism (BOCM) relies on a series of bilateral agreements between Japan and developing countries, whereby Japanese investors can fund an emissions reduction projects in partner countries. The financing program will finance part of an investment cost (up to the half), as premises for seeking to deliver JCM credits (at least half of issued credits) to government of Japan..

b. Eligible Criteria for Project Approval under the Clean Development Mechanism and the Joint Crediting Mechanism

In order to be eligible for funding under CDM or JCM, the project has to meet the criteria set by the project approval committee on addtionalility and co-benefits.

- Additionality is defined as the property of an activity being additional. A proposed activity is additional if the recognized policy interventions are deemed to be causing the activity to take place (Michael Gillenwater, 2012)

- Co-benefits of climate change mitigation projects is defined as the project that both targeting climate change mitigation at a global level and contributing to local sustainability through environmental pollution alleviation.

c. Small Hydropower Projects under CDM

Hydropower is the most prevalent project type in the CDM pipeline. It accounts for 25% of total 9.7 billion of certified emission reduction (CERs) in the year 2020. The favorability of developing hydropower under emission trading schemes was not only because it is the most effective way to reduce emission but it also brings profit in selling of electricity. However the co-benefits of developing a hydropower projects are still under debate. A study by Zhang and Wang (2011) reveals that hydropower project developed under CDM does not have a statistically significant effect in lowering sulfur dioxide emissions. To address the debate, the criteria on co-benefits of developing a hydropower project has been more emphasized under existing international offset schemes (CDM, JCM).

1.2 Research Goal and Objectives

The research goal is to propose the integrated mechanism of renewable energy supply (run-off-river hydropower) and decentralized wastewater treatment system. The proposed mechanism is expected to reduce greenhouse gas emission from power generation and alleviate environment pollution from domestic wastewater.

The objective of this study has been three-fold. First, to estimate the potential of small hydropower and its contribution to greenhouse gas emission reductions in the representative river basin of Vietnam. Second, to estimate the potential for greenhouse gas emission reductions by providing adequate domestic wastewater treatment facilities. Third, to demonstrate the co-benefits of the integrated mechanism through scenario analysis, considering social, financial feasibility, and carbon crediting scheme.

1.3 Scope of Study

This study examines the feasibility of implementing the mechanism to supply ROR hydropower and decentralized wastewater treatment for the rural areas of Vietnam by utilizing the existing climate finance support under Emission Trading Schemes (JCM) in a combination of national regulations. The implementation of the proposed mechanism would meet the increasing demand for household electricity consumption but not to increase the grid emission as to projection. On the other hand, the proportion of electricity generated will be allocated for operation of wastewater treatment system to reduce the system O&M costs. The implementation of wastewater treatment also results in environmental improvement and ensures the high access to adequate wastewater treatment for rural households. The co-benefits achievements from the proposed mechanism will be the benchmark for implementation of the mechanism.

The term integrated mechanism is defined as the market based mechanism that linking climate change mitigation and environmental pollution alleviation (co-benefits) in one project package.

This study set the boundary for analysis including the following conditions:

- This study analyzed the technical potential of run-off-river hydropower in the Vu Gia Thu Bon river basin, a representative basin of Vietnam. The potential for storage-pump hydropower potential was not covered. The hydrological models were developed for five subbasins. However, only Thanh My basin model was calibrated and validated. Due to observation data availability, after calibration/ validation of Thanh My sub-basin was done, the calibrated parameters were applied for the remaining sub-watersheds with the assumption that the model would give similar performance.

- Regarding wastewater treatment for rural communities, this study covered only three types of treatment including household latrines, conventional activated sludge treatment, and Johkasou. Greenhouse gas emissions were estimated only for direct GHG emissions that are methane emission from domestic wastewater treatment and indirect GHG emissions through electricity import for system operation. In the scope of this study, CO_2 and N_2O emissions from wastewater treatment were not considered. The CO_2 emission is biogenic origin that is part of the natural carbon cycle and does not contribute to global warming. Therefore it was not included in natural GHG emissions inventory. The N_2O emission was not included because of insufficient data and large uncertainties associated with the IPCC default emission factors for N_2O from effluent (IPCC, 2006).

- The financial parameters including capital investment, O&M cost data were obtained from the household survey, and existing literature including domestic sources and international sources, when there is the absence of domestic data.

1.4 Structure of Dissertation

The remainder of the dissertation is structured into four chapters as described below:

- Chapter two highlights the literature review, where some basic terminologies, concepts, and reviewed literature on key issues such as water, energy nexus, Integrated Water Resources Management, climate change mitigation were introduced.

- Chapter three highlights the methodology of the research that explains detail the process of collecting and analyzing data from the field and model development.

- Chapter four: the potential of small hydropower in the representative river basin of Vietnam was analyzed. Estimated run-off-river hydropower potential in Central

Vietnam was performed using a distributed hydrologic model and energy duration curve method. The result indicates total run-off-river hydropower potential is 277.342 MW with an average capacity factor of 40.2 %, which means the system can generate 1.02 million MWh in a year. The result indicates that ROR hydropower can be alternative system together with the national grid that provides electricity for rural households especially households living in remote areas and have no access to the national grid.

- Chapter five: four GHG emissions scenarios were examined, as well as the baseline scenario, to verify the potential of GHG reduction from domestic wastewater with adequate treatment facilities. The ArcGIS and Arc Hydro tools were employed to visualize and analyze GHG emissions resulting from the discharge of untreated wastewater, in rural areas of Vu Gia-Thu Bon River Basin, Vietnam. By applying the current IPCC guidelines for GHG emissions, we found that a reduction of GHG emissions could be achieved through treatment of domestic wastewater in the studied area. Compared with baseline scenario, a maximum 16 % of total GHG emissions can be reduced, in which 30 % of households existing latrines are substituted by Japanese Johkasou technology and other 20 % of domestic wastewater is treated by conventional activated sludge.

- Chapter six: the second and third pillar of sustainable development namely social and economic sustainability is addressed through household questionnaire survey and financial analysis. This chapter first examined rural electricity demand for a typical rural typical household by employing questionnaire survey. The total number of household respondents was 146 households. The financial analysis consists of estimating the investment cost, operation and maintenance cost, levelised cost of electricity generation, and abatement cost.

- Chapter seven presents the scenario-based analysis of the integrated mechanism under different input parameters. The policy framework was assumed following the development of one base case and five typical scenarios. The benchmarking analysis of project investment was performed to demonstrate co-benefits of the financial investment under the integrated mechanism. The sensitive analysis was then performed.
- Chapter eight gives the conclusions and ending with the provision of possible solutions and recommendations.
- Apart from main chapters, annexes were embedding to give detail information of questionnaire.

2 LITERATURE REVIEW

2.1 The Water, Energy and Climate Nexus Challenges

2.1.1 Climate change and water variability

In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources regarding quantity and quality (IPCC, 2014b). Climate change impact on water resources is related to extreme weather events such as flood, drought, or other abnormal climate phenomena. Extreme hydrological events are likely to increase in frequency, duration and magnitude in climate-sensitive regions (Burke, Brown, & Christidis, 2006; Milly, Dunne, & Vecchia, 2005; Sivakumar, 2011)

Water availability

Climate change has potential to affect surface water availability by altering river flow regimes (World Bank, 2013a). Arnell & Gosling (2013) assess the impacts of climate change on hydrological regimes across the global domain, using a global hydrological model run with climate scenarios constructed using pattern-scaling from 21 CMIP3. They conclude that by the year 2050 the "significance" change in hydrological regimes will likely to occur over a substantial proportion of land surface (in relative to the 1961–1990 mean). Another assessment done by Milly et al. (2005) suggests that the total annual river runoff is projected to increase between 105 and 40% for the period 2041 - 2060 for the A1B scenario. Up to date, a number of researches have been conducted to evaluate the potential impact of climate change to surface water from different regions such as Africa (Arnell, 2004), Asia (Bates, Kundzewicz, Wu, & Palutikof, 2008), Australia and New Zealand (Beare, 2002), Europe (Alcamo, Florke, & Marker, 2007), North and South America (Bates et al., 2008) (Table 1).

Climate change impact on groundwater has received less attention compare with other impacts such as groundwater withdrawal and land use change (Taylor et al., 2013). Reduce in precipitation and increased evapotranspiration by climate change will reduce groundwater recharge (Treidel, Jose, & Jason, 2012). Increased precipitation intensity may decrease groundwater recharge owing to an exceedance of the infiltration capacity (typically in humid areas), or may increase it owing to faster percolation through the root zone and thus reduced evapotranspiration (typically in semiarid areas). A study by Liu et al. (2011) conclude that in dry areas groundwater recharge and deep-rooted vegetation coverage increase with decreasing rainfall frequency (for a given amount of annual rainfall), with increasing average rainfall depth per rainfall event (for a fixed frequency) and with increasing frequency (for a fixed rainfall depth per rainfall event).

Table 1 - Project impact of climate change to surface water resource at regional scale

Region	Project impact	Source
Asia	Decrease in river runoff in January in Chao Phraya River basin in Thailand In Mekong River basin, monthly flows will decrease by 17-24%	(Bates et al., 2008; Champathong et al., 2013)
Africa		
North Africa	Climate change will impact 22% water shortage in 2050	Droogers et al.(2012)
North and South Africa	Decrease in runoff by 2055	(Arnell, 2004)
East Africa	Increase in runoff by 2055 Flows of Blue Nile will be reduced due to combination of climate change and upstream water development projects Stream flow in Nile River will increase (2010-2039), but will decline in the latter half of 21st century (A1 and B1 scenario)	(Arnell, 2004; Beyene, Lettenmaier, & Kabat, 2010; Elshamy, Seierstad, & Sorteberg, 2009)
West Africa	Slight mean increase in the Volta basin Substantial reduction in runoff in the Bani River basin (A2 scenario)	(Kunstmann, Jung, Wagner, & Clottey, 2008; Ruelland, Ardoin-Bardin, Collet, & Roucou, 2012)

Region	Project impact	Source
Europe		
	Current 100-year return period discharge will increase in Continental Europe but decrease in some part of Northern and Southern Europe by 2100	(Dankers & Feyen, 2008; Rojas, Feyen, Bianchi, & Dosio, 2012)
	North Europe: Annual average runoff will increase by approximately 5-15% by 2020s and by 9-22% by 2070s (A2, B2 scenario) South Europe: Annual average runoff will decrease by 0-23% by 2020s and by 6-36% by 2070s	(Alcamo et al., 2007)
America		
North America	Annual mean precipitation will decrease in the southwestern USA, but increase over the most areas in the North America by 2100. Therefore runoff will decrease or increase accordingly	(Bates et al., 2008)
Central and South America	Central America: Lempar river basin runoff will decrease 13-24% (scenario B1, A2) In central Chile, annual stream flows of the upper snowmelt-driven watersheds of the Limarí River will decrease due to reduction in precipitation	(Maurer, Adam, & Wood, 2009; Vicuna, Garreaud, & McPhee, 2011)

Water quality

With the effects of climate change (higher water temperature and variation in runoffs) are likely to impact water quality in rivers and streams (IPCC, 2007a). The major sources of NO_2 and N_2 emission in river streams are from agriculture activities, especially leachate Nitrate from the application of N-fertilizer (Bustamante et al., 2014; Mercedes M C Bustamante et al., 2015; Mosier et al., 1998). On the other hand, NH_4 mainly from untreated sewage inputs is the primary source of GHG emission from urban rivers and streams (Garnier et al., 2006; Harrison, Matson, & Fendorf, 2005; Watanabe, Ortega, Bergier, & Silva, 2012). With the present of climate change, warmer and wetter climate can lead to higher rates of nitrogen mineralization to atmospheric and aquatic environments (Galloway et al., 2004). In additional, in tropical ecosystem a rise in anthropogenic Nitrogen input would increase Nitrogen lost into the atmosphere (Matson, McDowell, Townsend, & Vitousek, 1999), this process induces climate change effect on the Nitrogen cycle. A study conducted by Hien et al,.(2015) found that climate change has a significance impact on water quality in the Cau River water (Vietnam), more specifically, the higher GHG emissions scenario cause a higher increase in annual NH_4+ load in river water.

Figure 1 shows the data of total GHG emission from the waste sector from some selected Non-Annex 1 countries with high economic growth in Asia, Annex 1 countries (Japan, USA) and EU countries (28 nations). In China, India, Vietnam, and Thailand, GHG emission from wastewater handling contributes a considerable amount compare with that of solid waste disposal on land. Developed countries, with advanced wastewater treatment system, emissions from this sector are less than emission from waste disposal.

Climate change with groundwater utilization will influence groundwater recharge and discharge thus impact on groundwater quality. Groundwater level decrease may lead to groundwater quality degradation due to the unbalancing of fresh water and saline water. This problem occurs not only in coastal areas but also inland aquifer due to the increasing pumping rate. Nevertheless, there are few studies on climate change and groundwater quality as compare with groundwater quantity (Treidel et al., 2012). coastal erosion cause the saltwater–freshwater interface to migrate inland over a distance of 37 m and to rise by 6.5 m near the coast to 3.1 m further inland. Table 2 shows the potential impact of climate change on groundwater quality through a change in recharge patterns and land use.

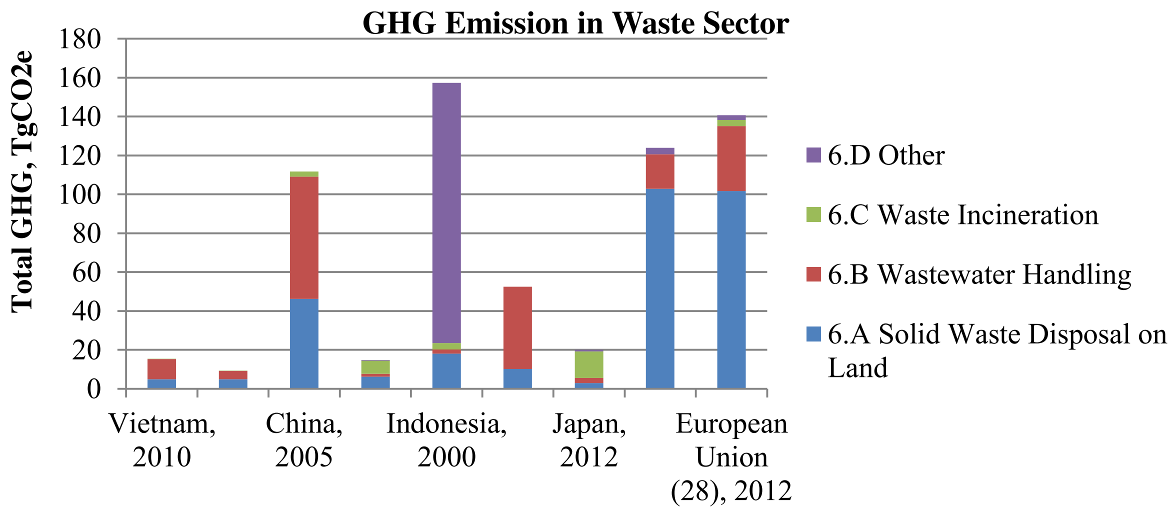

Figure 1 - GHG Emissions in Waste Sector
for selected Non-Annex 1 countries in Asia and Annex 1 countries
Source: UNFCCC Data Interface[1]

Lemineux et al. (2015) simulate the impact of climate change on groundwater resources of the Magdalen Island, Canada for a 28-year period. The authors conclude that the combination impact of sea-level rise, decreasing groundwater recharge and

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[1] The reporting and review requirements for GHG inventories are different for Annex I and non-Annex I Parties. The definition format of data for emissions/removals from the forestry sector is different for Annex I and non-Annex I Parties. Report produced on Tuesday, 20 October 2015 07:51:24 CEST

Table 2 - Potential scenarios and foreseen impacts on groundwater quality due to climate change (Kløve et al., 2014)

Scenario	**Foreseen impact on groundwater**	**Potential impact on aquifers**	**Potential impacts on ecosystems**	**Uncertainty related to impact**
Increased leaching due to more intense rainfall	Increased leaching of water soluble contaminants such as nitrates	Increased concentration of pollutants	Potential Impacts on ecosystems – Eutrophication and pollution	Changes in precipitation intensity vary regionally (this change is mainly foreseen for dry and warm climate)
Sea level increase	Saltwater intrusion in coastal aquifers	Increased groundwater salinity	More seawater exchanges to coastal lagoons. Changes in groundwater flow patterns in coastal ecosystems	The amount of intrusion will depend on coastal aquifer system water level and amount of water extraction
Changed agricultural practice	Increased leaching of water soluble nutrients due to longer growing season and/or intensified irrigation	The increase in agriculture can lead to increased pollution. Lower groundwater levels due to	Eutrophication, salinization. Reduced discharge to ecosystems	Increased CO_2can lead to less transpiration counteracting the irrigation needs and risk

Scenario	Foreseen impact on groundwater	Potential impact on aquifers	Potential impacts on ecosystems	Uncertainty related to impact
	Increased need for pesticides in cold climate	higher irrigation may add to the problem		of increased leaching
Changed snow accumulation and melt	Increased winter time groundwater recharge in a temperate climate with seasonal snow cover. Changes to the timing of snowmelt and corresponding recharge	Increase risk of salt intrusion from road runoff as more salt is use and recharge occur in winter	No direct impacts known on that change water quality in ecosystems	

2.1.2 Energy projection with climate change implications

Energy production and use affect climate both directly and indirectly. Energy use can change the amount of CO2 and other greenhouse gasses in the atmosphere as well as heating or cooling the immediate environment (PJ & MO, 1990; Virginia H. Dale,Rebecca A.Efroymson and Keith L.Kline, 2011).

Greenhouse gas emissions from the burning of fossil fuel for energy industry contribute two-third of the world total anthropogenic GHG emissions (Figure 2). The energy-related GHG emission increased from 20 $GtCO_2e$ in 1985 to 35 $GtCO_2e$ in 2014, in which CO_2 emissions from fossil-fuel combustion were over 90 % (International Energy Agency, 2015). The power generation sector contributes 25% of total GHG emissions by sectors, followed by agriculture, forestry and other land use 25%.

Greenhouse gas emissions from electricity generation and heat production are the largest source of global greenhouse gas emissions (Figure 3). Emission from electricity and heat generation in non-OECD countries leading by China have doubled since the beginning of the 21st century. The turning point between economic growth and energy-related emissions growth has been observed in the OECD in recent years with 1.8% decrease in emissions but 1.8% increase in economic development. The emissions reduction was due to the increasing of renewable energy shares and electricity efficiency. However, the couplings between economic development and energy-related emissions have been observed in the rest of the world. The major driver of this coupling is that most emerging and developing countries are in the energy-intensive process of building up their capital stock.

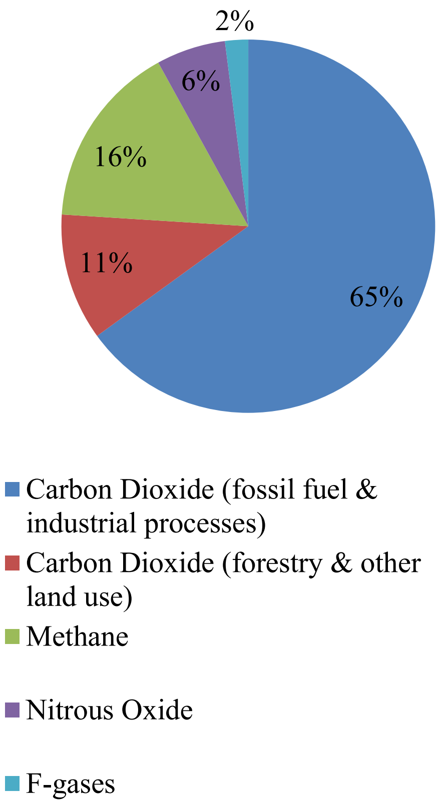


Figure 2- Global Greenhouse Gas Emissions by Gas (IPCC, 2014a)

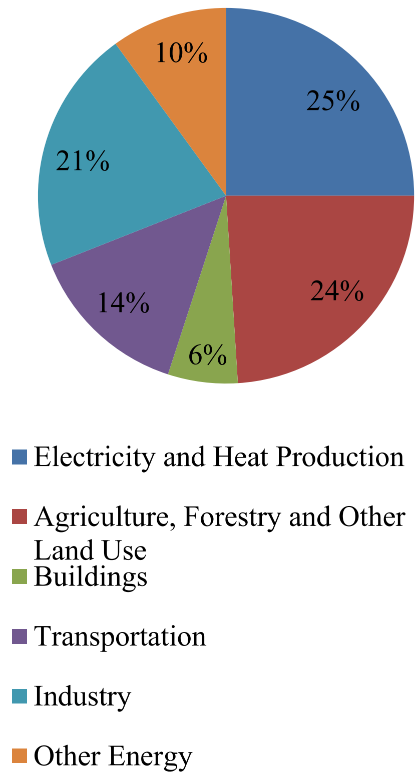


Figure 3- Global Greenhouse Gas Emissions by Economic Sectors (IPCC, 2014a)

Climate change results in a change of temperature, precipitation, sea level and frequency of extreme event would likely affect the energy sector in all phases from production, transmission/delivery, and consumption.

Temperature rises in summer and fall in winter would increase electricity demand for cooling and increase fuel for heating (oil, natural gas, coal). In a recent publication from IPCC (2007), the energy consumption in a nation for cooling would increase by approximately 5-20% when average temperature increases 1°C or increase by 3-15% when the temperature decreases 1°C.

Climate change affects to water availability would likely result in the capacity factor of power plants. Electric hydropower plant would likely be affected by the variability of water volume and stream flows. The decrease in precipitation might reduce electricity output. Increasing frequency or magnitude of the flood would likely affect hydropower dams while drought may pose a conflict between other water users such as irrigation, fishery.

2.2 The Water, Energy, Climate Nexus in Vietnam

The water - energy nexus

In our modern society, water and energy systems are interdependent. Water is used in all phases of energy production and electricity generation. Energy is required to extract, convey, and deliver water for diverse human uses, and then again to treat wastewater before their return to the environment.

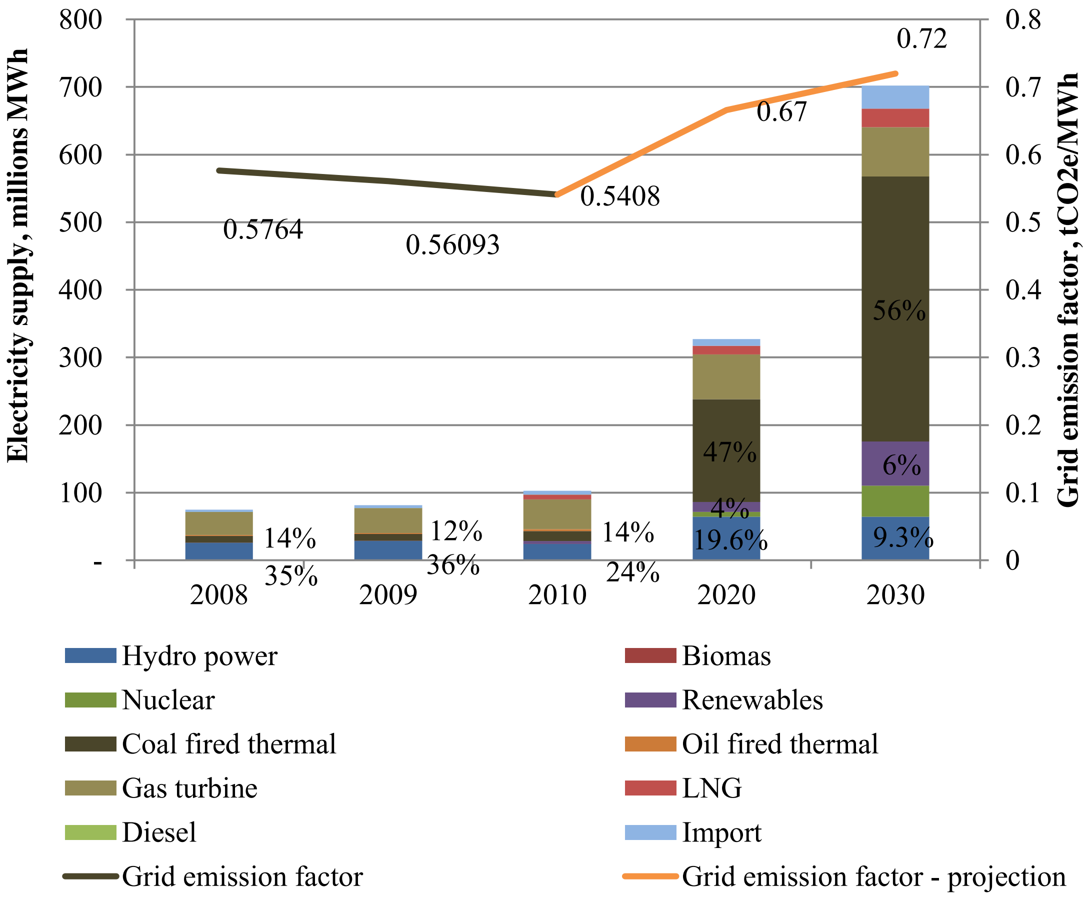


Figure 4 - Vietnam Energy Mix and Hydropower Proportion

Thanks to its abundant in water resource and dense river network, creating an advantage for Hydropower generation. Hydropower infrastructure development in Vietnam has been one of the priorities for economic development for over half a century, and yet has an enormous contribution to national economy. From 1980 hydropower accounted for only 20 % of Vietnam electricity mix; it increased to 60.4 % in 1990 and early 2008 accounted for 37.09 %.

To provide efficient use of energy resources to meet the demand for power with increasing quality, reasonable price for socio-economic development; ensure the national energy security, the government prioritizes hydropower development by maintaining the share of 25.5 % in the total energy mix in 2020 and 15.7 % in 2030 (MOIT, 2011). According to current statistic, the total capacity of water reservoirs is about 26 billion m^3, in which hydropower reservoirs account for around 19 billion m^3, most of which are multi-purpose such as flow regulation, flood control, irrigation and water supply. The adverse impact of hydropower development has been recognized as altering river flow regimes, sediment transportation, and resettlement of local livelihoods. Along with the development of the energy sector, the water demand for hydropower generation is increased and compete with other sectors for exploitation of the water resources. Aside from water demand for hydropower generation, other forms of energy in the sector also utilize water for extraction, mining, processing, refining and residual disposal of fossil fuels, cooling of electricity generator as well as for growing biofuel.

Water, on the other hand, is an energy intensive sector and a large consumer of electricity for the treatment of drinking water, wastewater, and water transportation. The growing demand for urban as well as rural water supply and environmental protection also leads to higher energy demand for water treatment.

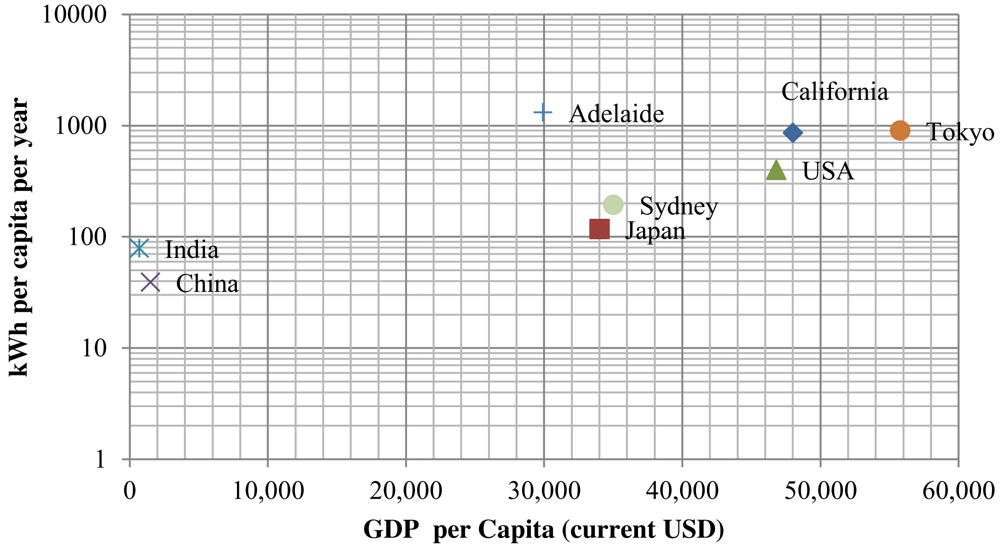


Figure 5 - Energy Intensity in Water Sector and GDP per Capita in Current USD

Vietnam has successfully progressed in improving its water supply situation over the past decades. There was an overall increase of 38% in the population using an improved drinking water source from 1990 to 2010. According to MOC until the year 2010, nearly 18.15 million people could have access to drinking water, accounting for 69 % of the total urban population. The average amount of water use of urban areas is 80-90 L/person/d; in which the amount of water use in large cities is 120-130 L/person/d. Therefore the amount of energy consume for the treatment of water supply is approximately 325 MWh/day and 650 MWh/day to treat wastewater generate from the urban population (about 0.3kWh energy for producing of 1m^3 clean water from surface water and 0.6 kWh for reclaim wastewater). Figure 6 specifies the urban water demand for the Mekong river delta – Dong Nai river system: the total amount of supply water shall increase to approximately 1 billion m^3 per day and require 975 MWh of electricity for water and wastewater treatment.

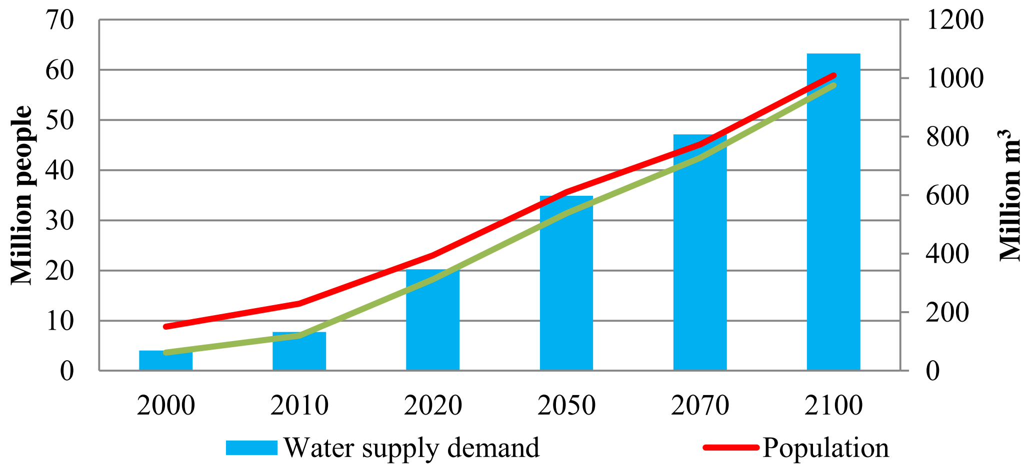


Figure 6 - Dong Nai River System Water Supply Demand and Energy Consumption for Water Treatment per Day Projection

The water -climate nexus

Water resource is the first sector to be affected. Firstly is the change in water availability and distribution over the territory. The main water resources are from the Mekong River Delta locates in the southern part of the countries and accounted for 60% of the total surface water reserves. Climate change will affect mostly to the remaining part of the countries such water scarcity in the Central Coast and Central Highlands. Seasonal distribution of water resource will likely be affected by changing rainfall pattern. In IPCC B2 emission scenario, rainfall intensity in the middle of the dry season would decrease up to 10-15% in the South comparing to the period of 1980-1999 while in the middle of the rainy season; rainfall will increase 10-15%. As a result, the intensity of drought in the dry season and flooding in the rainy season will increase.

From the climate change scenario provided: Annual flow at Mekong River at Tan Chau (the largest river system in Vietnam) for 2010-2050 increases about 4% for B2 and 7.6% for the A2 scenarios compared to the period 1985 – 2000; flood flows and flood peak tend to increase. Another study predicts for the Vu Gia – Thu Bon river basin in the Central region shows that the maximum increases in precipitation for A2 and B2 scenarios are +9.75 and +5.62 %, respectively, for 2080s relative to the baseline period (Trang,Sangam Shrestha and Bui Thi Thu, 2014).

It is predicted that, if sea level rises 1 m: 39% area of Mekong Delta, over 10% area of Red River Delta, 2.5% of the coastal area of the Central, will be inundated, and a large proportion of agriculture land will be affected. Sea level rise will lead to saline intrusion further upstream and salinization of groundwater aquifer, especially in dry season. A study conducted by(Yu, Zhu, Breisinger, & Hai, 2010) in indicates that for sea level rise of 30cm in the Mekong River Delta, in the dry season, areas affected by salinity intrusion with a concentration greater than 4 grams per liter would increase by 420,000 hectares leads to the loss of 13 % of the 2007 total rice harvest in the Delta [Yu, Zhu, Breisinger, Hai, 2010].

The climate change - energy nexus

Vietnam economy has recently emerged as one of the most active economies in the world, it also facing challenges relating to energy security and climate change. It is forecasted that, with current economic development, by the year 2025, the country will need to increase its primary energy supply by at least 3 -4 times and its electricity generation by 6-7 times the level seen in the year 2007(Dinhlong Do,Il Hwan Ahn, Suduk Kim, 2010). The energy sector in Vietnam is similar in other countries, has the largest share of GHG emissions. In 2010, GHG emission proportion from energy sector was 35%, equivalent to 52.8 TgCO2 of total 150.9 TgCO2 emissions (MONDRE, 2010) and will continue to increase as projection until 2030. Emissions from energy, agriculture, and Land use- Land use change and Forestry sectors are projected to be 169.2, 300.4, and

515.8 TgCO2e in 2010, 2020, and 2030, respectively. The energy sector accounts for 91.3% of projected total emissions for 2030.

Although the energy sector put effort to maintaining the share of renewable energy supply, the main source of electricity generation comes from fossil fuel. The Carbon emission from the energy generation has been doubled for over four year's period together with the increasing of electricity supply. However, the emission factor of the national grid is reported 0.56 t-CO2/MWh in 2010, equals to the emission of Singapore, Lao, Thailand and other countries in Asia with emission factor less than 0.6t-CO2/MWh (IGES).

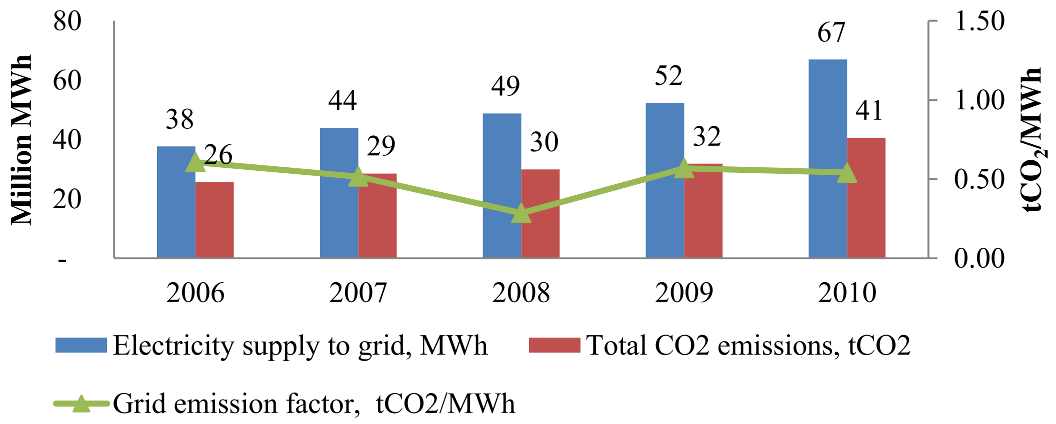


Figure 7 - Total Electricity supply to grid in and emission factor of the National Grid (Tuyen & Michaelowa, 2006)

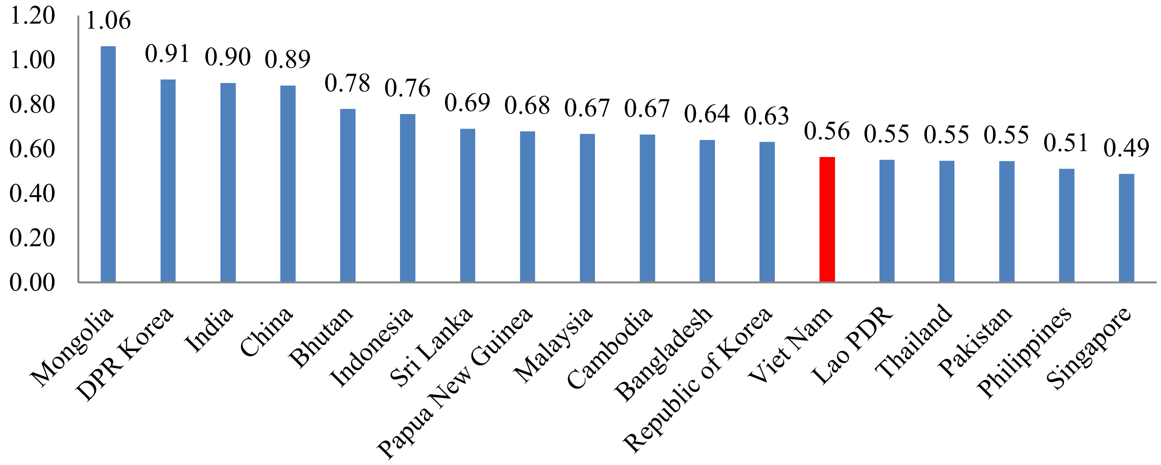


Figure 8 - Grid Emission Factor (tCO_2/MWh) in 2010 of some Asian Countries (Source: host country's government, compiled by IGES)

The energy sector is not only a major contributor to greenhouse gasses, but it is also vulnerable to climate change and will have to adapt to future climate conditions (Maryse Labriet et al., 2013). Climate change influences energy through its effects on demand, distribution, intensities, and types of energy that are available and being used (Wilbanks TJ et al., 2007). For example, as climate changes, so do patterns of energy use, with increasing demand for air conditioning as temperatures increase and increasing demand for heating when temperatures fall(Virginia H. Dale,Rebecca A.Efroymson and Keith L.Kline, 2011).

For the past 50 years (1958-2007), average annual temperatures increased by about 0.5 to 0.7^{o}C. Temperatures for winters and northern climate zones increased at faster rates compared to summer and southern climate zones, respectively. From prediction, winter temperatures are likely to increase faster than summer in all climate regions. Temperatures in northern regions are projected to rise at a faster rate than southern ones (FAO, 2011). The hot season in lowland areas will last longer and the cold season will last shorter in all regions.

Table 3 - Increases in Temperature According to the Three Climate Change Scenarios compared to 1980-1999 [FAO, 2011]

Element/ Region	**2020**			**2050**			**2100**		
Scenario	**B1**	**B2**	**A2**	**B1**	**B2**	**A2**	**B1**	**B2**	**A2**
Northwest	0.5	0.5	0.5	1.2	1.3	1.3	1.7	2.6	3.3
Northeast	0.5	0.5	0.5	1.2	1.2	1.3	1.7	2.5	3.2
Red River Delta	0.5	0.5	0.5	1.2	1.2	1.3	1.6	2.4	3.1
North Central Coast	0.5	0.5	0.6	1.4	1.4	1.5	1.9	2.8	3.6
South Central Coast	0.4	0.4	0.4	0.9	0.8	1.0	1.2	1.0	2.4
Central Highlands	0.3	0.3	0.3	0.8	0.8	0.8	1.1	1.6	2.1
Mekong Delta	0.4	0.4	0.4	1.0	1.0	1.0	1.4	2.0	2.6

The zone-polar air influenced Vietnam climate and expressed by the frequency of cold fronts crossing the North region. With climate change, the frequency of cold fronts in the Northern latitudes may slightly increase in comparison with previous decades. The rate of cold fronts penetrating into the Northwest will be lower in comparison with that of the past. As the consequence of temperature change, energy use for cooling in summer days and heating on cold days will increase together with the urbanization increase which leads to more people use electricity for heating. Although heating and cooling represent a relatively small contributor to total energy consumption, the climate change impact on the energy sector is not negligible.

Hydropower is particularly vulnerable to changes in precipitation patterns (Markoff MS, 2008). For example, low water flow can increase the frequency and extent of times when water turbines cannot operate. In areas that rely on hydroelectric power, fluctuations in precipitation and evaporation rates can impact energy output from dams (Virginia H. Dale,Rebecca A.Efroymson and Keith L.Kline, 2011). Research by Wanga et al (2012) indicated climate effects accounted for about 30% of total stream flow changes into the Hoa Binh reservoir - the largest (V=9.5 km3) and highest (120 m) dams in South-East Asia in the Red River basin.

2.3 From Integrated Water Resources Management to Water-Energy Nexus

2.3.1 Integrated Water Resources Management (IWRM)

Integrated Water Resources Management is an empirical concept which was built up from the on-the-ground experience of practitioners (DHI Water Policy & UNEP-DHI Center for Water and Environment, 2009). Though the IWRM concept has been implemented over decades and in many countries all over the world, there is no clear understanding of what exactly IWRM means (Biswas, 2014). The most famous and frequently quoted definition was proposed by the Global Water Partnership (GWP-TAC,Global Water Partnership - Technical Advisory Committee, 2000): "IWRM is process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". This definition has a sound theoretical basis, though the practical implementation of an ideal IWRM scenario presents many challenges (van der Zaag, 2005). Though there have been calls for clarification of the definition itself, IWRM has remained elusive and fuzzy (Biswas, 2014). To some extend IWRM has degenerated into a buzz word with different meanings (Jonch-Clausen & Fugl, 2001). Even though IWRM is understood and implemented from different perspectives and by different scholars, the definition of IWRM proposed by GWP (2000) is employed in the present chapter.

IWRM is based on the equitable and efficient management and sustainable use of water (The 3Es principles proposed by (Postel, 1992)). The challenges to implementing this principle lie in reducing the gap between theoretically agreed policies and implementation (Biswas, 2014; GWP-TAC, Global Water Partnership - Technical Advisory Committee, 2000; Jewitt, 2012).

According to GWP, IWRM approach lies on three pillars namely: enabling environment, institutional framework and management instruments (Figure 9). These pillars aim at avoiding a fragmented approach to water resources management.

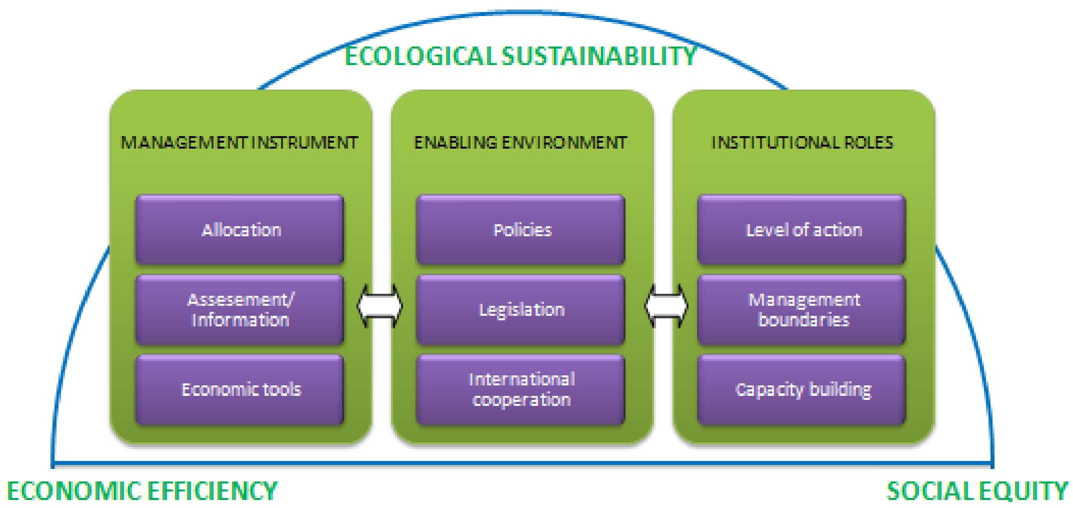


Figure 9 - The General Framework for IWRM (Source: GWP homepage)

The concept of IWRM was first introduced as an approach to incorporate the multiple competing uses of water resources at a United Nations Conference on Water in the Mar del Plata on 1977, however the concept has gained popularity since it was proposed at the Dublin Conference in 1992 and embraced by GWP-TAC (2000) and Biswas (2008) later on. IWRM concept shares a similarity in approach to the Sustainability Science approach, which recognizes that water issues have become multidimensional in character with respect to time, space, multidiscipline and stakeholders (Thomas, 2003, Biswas, 2014). IWRM is not an end state to be achieved; it is a continuous process of balancing and making trade-offs between different goals and views in an informed way (Thomas, 2003)

2.3.2 The nexus approach

The importance of the energy–water nexus has been recognized by some international institutions. The challenges for policymakers and industry are to develop effective policies, processes, and analytical tools that integrate the energy–water nexus (and related issues such as food security) into policy and investment decisions. How do policies aimed at climate mitigation and adaptation affect policies developed in the energy and water sectors, and, specifically, the energy–water nexus?

The nexus concept was first developed by the World Economic Forum in 2011 (WEF) to respond to global food, water, and energy crisis. In the same year, the Nexus Conference held in Bonn became the first international event that exploring the nexus approach.

David et.al (2015) argued the similarities and differences between IWRM and nexus approach from the six core elements including integration, optimal governance, scale, participation, resource use and sustainable development. The authors conclude that the nexus proves to offer some advance on IWRM. However, there are still some limitations when developing upon IWRM management strategies. This study calls for further research for local nexus approaches to better understanding the context of integration among water, food, and energy at the multiple scales.

There is an urgent need to promote an initiative that can be disseminated to the public policies, energy and water sector. Karen and Jamie (2012) suggests some possible project approaches including integrating climate-energy-water and related integrations into existing planning. They emphasize on understanding energy and water use nexus;

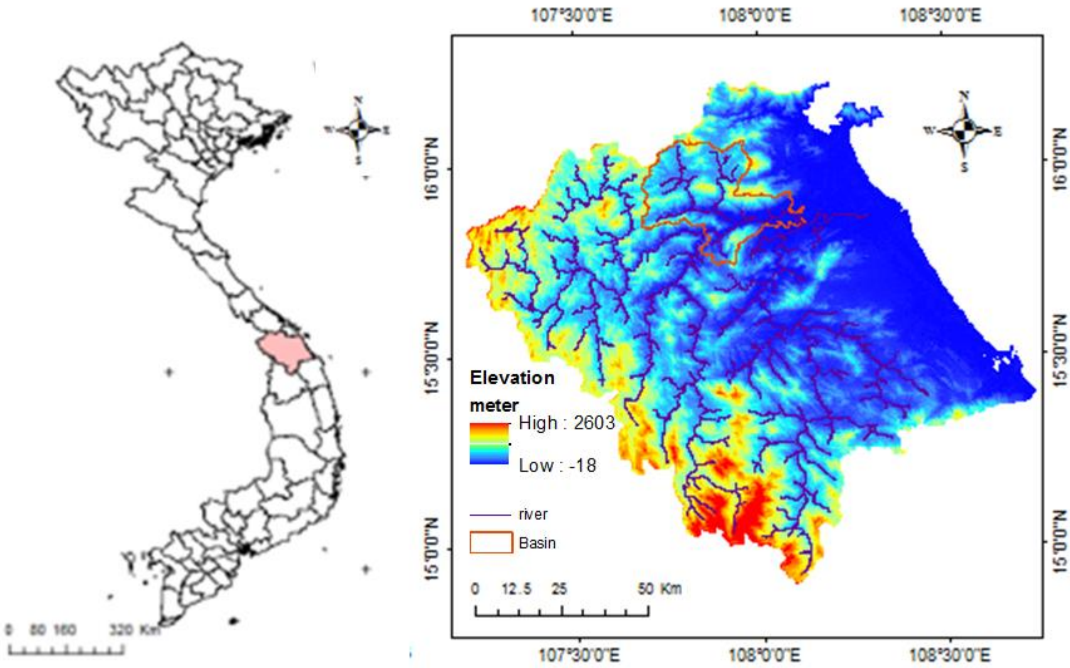
address the disequilibrium between energy and water and develop the energy-water nexus in the context of climate/carbon agenda; the impact on water resources from biofuels and carbon offsets; promote technology that seeks to decouple the water and energy nexus.

3 MATERIAL AND METHODS

3.1 Vu Gia-Thu Bon River Basin

3.1.1 Natural and Socio-Economical features

Vu Gia - Thu Bon river basin is one of the 5th largest river basins in Vietnam with the catchment area over 10,500 km^2. Two main rivers form the system named Vu Gia and Thu Bon, both origins from the Truong Son mountain range (Figure 10). This river basin is the major water resource for the region especially high potential for hydropower development. The area with 75 % of hills and mountains are favored for small and medium hydropower projects. This river basin locates within the tropical monsoon climate region and influenced by the Truong Son mountain range with relatively high precipitation but unevenly distributed over the basin regarding spatial and temporary. The annual rainfall ranging from 3500 mm to 2000 mm of which 65 % to 80 % of total annual rainfall is accounted for wet season (peak in October and November).



(a) (b)

Figure 10 - Map showing location of study area (a), Vu Gia-Thu Bon River basin (b) (ArcMap 10.0)

The Vu Gia-Thu Bon River basin has experienced rapid economic growth over the past ten years with the annual industrial growth rate at 16.9 % and 18.2 % in Danang and Quang Nam respectively. Industrial, as well as economic development in the basin, drives the increasing of energy demand which has been mainly from hydropower development.

Quang Nam province covers the largest areas of the three main provinces in the Vu Gia-Thu Bon River basin (Danang, Quang Nam, Kontum province). Quang Nam has a relatively low GDP per capita compared to the national average with 1,248 US Dollar (Table 4). The ethnic minorities that have a large population living below the poverty line inhabit the mountainous districts where lack of electricity supply and adequate wastewater treatment has been seen as a most vulnerable issue for their livelihoods.

Table 4 - Socio-economic indicator of Quang Nam province, 2012

Socio-Economic indicators	**Unit**	**Quang Nam[1]**	**National[2]**
GDP per capita at current price	USD	1,248	1,749
Average monthly income per capita at current price	USD	73	93
Gross output of Industry	bil. USD	1.73	209.62
Household living under poverty line	%	17.93	14.20
Literacy rate	%	-	97.10
Household access to electricity	%	95.57	97.60
Household access to hygienic latrine	%	80.00	77.40
Urban population	%	19.18	31.84
Rural population	%	80.92	68.16

[1](General Statistics Office, 2013)
[2](Quang Nam Statistics Office, 2013)

3.1.2 Hydropower development in Vu Gia-Thu Bon River basin

The Vu Gia-Thu Bon River Basin hosts some of the largest hydropower plants that have an important role to supply to the national grid. There is total eight large-scale hydropower projects with total installed and planned capacity of 1,100MW (10 % of total hydropower capacity of the country) and 37 small-medium hydropower projects with total capacity of 346MW (ICEM, 2008b). Most of the hydropower plants sell electricity to national grids and locate upstream of the basin (Figure 11), therefore, in many areas; the people are not able to have access to electricity although the community locates very near to the plant.

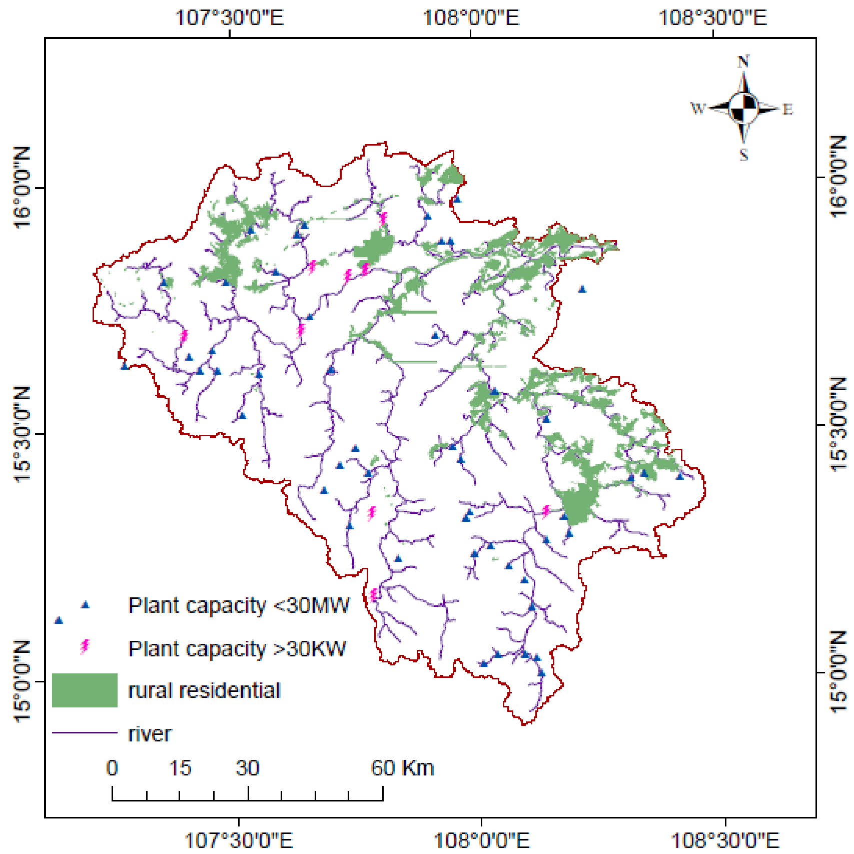


Figure 11 - Existing and planned hydropower plant

3.1.3 Domestic wastewater treatment and discharge from households

Household pour-flush pit latrines are seen as the most common wastewater treatment facility in this region, which is similar to other parts of the country. Rural households usually install underground chambers to collect wastewater mostly blackwater. Generally, blackwater is collected and seepage into the ground, sludge and feces are settled while gray water is discharged to gardens or farmland (Figure 12). In some cases especially in towns or wealthy households, wastewater collected in septic tanks are a mixture of black and greywater, or if there is present of sewer, septic tanks only receive blackwater. Also due to lack of sludge treatment infrastructure and service, sludge is not emptied regularly. The house owners usually empty septic tanks when they are full which can take from 1 to 10 years (World Bank, 2013b). There are several micro-credit facilities to the rural household to borrow a certain amount of cash average 600 US dollar, to construct latrine with zero percentage of interest rate from the local government funds.

(a) (b)

Figure 12 - Typical Household pour-flush pit latrine
(a); Blackwater overflow and gray water discharged to backyard (b) (Photo taken by Author)

3.2 Methodologies

3.2.1 Field measurement

In addition to recorded data from the existing meteorological stations, two rainfall stations, and two discharge station were set up to obtain precipitation and river flow in the period from September 2014 to January 2015.

A site investigation was conducted in the first field work in May 2014. The 02 sites were selected namely Ha Duc Bac and Suoi Tho as a representative catchment for the whole river basin.

3.2.1.1 Rainfall station

The automatically recorded rainfall gauges RAINWISE (Figure 13) were set up at two selected catchments. The rainfall data were recorded in minute-interval. The locations of rainfall gauges were shown in Figure 14. The data were stored by Data logger embedded with the rain gauge. Data were collected at the end of the field campaign.

RL-Loader version 2.2.2 software (Figure 15) provided by Rainwise Inc. was used to configure and download data from the Rainlog.

Figure 13 - Rain Gauge
With Tipping Bucket (a), 8" Diameter Collector (b) and auto logger (c)

Figure 14 - Rain gauge installation

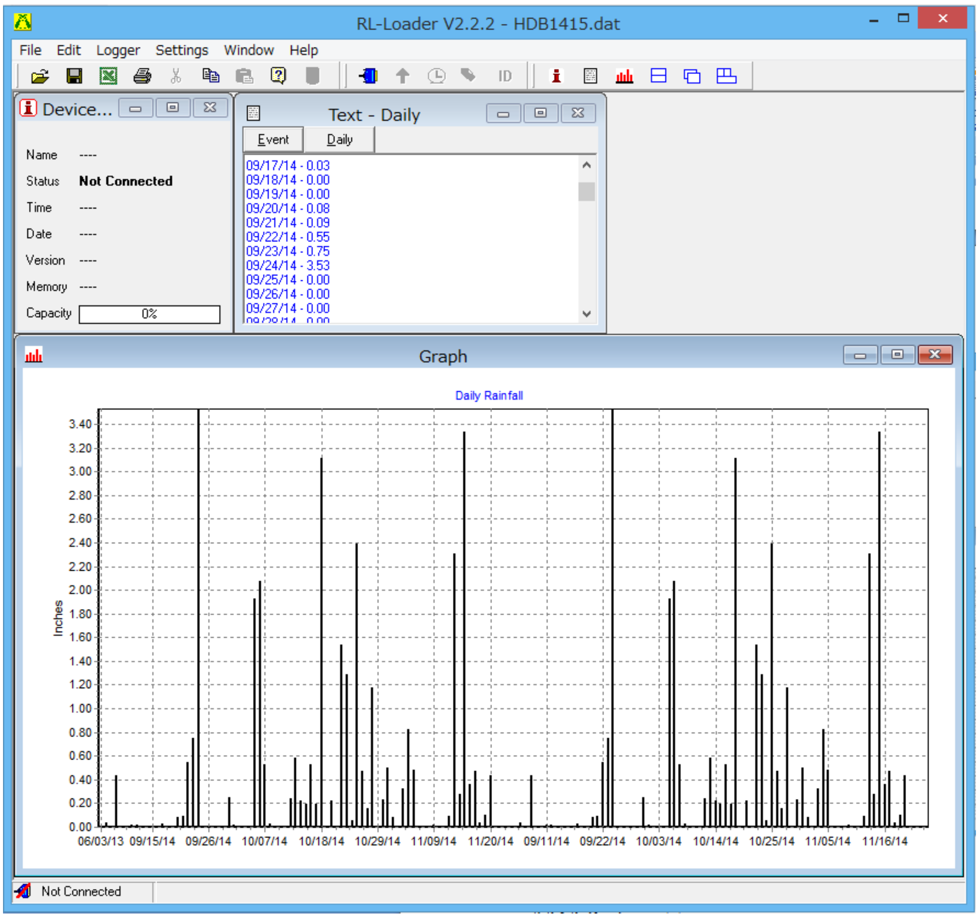


Figure 15 - RL-Loader V.2.2.2 Screen shot showing rainfall data extracted from Auto Logger

3.2.1.2 Discharge station

The stations were located under the bridges at Ha Duc Bac and Suoi Tho. Two automatic water level data loggers HOBO 30-Foot Depth were set up. Data recorded from water level logger were collected using the BASE-U-4 base station with the required coupler (Figure 16). HOBOware Pro software was installed to PC to obtain data from the loggers (Figure 17).

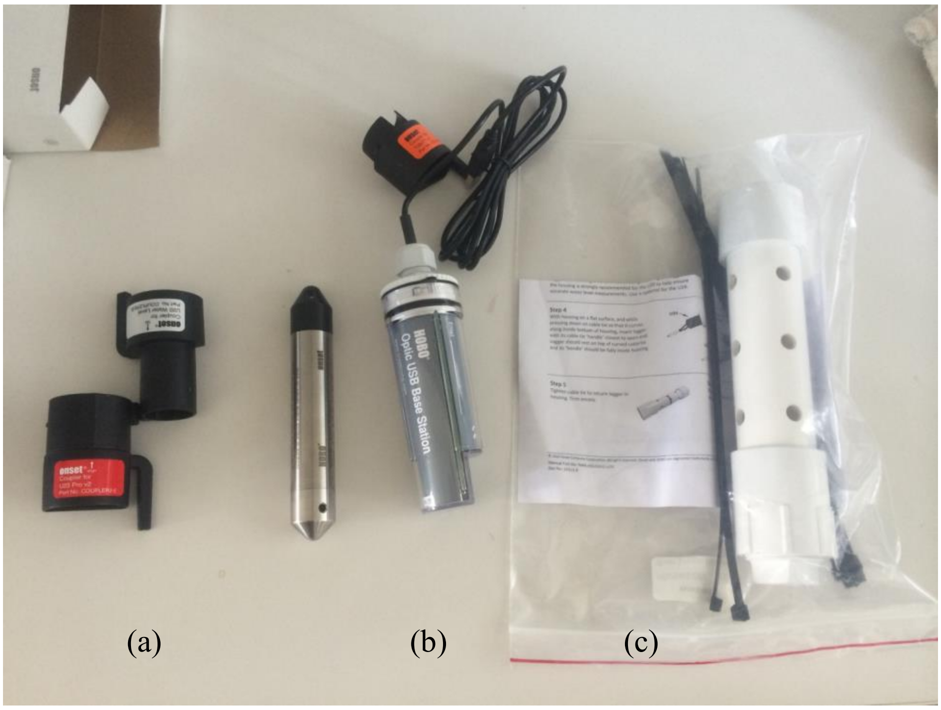


Figure 16 - HOBO 30-foot Depth Automatic Water Level Logger Set including couplings (a), water logger (b), USB base station (c) and housing (d)

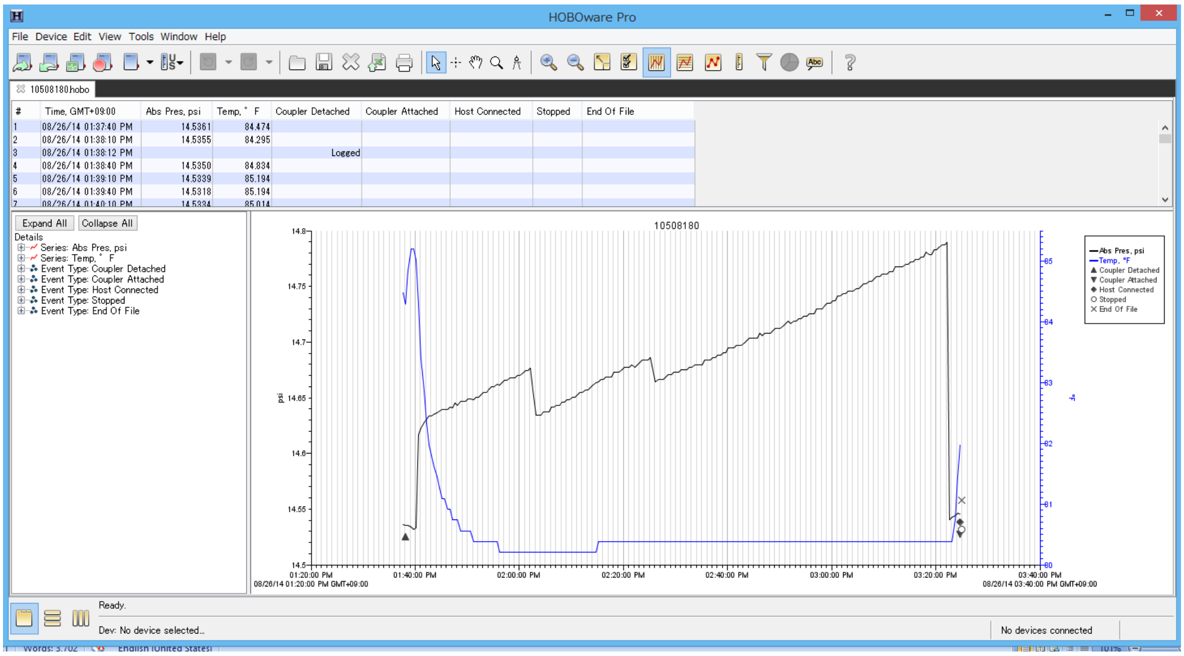
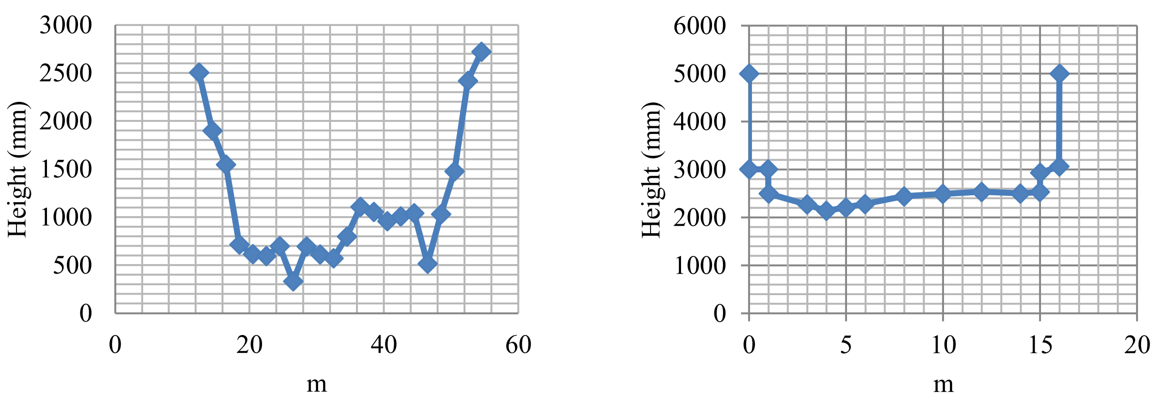


Figure 17 - HOBOWare Pro Screenshot
showing data extracted from automatic water level logger

River cross section (Figure 18) and velocity at the discharge point were measured. Depending on the water depth, flow velocity was measured at a different depth from the surface; otherwise, it was measured at 0.6 depths.



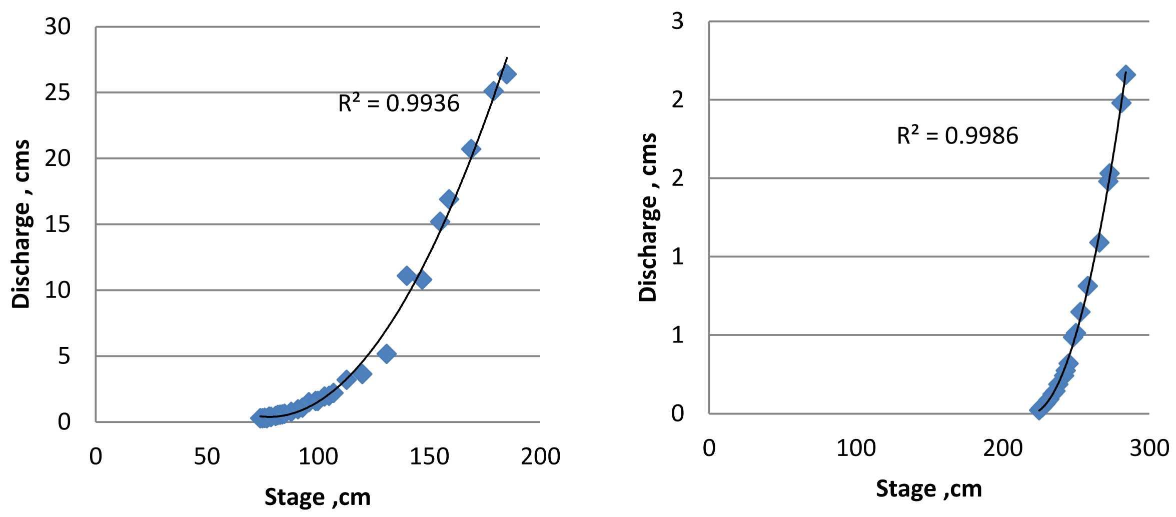
(a) (b)

Figure 18 - Measured River Cross Section
Ha Duc Bac Bridge (a) and Suoi Tho Bridge (b)

Table 5 shows the example of discharge measurement result on 9/16/2014 15:45. To obtain the discharge data, a stage-discharge relation curve was constructed based on 33 and 26 pairs of measured H-Q for Ha Duc Bac and Suoi Tho respectively (Figure 19). After stage-discharge curves had been constructed, only water level data was recorded using auto level water logger.

Table 5 - Cross Section and Discharge Measurement Results for Ha Duc Bac
(9/16/2014 15:45)

Depth (m)					**Cross section (m2)**					**Discharge**		
No	Distance from IP (m)	Depth (m)			Width	Depth (m)		Cross section area		Velocity		Discharge (m3/s)
		1	2	Mean		Depth	Depth	F	F	v	Mean V	
Initial point	1.4	0	0	0		0.00						
I	2	0.13	0.13	0.13	0.6	0.13	0.07	0.04	0.04	0.11	0.09	0.004
II	2.5	0.15	0.15	0.15	0.5	0.15	0.14	0.07	0.07	0.2	0.16	0.011
III	3	0.12	0.12	0.12	0.5	0.12	0.14	0.07	0.07	0.13	0.17	0.012
MT	3.75	0	0	0	0.75	0.00	0.06	0.05	0.05	0.13	0.10	0.005
								F'=	0.23		Q'=	0.032



(a) (b)

Figure 19 - Stage-discharge Relation Curve
Ha Duc Bac (a) and Suoi Tho (b) outlets

3.2.1.3 Flow assessment using the Soil and Water Assessment Tool (SWAT)

SWAT is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods (Arnold et al., 2012). The development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modeling experience that spans a period of roughly 30 years (Gassman, M. R. Reyes, C. H. Green, & J. G. Arnold, 2007). This model is considered appropriate for the study because it is applicable for watershed scale, with different modeling time steps (i.e. daily, sub-daily); it is coupled with ArcGIS interface with user support. Moreover, the model can simulate various land management operations and able to simulate future scenarios (EPA Region 6 Water Quality Protection Division U.S. Environmental Protection Agency, 2011).

There are two methods for estimating surface runoff. In this study, the SCS curve number provided by USDA (USDA Soil Conservation Service, 2004a) was employed.

The SCS curve number equation is calculated as:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)} \quad [1]$$

Where

Q_{surf} : accumulated runoff or rainfall excess, mmH_2O

R_{day}: rainfall depth of the day, mm H_2O

I_a: initial abstractions which include surface storage, interception, and infiltration prior runoff, mm H_2O

S: retention parameter, mm H_2O

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad [2]$$

Where

CN: curve number for the day

In this study, ArcSWAT was employed to model rainfall-runoff in the river basin. ArcSWAT is SWAT version designed to run on ArcMap interface. The model run following the steps as described below:

Watershed delineation

Digital elevation model (DEM) was extracted and projected to Universal Transverse Mercator (UTM) coordinate system UTM Zone 48N. Auto delineation was performed after outlet point of the basin was selected. Subbasin Parameters have calculated automatically (Figure 20).

Create Hydrologic Response Units

Hydrologic Response Units (HRUs) were created by dividing the basins into smaller units with particular land use, soil type, and slope range. Land use maps, soil type (categorized under FAO soil types) and slope extracted from DEM were used (Figure 21).

Swat setup and run

Weather data including precipitation, temperature, wind speed, solar radiation were written. Simulation period, rainfall-runoff/routing method was selected (Figure 22).

Calibration and validation

Model calibration was performed by editing the model's sensitive parameters within the recommended ranges to best match with the observed data (Figure 23).

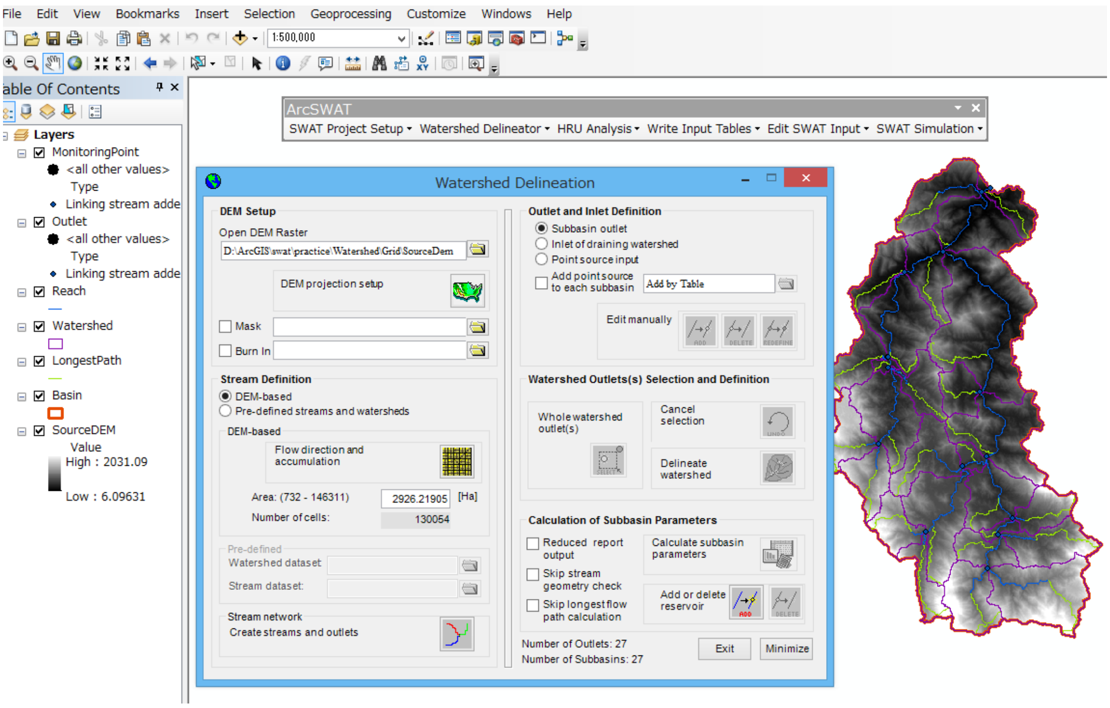


Figure 20 - Screen Capture: Watershed Delineation for Thanh My Subbasin Using ArcSWAT

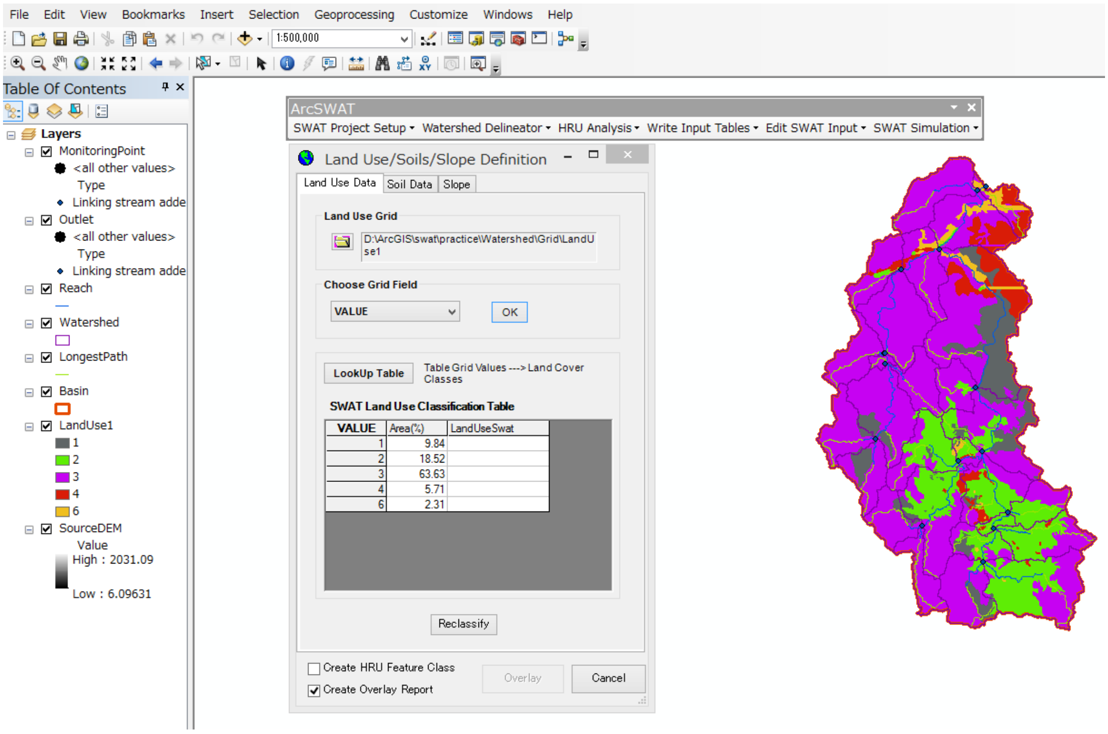


Figure 21 - Screen Capture: Hydrologic Response Units for Thanh My Subbasin

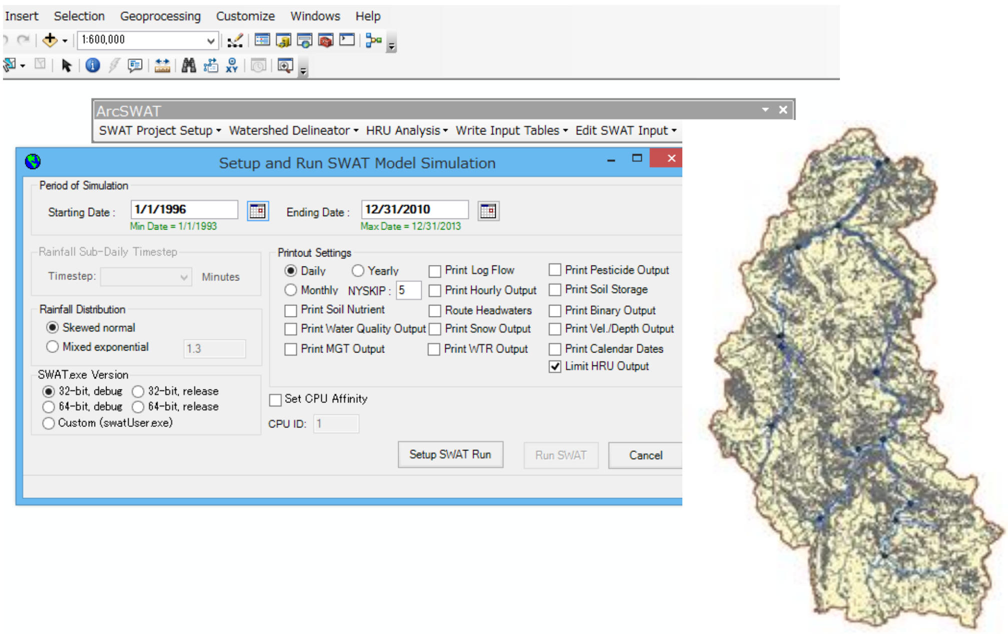


Figure 22 - Screen Capture: Model Setup and Run for Thanh My Subbasin Using ArcSWAT

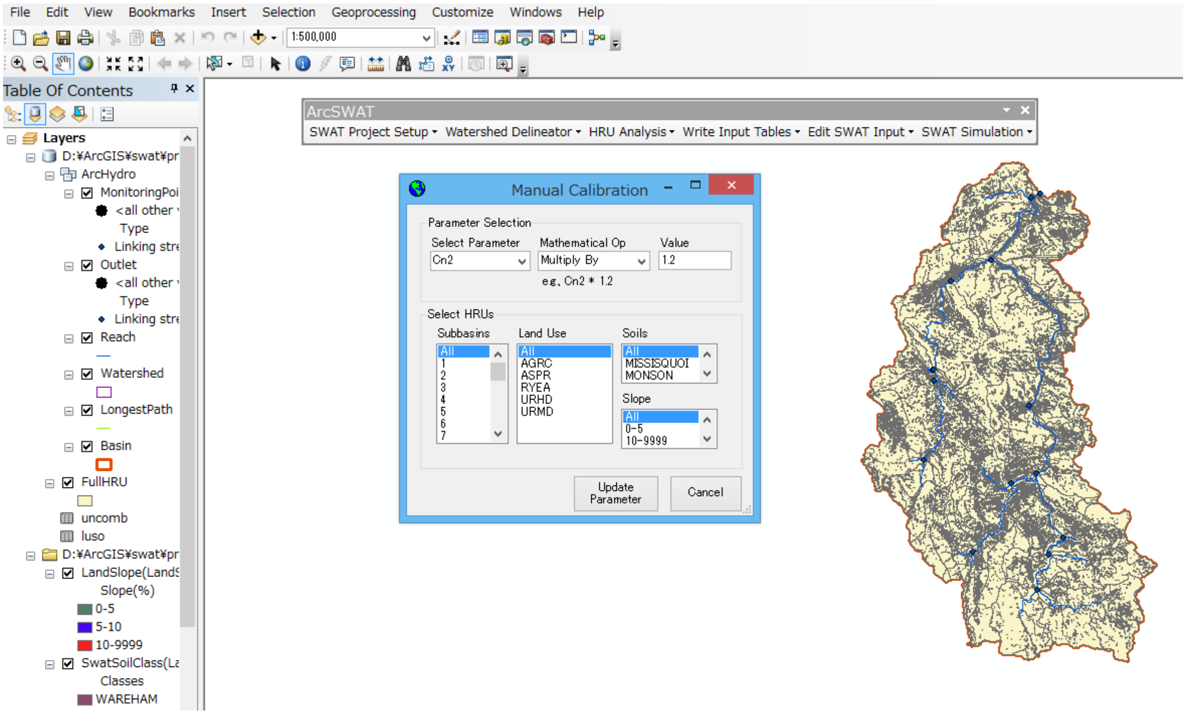


Figure 23 - Screen Capture: Model Calibration for Thanh My Subbasin Using ArcSWAT

3.2.1.4 Flow duration curve

A flow-duration curve represents the percentage of time that a flow level is equaled or exceeded in a stream (USDA Soil Conservation Service, 2004b). In power and energy sector, the flow-duration curve is applied to anticipate availability of the flow over time, results in energy availability.

This method is very common and extremely useful to evaluate various dependable flows in many of the water engineering projects including hydropower projects. The data is arranged in the descending order base on flow rate using class intervals. Flow duration intervals are expressed as a percentage of exceedance, with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 to the lowest (i.e., drought conditions).

Frequency of occurrence is obtained using the following formula:

$$F = 100 * \frac{R}{N + 1} \quad [3]$$

Where

F is frequency of occurrence (expressed as % of time a particular flow value is equaled or exceeded);

R is Rank

N is Number of observations.

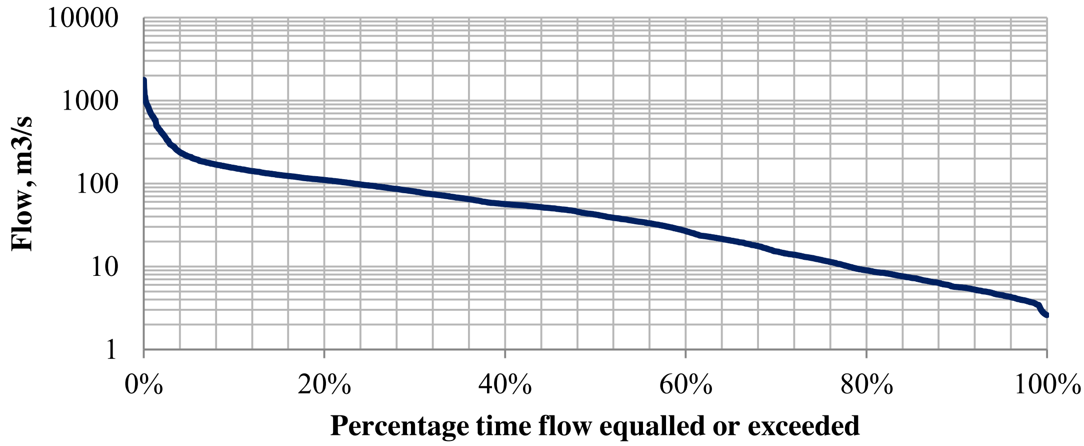


Figure 24 - Flow Duration Curve at Outlet of Thanh My Subbasin

3.2.1.5 Power assessment

The power potential is calculated as

$$P = \eta \ \rho \ Q \, g \, H \quad [4]$$

Where

P is the mechanical power produced at the turbine shaft (Watts);

η is hydraulic efficiency of the turbine (85%);

ρ is the density of water (1000 kg/m^3);

g is the acceleration due to gravity (9.81m3/s);

Q is the volume flow rate passing through the turbine (m^3/s);

H is the head of water across the turbine (20m).

The downstream release of 10 % is considered for environmental consideration.

3.2.1.6 **Power duration curve**

Power available is calculated based on flow using [4]. Based on Flow duration curve, Power duration curve was constructed (Figure 25).

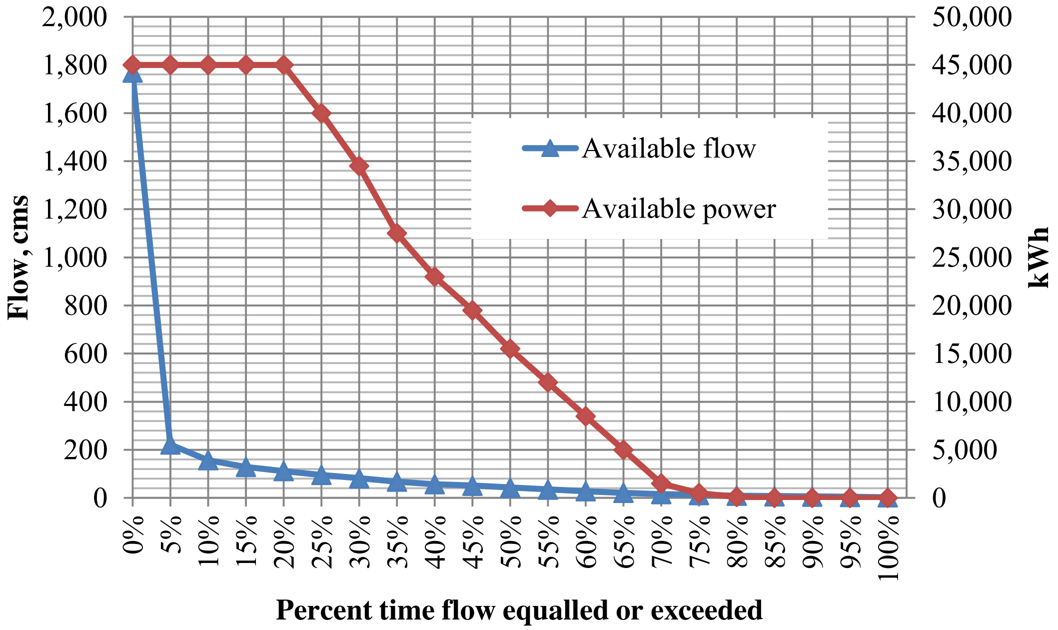


Figure 25 - Power Duration Curve

Hydropower available is determined by calculating the area under the power-duration curve. The annual available energy E_{avail} is calculated from P by:

$$E_{avail} = \sum_{k=1}^{n} \left(\frac{P_{5(k-1)} + P_{5k}}{2} \right) \frac{5}{10} 8760(1 - l_{dt}) \quad [5]$$

Where

P_5 is the power at each flow with 5% interval of the curve

8760 is the number of hour per year

l_{dt} is the annual downtime losses

Hydropower plant capacity factor K

Assuming that all energy available at the plant is absorbed by local grid, the capacity factor is defined as the average output of the plant compared to its rated capacity:

$$K = \frac{E_{avail}}{8760\ P_{des}} \quad [6]$$

Where

P_{des} is the power capacity at the designed flow (with 25% exceedance P_{25})

3.2.2 Greenhouse Gas Emission analysis

GHG emissions from watersheds were calculated based on GHG Protocol and IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). In the scope of this study, CO_2 and N_2O emissions from wastewater treatment were not considered. The CO_2 emission is biogenic origin that is part of the natural carbon cycle and does not contribute to global warming. Therefore it was not included in natural GHG emissions inventory. The N_2O emission was not included because of insufficient data and large uncertainties associated with the IPCC default emission factors for N_2O from effluent (IPCC, 2006).

Methane emission inventory was constructed as followed:

Step1: Estimate total organically degradable carbon in wastewater (TOW)

$$TOW \quad = P \quad \times BOD \times 0.01 \times I \times 365 \quad [7]$$

Where

P: population of watershed in inventory year, person

BOD: per capita BOD in inventory year, g/person/day

I: correction factor for additional industrial BOD discharged into sewers, I = 1.00 for uncollected

Step 2: Select the pathway and systems according to country activity data. Then obtain the emission factor for each domestic wastewater treatment/discharge pathway or system using the following formula:

$$EF = B_o \times MCF \qquad [8]$$

Where

EF: emission factor of treatment pathway, kg CH_4/kg BOD

B_o: maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF: methane correction factor of treatment pathway

Step 3: Estimate emissions, adjust for possible sludge removal and CH_4 recovery and sum the results for each pathway/system with the following formula:

$$CH_4 = \left[\sum_{ij} \left(U_i \times T_{ij}.EF_j\right)\right](TOW \quad - S \quad) - R \qquad [9]$$

Where

CH_4: Methane emission in inventory year in watershed i, kg CH_4/year

S: organic component removed as sludge in inventory year, kg BOD/year

Ui: fraction of population in income group k in inventory year

Tij: degree of utilization of treatment pathway j

R: amount of CH_4 recovered in inventory year, kg CH_4/year

3.2.3 Economic and Social Analysis

3.2.3.1 Household questionnaire survey

The survey covered total 146 households of the three communes Dai Quang, Dai Lanh (rural) and Dai Nghia (town) in Dai Loc district (Figure 26). Household respondents were randomly selected from map and GPS device. The characteristics of the sample are shown in Figure 26 and Table 6.

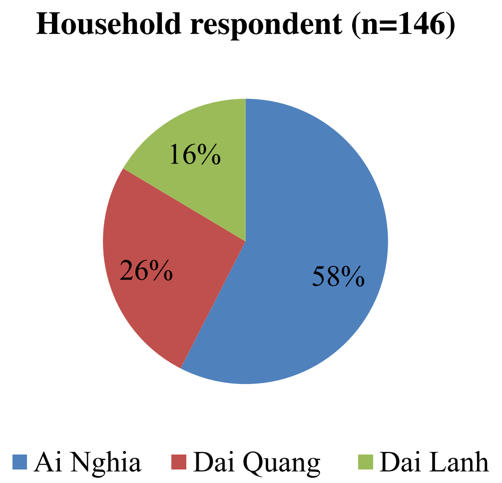


Figure 26 - Household Respondent Distribution

Table 6 - Distribution of Sample Size and Characteristics

	Ai Nghia	Dai Quang	Dai Lanh
Total Households	4000	3000	2000
Confidence level	95%	95%	95%
Standard error	0.056	0.08	0.1
Sample size	84	38	24

Figure 27 - Interviewing the Household Representative
(photo by author)

The questionnaire including 28 questions yes/no, multiple choices, open answers question. The outline of questionnaire is followed:

- **Part 1**: General information of the household respondent
    - Information of the respondent
    - Properties, including shelter type, annual income
- **Part 2**: Electricity consumption pattern
    - Energy sources for cooking, lighting, other daily activities.
    - Electricity appliances and usage
    - Monthly electricity consumption and payment
- **Part 3**: Household water supply and sanitation status
    - Water supply sources for drinking/cooking, washing
    - Water supply monthly payment
    - Toilet type cost for construction
    - Wastewater treatment system available
- **Part 4:** Household willingness to participate in sanitation projects

3.2.3.2 Financial analysis

In this scope of the study, Capital expenditure (CAPEX) is defined as the capital required at the beginning phase of a project to finance or purchase materials, land, labor and any other costs related to construction and project implementation. Operational expenditure (OPEX) is defined as the money that is required to sustain a facility or activity (including labor, fuel, and all other operation and maintenance costs).

In the cash flow, CAPEX usually inputs at the beginning of a project phase. In this study, CAPEX for ROR hydropower generation is paid in a 5-year phase. While CAPEX for wastewater treatment system is paid in two times, at first 70% of the cost will be paid, and the remainder 30% of the cost will be paid after 20 years.

Levelised Cost of Electricity (LCOE) from off-grid ROR hydropower scheme is as followed

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \ (\mathrm{USD/kWh}) \qquad [10]$$

Where

I_t is the investment expenditure;

M_t is O&M expenditure,

n is the system lifetime;

E_t is the electricity generation in the year t.

The abatement costs (AC) was calculated to compare the difference between the ROR hydropower scheme and diesel based electricity generation as followed:

$$\mathrm{AC} = \frac{LCOE_{Off\ grid\ hydropower} - LCOE_{Diesel}}{Emissions_{Diesel} - Emissions_{Off\ grid\ hyropower}} \ (\mathrm{USD/tCO_2}) \qquad [11]$$

4 RUN-OFF-RIVER HYDROPOWER FOR RURAL ELECTRIFICATION

In this chapter, the potential of small hydropower in the representative river basin of Vietnam was analyzed. Estimated run-off-river hydropower potential in Central Vietnam was performed using a distributed hydrologic model and flow duration curve method. The result indicates total Run-off-river hydropower potential is 277.342 MW with an average capacity factor of 40.2 %, which means the system capable of generating 1.02 million MWh in a year. The results indicate that run-off-river hydropower can be alternative system together with the national grid that provides electricity for rural households especially households living in remote areas and have no access to the national grid.

4.1 Introduction

Vietnam is one of the most climate change vulnerable and disaster-prone countries (Dasgupta et al., 2007). Latest projection indicates that Vietnam will be especially hard hit by sea level rise and intense and frequent extreme weather (Chaudhry & Greet, 2007; IPCC, 2007b). Climate change can affect the spatial and temporal distribution of water resource as well as intensity and frequency of the extreme hydrological event (Khoi & Hang, 2014). Consequently, climate change generate extreme impact on socioeconomic development and challenging the natural resource management system of the country, especially water resource management system (Giang et al., 2012). The climate change mitigation measures introduced aim at GHG emissions reduction and hydropower is recognized as the most effective and affordable source for developing countries. Therefore, the development of energy sector especially hydropower is interlinked with water resources management and climate change mitigation.

Small hydropower is amongst renewable energy sources that have the high potential not only to supply electricity for the local communities living in rural and remote areas but also to increase renewable energy share, hence reduce the grid emission factor. Unfortunately, the potential of small, medium hydropower has not been studied in the country although there were some different official number between 2925 MW and 4015 MW (PECC1, 2005). Therefore it is difficult to project as well as implement feasible strategies in the power sector to address climate change and restructure the economy towards Low carbon economy. Also, hydropower is water resource dependence sector which is highly likely to be affected by climate change; thus the medium and long-term projection of small medium hydropower development is needed.

In this chapter, the potential of small hydropower in the representative river basin of Vietnam was analyzed. Estimated run-off-river hydropower potential in Central Vietnam using a distributed hydrologic model and flow duration curve method

4.2 Materials and Methods

Hydropower potential is estimated from two major components: the head and the availability of flow. The flow assessment is conducted by employing Arc-SWAT model, and then the availability of flow is performed using the flow duration curve.

This study assesses only the run-of-river hydropower which the power is generated without reservoir construction but diverting water from streams to a bypassing pipe or channel and finally into the turbine. Run-of-river hydropower is a small hydropower scheme that favorable for rural electricity supply especially in a hilly region like the Vu Gia-Thu Bon River basin. In this study, the low head Run-of-river scheme is chosen with the head of 20m; this is also to ensure that the tail race of the upstream site is not influenced by the reservoir of the downstream site. Also, these ROR hydropower projects shall locate near to rural communities. Therefore only watersheds with rural settlements were selected.

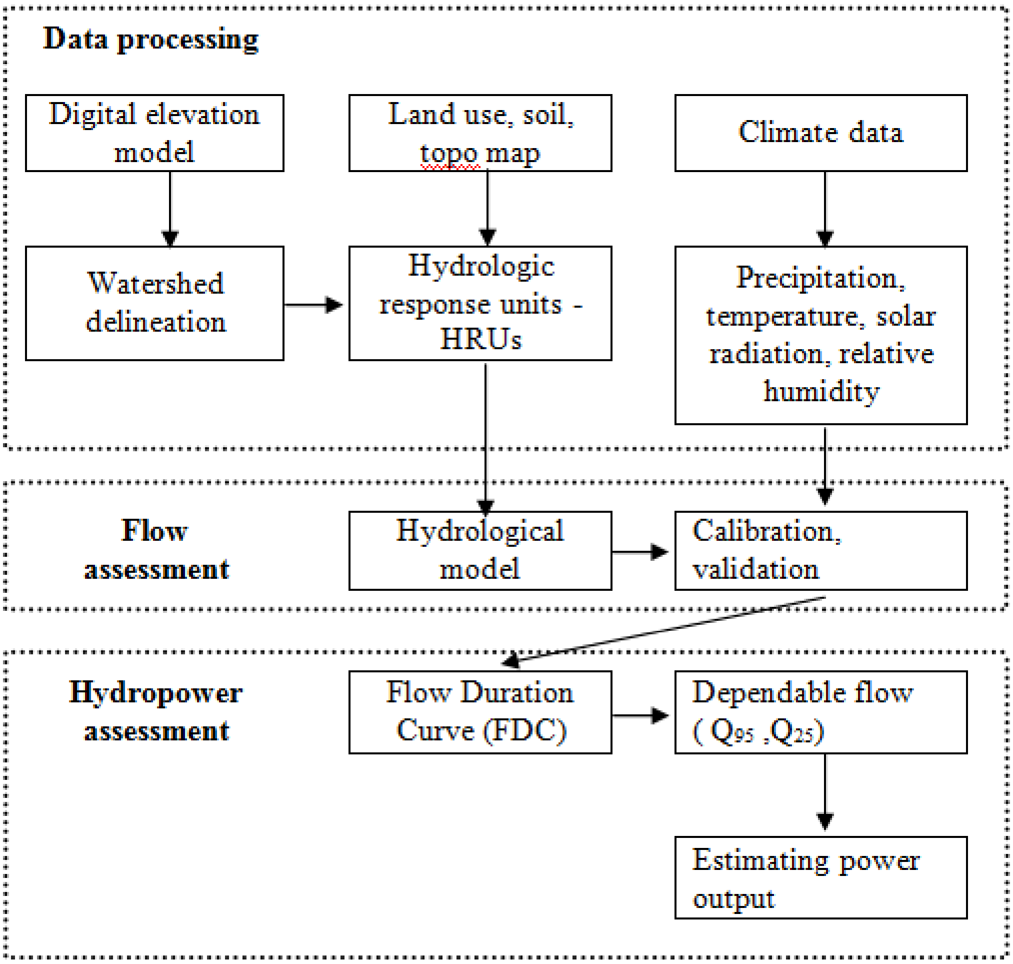


Figure 28 - Methodology Flowchart

Data processing

Digital maps, DEM, land use, and soil, in raster format, are needed to derive watershed characteristics for the Arc-SWAT model input. DEM resolution of 30 m is derived from Digital topographic map, scale 1:50000. The digital maps are obtained from Quang Nam Natural Resource and Environment Department.

Daily rainfall data were collected for the fifteen year period (from 1996 to 2007) from 16 meteorological stations established within the watershed. These data were preprocessed and check for continuity and applicable to the Arc-SWAT model requirement.

Temperature, the wind, relative humidity and solar radiation data pre-processed for SWAT model were obtained from The National Centers for Environmental Prediction (NCEP).

Discharge data were obtained from Thanh My station with a daily record from the year 1996 to 2007.

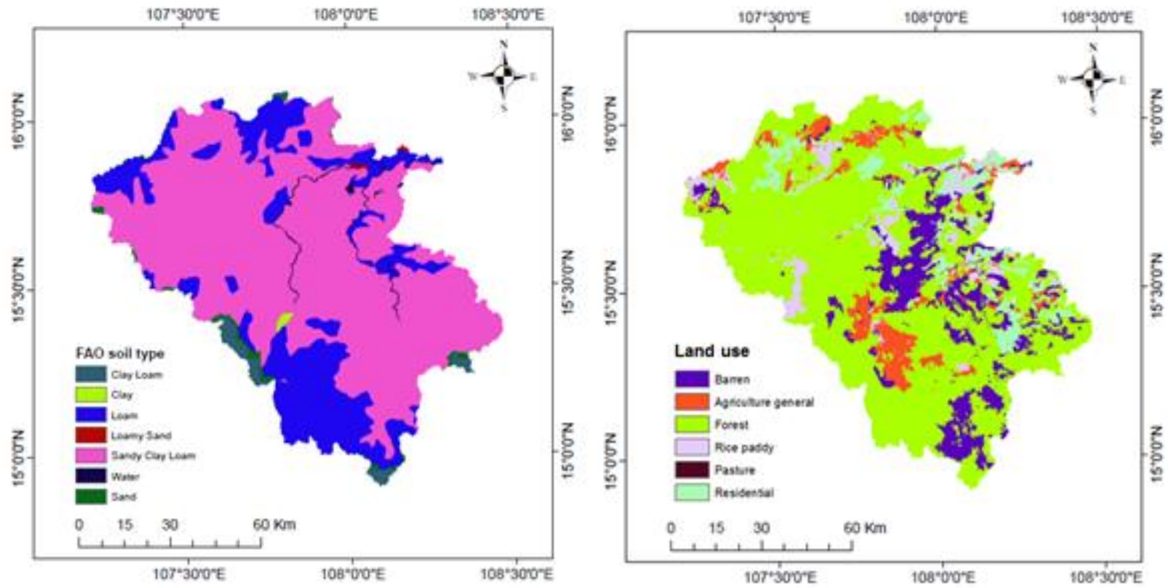


Figure 29 - Soil Map (left) and Land Use Map (right)

Estimation of flow

Flow data for each of river reaches is needed to construct a Flow Duration Curve at sub-watershed level. This study employs simulation model to obtain flow data. There are varieties of models available to choose, from empirical, conceptual of physical models. The SWAT model (Soil and Water Assessment Tool) is chosen among some most popular models. Chapter 3, Session 3.2.2.1 explained the methodology applied to estimate river discharge using rainfall- runoff modeling.

SWAT model calibration and validation improve the reliability of model estimates. In this study, a semi-auto calibration and validation are employed.

The model performance was evaluated by comparing of simulated and observed discharge data using two statistical indices: Coefficient of determination (R^2) (Willmott, 1981) and Nash and Sutcliffe efficiency (NSE) (Nash & Sutcliffe, 1970)

Estimation of power potential

Hydroelectric power potential can be obtained from a flow duration curves (FDCs). Flow duration curve analysis is a method involving the frequency of historical flow data over a specified period. From SWAT model output, flow data is extracted by daily time scale. The data is then used to construct FDCs for each of the watersheds. The construction of a flow duration curve was presented in section 3.2.2.2

The hydroelectric power was calculated at the outlet of each basin to represent the optimum ROR hydropower potential at the basin scale. The water head of 20 meters was chosen as the minimum vertical flow of water from the upstream level to a downstream level that represents low head ROR hydropower stream.

The dependable flows (Q_{95}, Q_{25}) were used to determine the power output from each watershed. These flow represented the ability of the ROR hydropower scheme to operate throughout the year, and during peak flow period.

The theoretical power potential is calculated as

$$P = \eta \, \rho \, Q \, g \, H \qquad [12]$$

Where

P is the mechanical power produced at the turbine shaft (Watts);

η is hydraulic efficiency of the turbine (85%);

ρ is the density of water (1000 kg/m^3);

g is the acceleration due to gravity (9.81m3/s);

Q is the volume flow rate passing through the turbine (m^3/s);

H is the head of water across the turbine (20m).

The downstream release of 10 % is considered for environmental consideration.

4.3 Results and Discussion

4.3.1 SWAT model calibration and validation

To optimize the simulation process using ArcSWAT, the Vu Gia-Thu Bon River basin was divided into five sub-basins as shown in Figure 30.

Firstly, the model performs the daily simulation for Thanh My sub-basin from January 2005 to December 2007 (including five years warm-up period) for calibration. The parameters were used to calibrate the model is listed in table 7.

	Sub basin	Area, km^2
A	Thanh My	2464.62
B	Song Bung	2450.67
C	Song Con	913.43
D	Nong Son	1346.56
E	Hiep Duc	2334.06

Figure 30 - Sub Watersheds Delineation

Calibration parameters from Thanh My simulation are used for model validation for the three years period (January 2002 to December 2004) at Thanh My sub-basin. Due to observation data availability, after calibration/ validation of Thanh My sub-basin was done, the calibrated parameters were applied for the remaining sub-watersheds with the assumption that the model would give similar performance.

Table 7 - Calibrated Parameters

Process	Parameters	Definition	Value
Surface runoff	CN2.mgt	Initial CNII values (relative value)	0.136
Surface runoff	ESCO.hru	Soil evaporation compensation factor	0.913
Base flow	ALPHA_BF.gw	Base-flow recession alpha factor , days	0.313
Base flow	GW_REVAP.gw	Groundwater revap coefficient	216.6
Base flow	SOL_K(..).sol	Saturated hydraulic conductivity (relative value)	0.012
Base flow	GW_DELAY.gw	Groundwater delay, days	23.96
Flow in channel	CH_N2.rte	Manning's "n" value for the main channel	0.084

Statistical evaluation of the model calibration and validation are given in Table 8 . Nash – Sutcliffe efficiency value (NSE) and Coefficient of determination (R^2) indicate that there is good agreement between simulated and observed discharge at Thanh My station.

Table 8 - Model Evaluation Parameters

Parameters	Calibration period (Jan 2002 – Dec 2004)	Validation period (Jan 2005 – Dec 2007)
R^2	0.61	0.60
NSE	0.50	0.53

The model simulated quite good especially in the dry season but slightly under-predicted of discharge during monsoon season. The dry season flow or low flow in rivers is fundamental for hydropower development projects. Hence, the model shows good simulation in dry period indicates the suitability of SWAT to perform flow prediction for hydroelectric power generation on the daily basis.

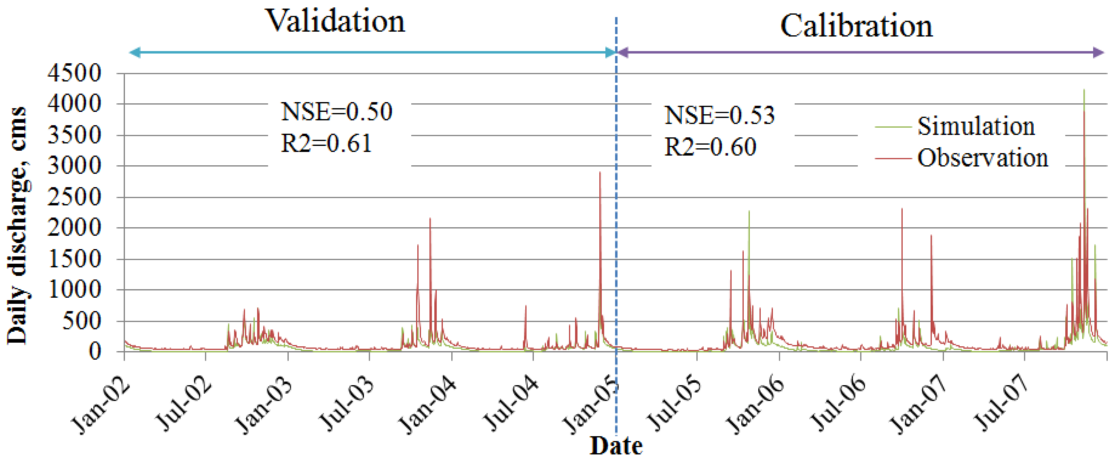


Figure 31 - Calibration and Validation of ArcSWAT Model at Thanh My Station

The calibrated parameters were used to validate the remaining sub-watersheds. Table 9 shows the mean and standard deviation of monthly discharge at each sub-watershed outlet in 10 year simulation period. The result of mean annual flow shows that there are two distinct seasons namely flood season and low flow season. The flood season starts from September and ends in January with the flow accounted nearly 70% of the total flow and peaks in October with over 20% of total annual runoff. The dry season comprises only 30 % of total annual flow. The driest month is April. It is exceptional in May and June; there is the secondary rainfall peak in a year and form a Tieu Man flood period in the river basin.

Figure 32 and Figure 33 shows the model performance at the 02 monitoring stations. The model overestimates the flow rate at Suoi Tho discharge point, while underestimating the flow rate at Ha Duc Bac discharge point. The model performance was affected by the backwater impact from the mainstream. In additional, the monitor data was not enough to perform statistical analysis.

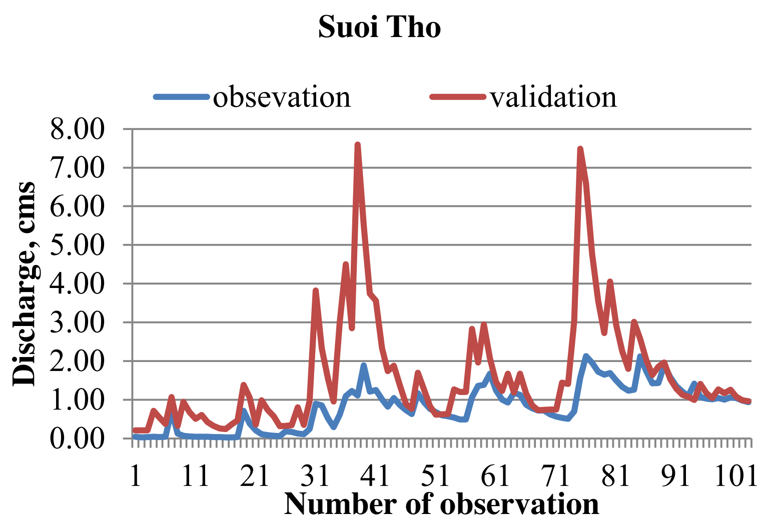


Figure 32 - Model Validation at Suoi Tho Discharge Point

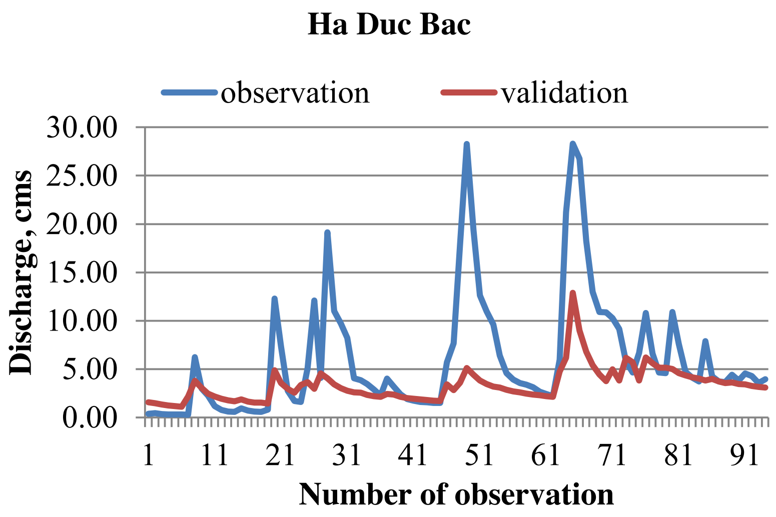


Figure 33 - Model Validation at Ha Duc Bac Discharge Point

Table 9 - Mean and standard deviation (σ) monthly discharge at sub-watershed outlet
(Model simulation result for ten year period: January 2002- December 2011)

Monthly flow,	**Thanh My**		**Hiep Duc**		**Song Bung**		**Song Con**		**Nong Son**	
cms	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
Jan	62.18	21.25	103.99	45.96	16.17	6.26	5.73	7.53	84.14	39.02
Feb	31.62	9.72	50.81	21.80	7.22	4.38	4.88	19.99	56.29	58.43
Mar	15.99	8.11	23.13	11.07	2.23	1.67	2.47	5.53	30.12	21.23
Apr	13.50	14.16	12.89	6.98	1.57	1.12	5.14	22.97	25.42	58.50
May	38.59	46.91	17.30	16.05	2.84	2.16	6.73	31.74	29.69	70.46
Jun	62.21	66.26	30.23	32.63	6.47	12.48	6.43	20.04	39.94	75.67
Jul	66.12	48.05	24.95	12.15	6.82	5.80	5.79	8.36	36.43	51.97
Aug	132.41	170.80	62.71	124.66	24.60	41.34	18.70	80.61	67.82	159.00
Sep	154.44	107.05	95.22	123.95	29.80	28.20	30.28	105.65	103.79	233.42
Oct	219.34	160.05	268.55	268.72	43.66	35.82	109.10	312.95	272.48	561.04
Nov	185.04	165.62	328.11	329.35	40.40	37.14	72.72	229.48	244.94	484.08
Dec	114.92	65.50	220.52	208.86	28.43	20.82	27.95	98.52	151.24	217.69

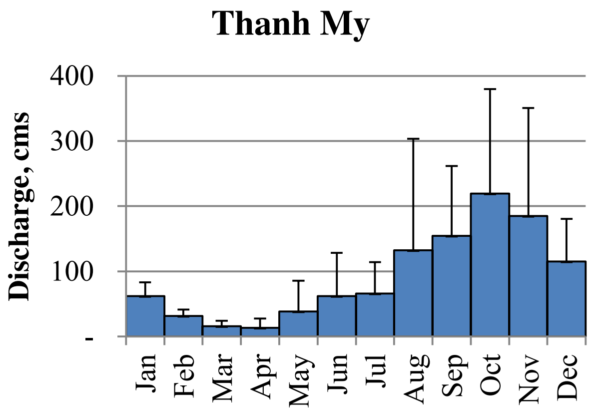


Figure 34 - Mean monthly discharge at Thanh My outlet (Model simulation result for 10 year period: January, 2002- December, 2011)

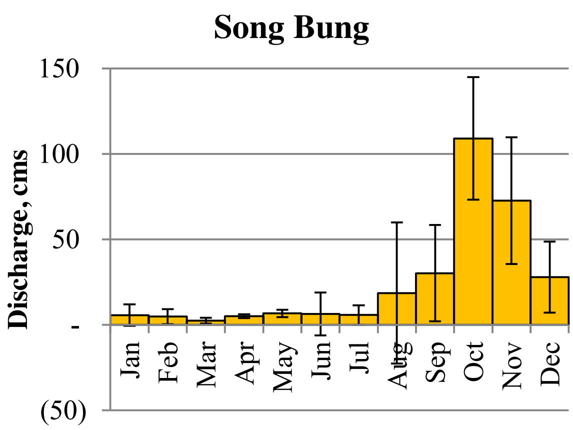


Figure 35 - Mean monthly discharge at Song Bung outlet (Model simulation result for 10 year period: January, 2002- December, 2011)

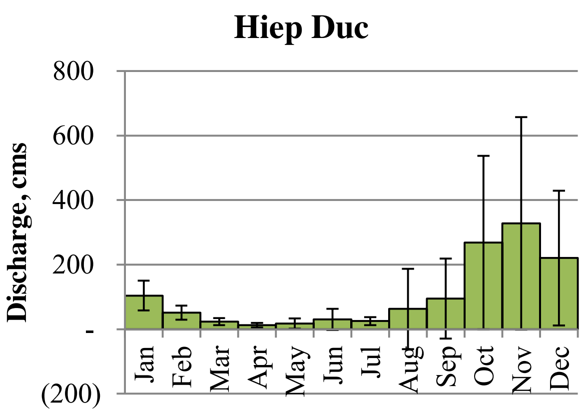


Figure 36 - Mean monthly discharge at Hiep Duc outlet (Model simulation result for 10 year period: January, 2002- December, 2011)

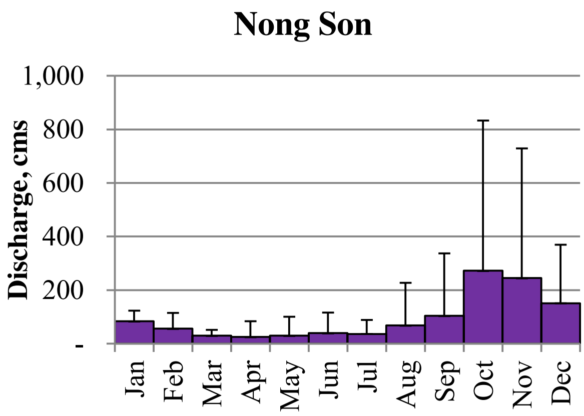


Figure 37 - Mean monthly discharge at Nong Son outlet (Model simulation result for ten year period: January 2002- December 2011)

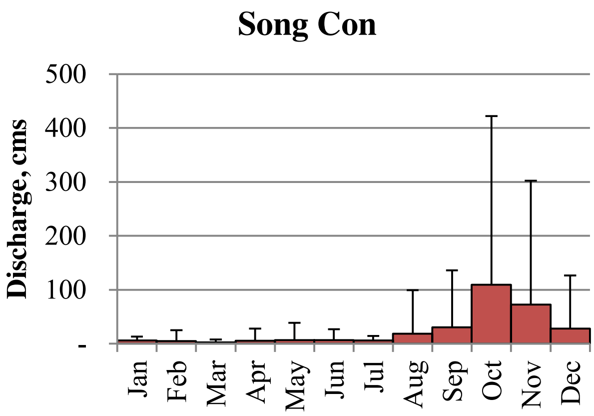


Figure 38 - Mean monthly discharge at Song Con outlet (Model simulation result for ten year period: January 2002- December 2011)

4.3.2 Flow Duration Curves (FDCs)

Daily discharge data from each of the watersheds is extracted from SWAT output files for ten years period (from 1998 to 2007). The flow obtains from the model output is then computed into FDC's curves for each of the sub-watershed as shown in Figure 39 to Figure 4-14. Each line represents one FDC for one corresponding watershed in the sub-basins. The extracted FDCs were selected so that represented watersheds are applicable for local electricity supply.

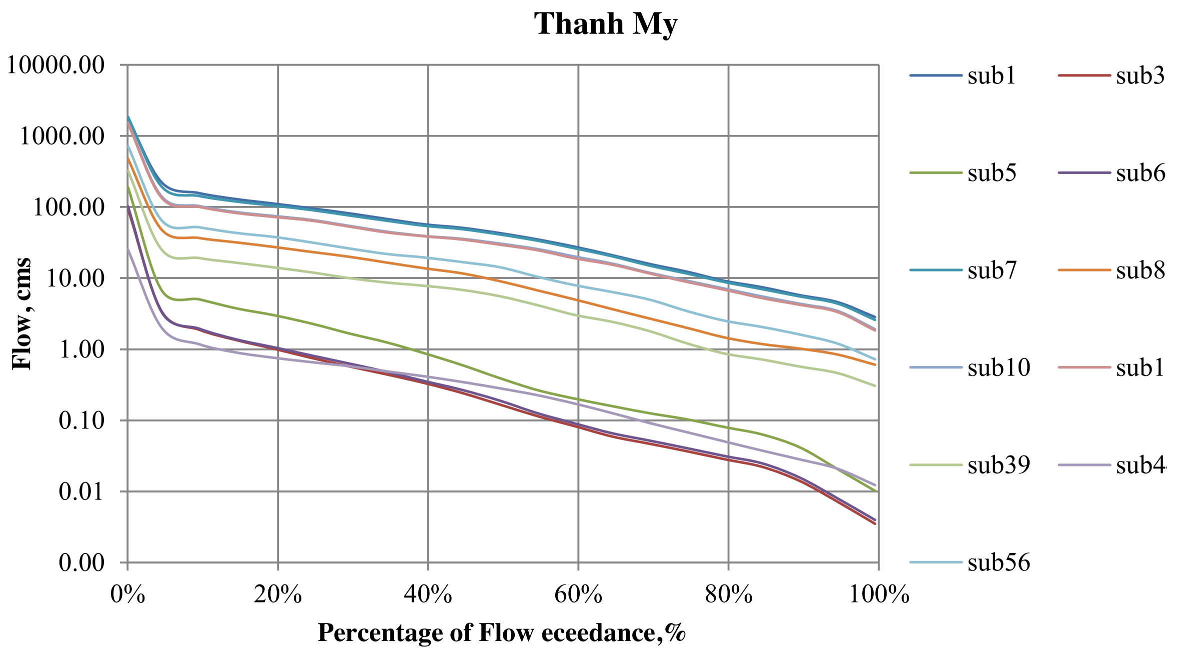


Figure 39 - Flow Duration Curve for Thanh My Subbasins (1998 to 2007)

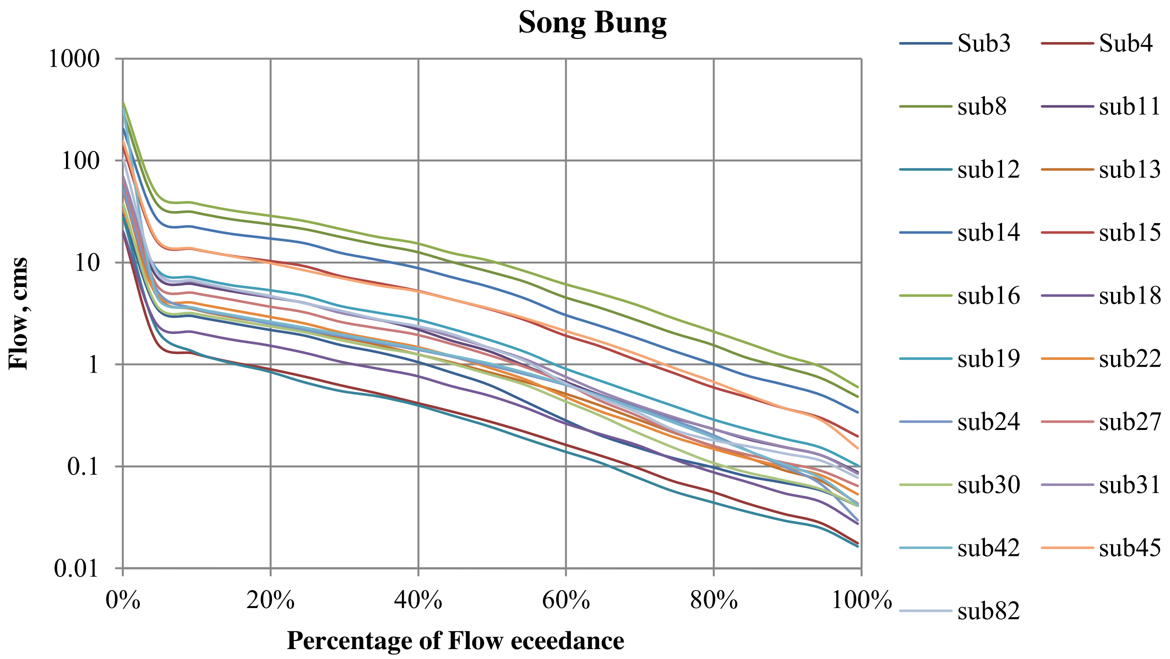


Figure 40 - Flow Duration Curve for Song Bung subbasins (1998 to 2007)

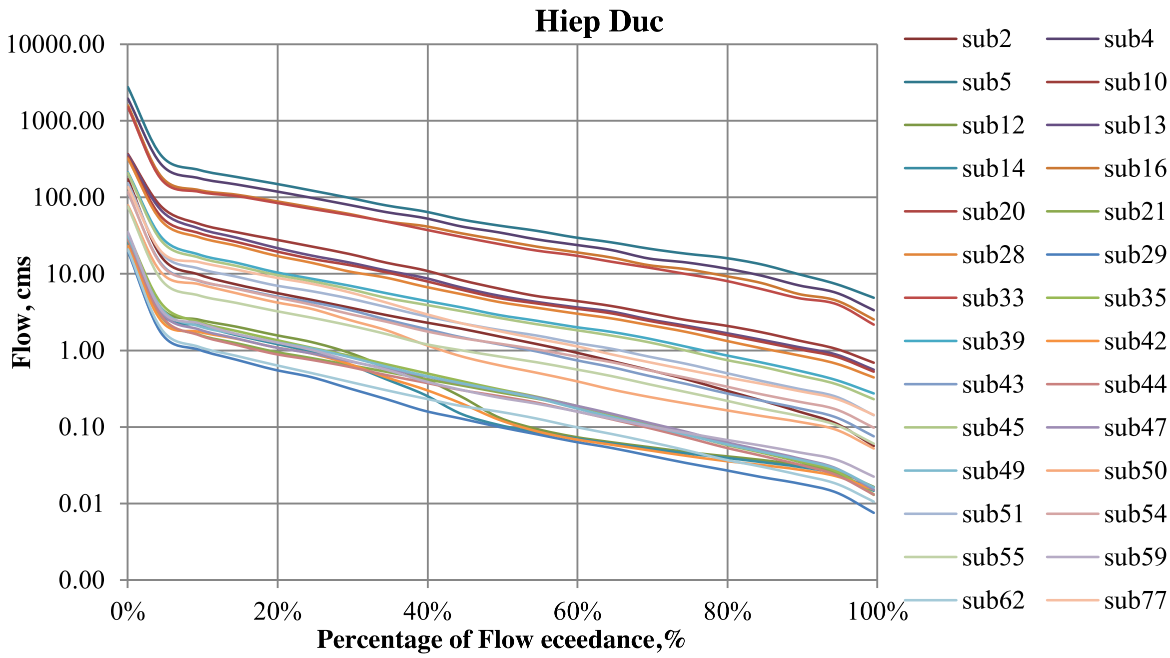


Figure 41 - Flow duration curve for Hiep Duc subbasins (1998 to 2007)

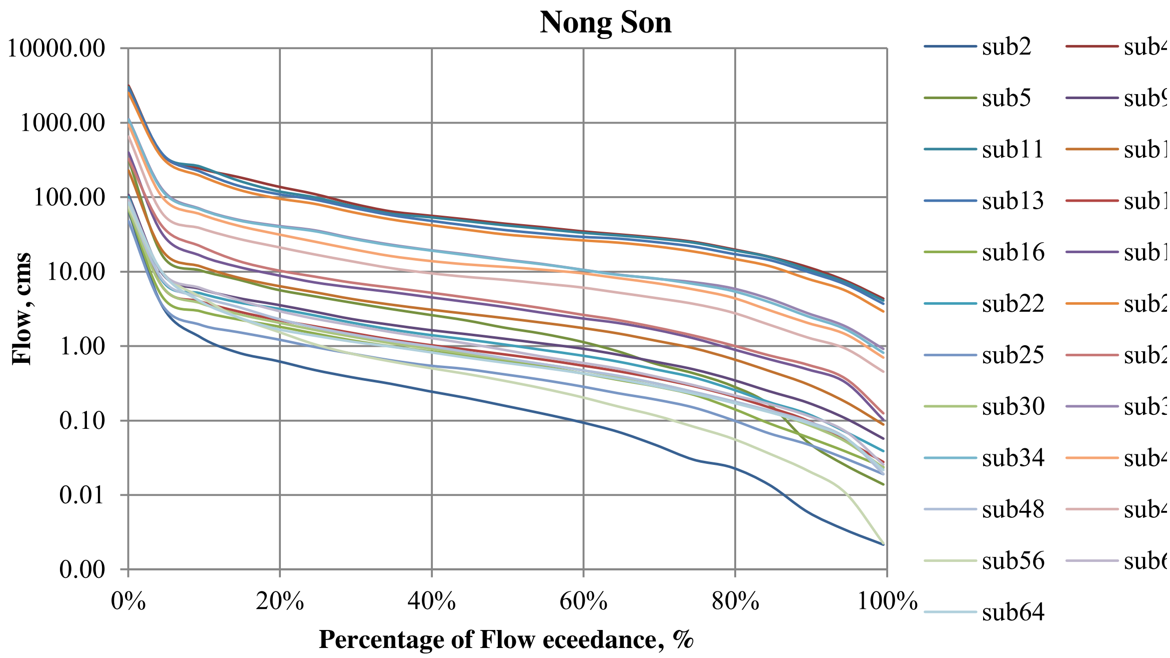


Figure 42 - Flow Duration Curve for Nong Son subbasins (1998 to 2007)

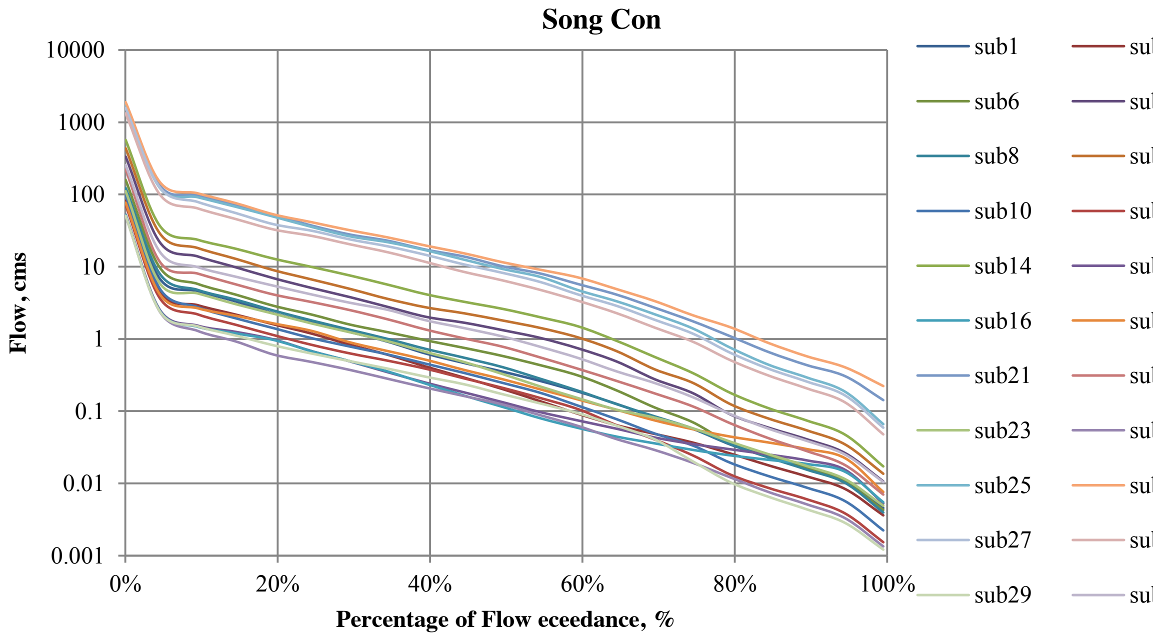


Figure 43 - Flow Duration Curve for Song Con subbasins (1998 to 2007)

4.3.3 Hydropower potential estimation

The constructed FDCs for each watershed will give the information of the flow availability throughout the year. For hydropower project, the percentage of flow exceedance at 25% is used to design plant capacity this is to ensure that there is enough flow of 25% time for hydropower generation. The total potential ROR hydropower in each sub-basin is calculated using equation [4] and [5] for the five subbasins is shown in Table 10. The potential of all 103 watersheds was computed using ArcGIS is shown in Figure 44 to Figure 48. The total theoretical ROR hydropower potential is 277.342 MWh. The potential and distribution of ROR hydropower vary as presented in Table 10. The Nong Son subbasin has the highest power potential compared with other four subbasins. Hydropower potential was categorized according to size from micro (5kW-100kW), mini (100kW-1MW), small (1MW-10MW), medium (10MW-100MW), as presented in Table 11. The majority number of the power plant is mini size ROR hydropower plant with 62 sites. With this size, it could able power 6200 to 62000 households with an average annual electricity consumption of 3,500 kWh.

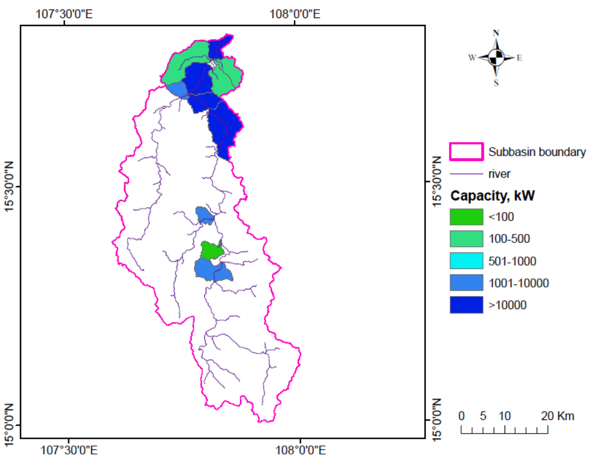


Figure 44 -Thanh My Run-off-river hydropower potential

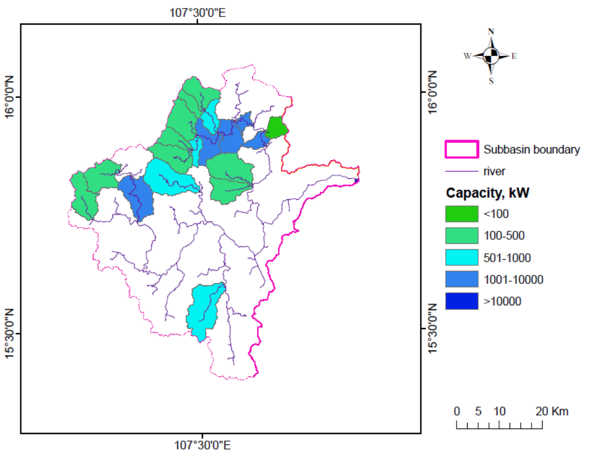


Figure 45 - Song Bung Run-off-river hydropower potential

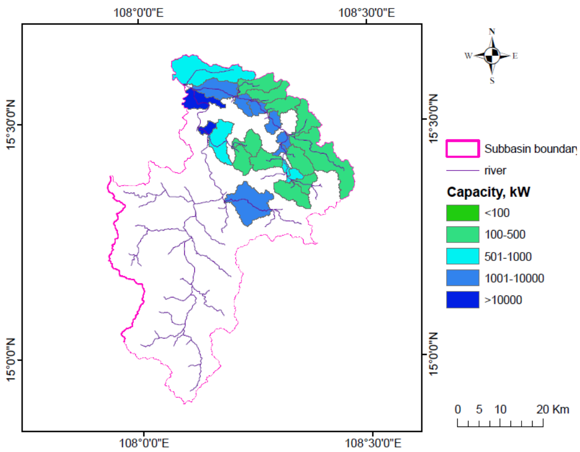


Figure - 46 Hiep Duc Run-off-river hydropower potential

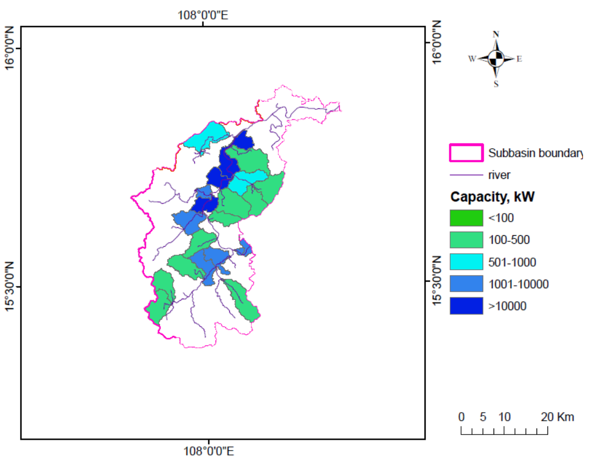


Figure 47 - Nong Son Run-off-river hydropower potential

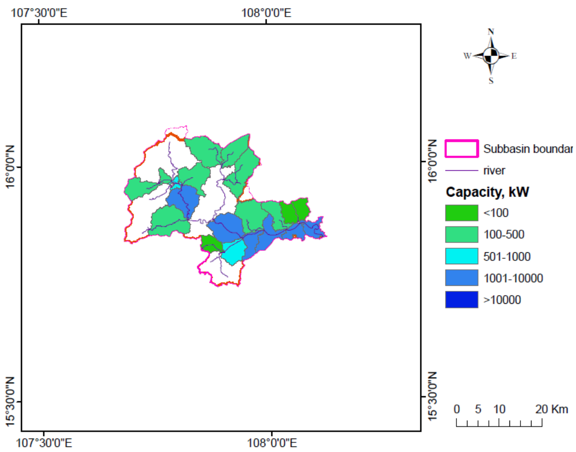


Figure 48 - Song Con Run-off-river hydropower potential

Table 10 - Run-off-river Potential at Subbasins

	Subbasin	Capacity, kW	Capacity factor, %	Annual electricity generation, MhW
A	Thanh My	62.099	41	63,172
B	Song Bung	17.459	41	237,845
C	Hiep Duc	78.226	39	277,811
D	Nong Son	86.176	44	331,426
E	Song Con	33.382	36	109,408
	Total	277.342		1,019,661

Table 11 - ROR Hydropower Potential Categorization (number of sites)

Hydro Category	Power Range	Thanh My	Song Bung	Hiep Duc	Nong Son	Song Con	Total
Micro	5 kW – 100 kW	1	1	2	1	4	9
Mini	100 kW – 1 MW	10	13	15	12	12	62
Small	1 MW – 10 MW	4	5	7	6	6	28
Medium	10 MW – 100 MW	4	-	4	4	-	12

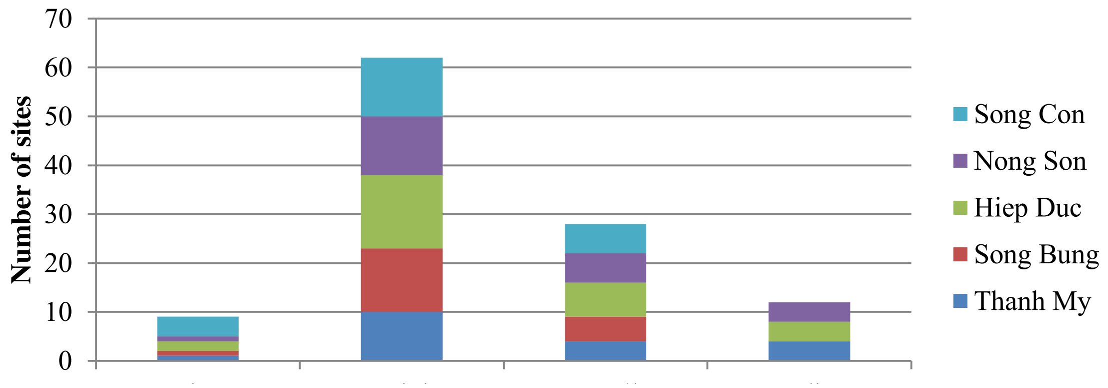


Figure 49 - ROR Hydropower Potential (number of sites)

4.4 Conclusions

The technical ROR hydropower potential was estimated using ArcSWAT, flow duration curves and energy duration curves. The hydrological models for the five subbasins of the Vu Gia-Thu Bon River basin were developed by the Soil and Water Assessment Tool (SWAT). According to this study, the total Run-off-river hydropower potential is 277.342 MWh with an average capacity factor of 40.2 %, which means the system capable of generating 1.02 million MWh in a year.

The ROR hydropower potential estimated in this chapter provide fundamental information to the government and developers as well as the community to formulate plans and policies to develop small hydropower in the river basin.

If the scheme is implemented in the entire watershed, electricity supply to the household can be surplus. The result indicates that ROR hydropower can be alternative system together with the national grid that provides electricity for rural households especially households living in remote areas and have no access to the national grid.

In this chapter, technological ROR hydro potential was estimated. Economical feasible of the proposal was assessed in chapter 6.

5 GREENHOUSE GAS EMISSION REDUCTIONS FROM WASTEWATER TREATMENT IN THE CONTEXT OF RURAL VIETNAM

Currently in many cities and rural areas of Vietnam, wastewater is discharged to the environment without any treatment, which emits a considerable amount of greenhouse gas (GHG), particularly methane. In this chapter, four GHG emission scenarios were examined, as well as the baseline scenario, to verify the potential of GHG reduction from domestic wastewater with adequate treatment facilities. The ArcGIS and Arc Hydro tools were employed to visualize and analyze GHG emissions resulting from the discharge of untreated wastewater, in rural areas of Vu Gia-Thu Bon River Basin, Vietnam. By applying the current IPCC guidelines for GHG emissions, we found that a reduction of GHG emissions could be achieved through treatment of domestic wastewater in the studied area. Compared with baseline scenario, a maximum 16 % of total GHG emissions can be reduced. Under the preferred scenario, the proportion of 30 % of households having latrines are substituted by Japanese Johkasou technology and other 20 % of domestic wastewater is treated by conventional activated sludge.

5.1 Introduction

Vietnam in recent years, after economic reforms (Doi Moi, 1986), has been experiencing rapid economic growth, with an average annual growth rate of 5.4 % in Gross Domestic Product (GDP). The GDP per capita in Vietnam is projected to reach around 2333 USD in the year 2030, which might bring an increase in energy consumption and impel a corresponding increase in GHG emissions. The energy sector is the largest source of Vietnam GHG emissions. In 2000, GHG emissions proportion from energy sector was 35 %, equivalent to 52.8 $TgCO_2$ of total 150.9 $TgCO_2$ emissions (MoDRE, 2010) and will continue to increase as projected until 2030. Total emissions from energy, agriculture, land-use, land use change and forestry sectors are projected to be 169.2, 300.4, and 515.8 $TgCO_2e$ in 2010, 2020, and 2030, respectively. The energy sector accounts for 91.3 % of projected total emissions for 2030.

The waste and wastewater sector has a small share in total GHG emissions of the country. However, this sector emission is likely to increase, due to population growth and the lack of wastewater treatment in cities and as well in rural areas. The major GHGs including CH_4 and NO_2 can be produced and emitted at many stages from sources and final disposal along the discharge pathways (Bogner et al., 2008). Currently, the urban population is 28 %, and accessing of drainage and wastewater treatment facilities is still too low compared to accessing of drinking water supply services. There is only 40 % to 50 % of the urban population served by sewage system, in which only 10 % of the wastewater collected is treated with adequate treatment technology before entering the environment (WHO et al., 2012). The rest of urban wastewater is discharged into natural water bodies. Under tropical climate with relatively high temperature throughout the year, anaerobic processes take place to different extents and methane is released into the atmosphere (IPCC, 2006). Meanwhile in rural areas, the most common sanitation practice is household latrines. Household wastewater (including gray water and black water) is collected in underground chambers and seepage to ground or discharged directly to farmland or gardens, eventually entering open water bodies. The high methane conversion factor (MCF) value of household latrines (Doorn et al., 2000; IPCC, 2006) indicates a significance amount of methane emission from this treatment facility. Thus, having a proper wastewater treatment facility would reduce GHG emissions from domestic wastewater discharge and handling. However, the inventory of GHG emission from wastewater sector as well as options to reduce GHG emission in the sector was not described in any of Climate Change mitigation policies of the country. Also, taking the sectoral approach by targeting each sector (i.e. emissions targeted in VGGS (2012)) in the economy might result in unbalance of development in the sector because many of the sectors are highly independent on each other especially the nexus of water, energy sector.

Previous studies have indicated that CH_4 mainly from untreated sewage inputs is the primary source of GHG emission from urban rivers and streams (Harrison et al., 2005; Watanabe et al., 2012). However, there are few studies targeting GHG emissions from wastewater in a river basin scale. In a study by Galloway et al., (1996), emission from watershed was analyzed because its physiographic and hydrological features shape a biogeochemical system; these same features shape systems of human interaction. In this analysis, the watershed is considered as one of the four major reservoirs, namely: atmosphere, watershed, coastal and shelf region, and open ocean. The result of this study shows the major source of N is from N-fertilizer input. However, this study did not include inputs from sewage discharge to the watershed. Another related study from (B. Liu et al., 2013) examined the life cycle GHG emission from sewage sludge treatment in the Tai Lake Watershed in China. This study selects different sludge treatment and disposal processes to reduce emissions in the watershed and suggests the optimum choice for the Tai Lake Watershed. The proportion of GHG emission from this process calculates about 40% of total emission from sewage treatment and handling (Brown et al., 2010; Siddiqi & Anadon, 2011). The case of Tai Lake is much different from other developing countries, where sewage discharged without proper treatment and became the major source of GHG emission from rivers and streams. Therefore, it is important to study the GHG emission from wastewater discharge and handling in the watershed to provide the optimum solution of the wastewater system for the river basin.

This chapter analyzes GHG reduction from domestic wastewater by providing adequate wastewater treatment facilities under different emission scenarios for the Vu Gia-Thu Bon River basin. GHG reductions from domestic wastewater handling and disposal from sub-watershed is then analyzed using ArcGIS.

5.2 Materials and Methods

GHG emissions from watersheds were calculated based on GHG Protocol and IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The boundary of this study included direct GHG emissions that are methane emission from domestic wastewater treatment and indirect GHG emissions through electricity import for system operation. In the scope of this study, CO_2 and N_2O emissions from wastewater treatment were not considered. The CO_2 emission is biogenic origin that is part of the natural carbon cycle and does not contribute to global warming. Therefore it was not included in natural GHG emissions inventory. The N_2O emission was not included because of insufficient data and large uncertainties associated with the IPCC default emission factors for N_2O from effluent (IPCC, 2006). The system boundary and wastewater discharge pathways are shown in Figure 50.

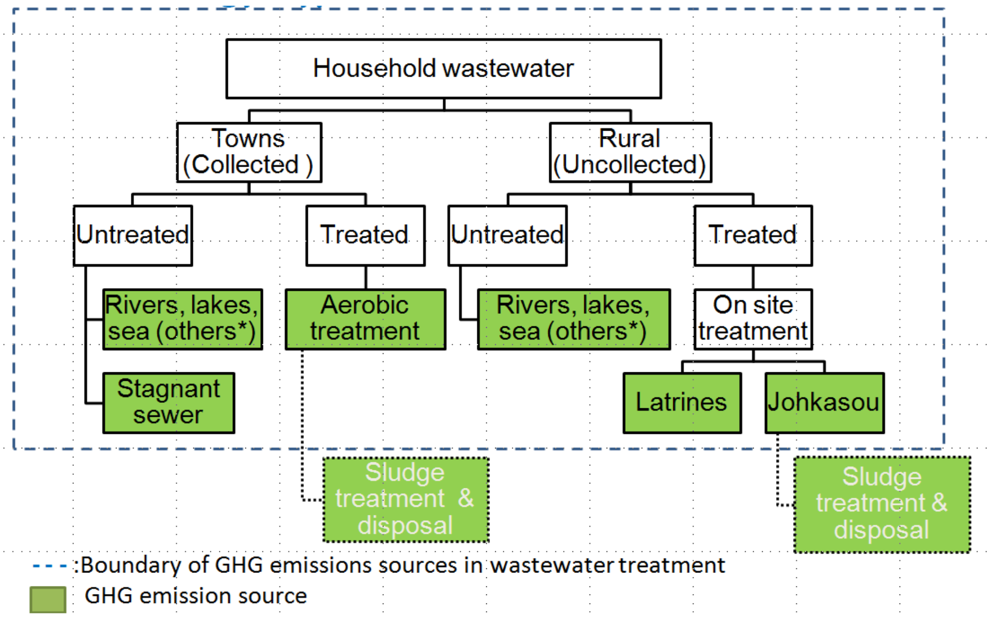


Figure 50 - System Boundary and Wastewater Treatment Pathways

The Total CH_4 emission from domestic wastewater discharged in the watershed was calculated based on the following equations.

Total organically degradable carbon in domestic wastewater discharged in watershed i

$$TOW_i = P_i \times BOD \times 0.01 \times I \times 365 \quad [13]$$

P_i: population of watershed I in inventory year, person

BOD: per capita BOD in inventory year, g/person/day.

I: correction factor for additional industrial BOD discharged into sewers, I = 1.00 for uncollected

CH_4 Emission factor for each domestic wastewater treatment

$$EF_j = B_o \times MCF_j \qquad [14]$$

EF_j: emission factor of treatment pathway j, kg CH_4/kg BOD

B_o: maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF_j: methane correction factor of treatment pathway j, see Table 12.

CH_4 emission from domestic wastewater discharged in watershed i excluding emission from Johkasou was calculated

$$CH_{4\,i} = \left[\sum_{k,j}\left(U_k \times T_{k.j} EF_j\right)\right](TOW_i - S_i) - R_i \qquad [15]$$

CH_{4i}: methane emission in inventory year in watershed i, kg CH_4/year

S_i: organic component removed as sludge in inventory year, kg BOD/year

U_k: fraction of population in income group k in inventory year, $U_k = 1$

T_{kj}: degree of utilization of treatment pathway j, see Table 12.

R_i: amount of CH_4 recovered in inventory year, kg CH_4/year, Ri=0

There were several assumptions to the calculation of total Methane emission as followed

Fraction of degradable organic component removed as sludge is Si=0

Maximum methane yield is 0.6 kg CH_4/kg BOD.

Methane correction factor for additional industrial BOD discharged into sewers is I= 1 for uncollected system

No recovery or flaring of methane Ri=0

Global warming potential for methane GWP=34 (IPCC, 2013)

Because Johkasou treatment was not mentioned in the IPCC guideline, the author use emission factor for Johkasou with domestic wastewater treatment (Gappei-shori Johkasou) value of 1,835 gCH_4/person/year (Ebie et al., 2014). The total methane emission from Johkasou in watershed i ($kgCH_4$/year) was calculated using the following formula

$$CH_{4iJoh} = \frac{1{,}835 \times T_{k,j}}{1000} \qquad [16]$$

Total CH_4 emission from domestic wastewater discharged in watershed i

$$CH_{4\ i\ total} = CH_{4\ I} + CH_{4\ Joh} \quad [17]$$

The model simulated carbon emissions for 30 years from January 2012 to December 2041 under four scenarios. Scenarios description is provided in Table 12.

Table 12 - Scenarios description and model input parameters

Parameters	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Population increasing rate, %	0.5	0.5	0.5	0.5	0.5
BOD_5value in domestic wastewater, g/person/day[1]	40~60	40~60	40~60	40~60	40~60
Wastewater discharge pathways,%					
- Latrines	80	20	20	20	20
- Sewer	-	10	10	10	10
- Conventional activated sludge	-	50	20	-	20
- Johkasou	-	-	30	50	30
- Other treatment pathways	20	20	20	20	20
Methane correction factor for each treatment pathways[2]					
- Latrines	0.7	0.7	0.7	0.7	0.7
- Sewer	0.5	0.5	0.5	0.5	0.5
- Conventional activated sludge (CAS)	0.2	0.2	0.2	0.2	0.2
- Other	0	0	0	0	0
Energy consumption for CAS, kWh/person/year[3]	30	30	30	30	30
Energy consumption for Johkasou, kWh/person/year[4]	88	88	88	75	75
Grid emission factor, tCO_2/kWh	0.56~0.72	0.56~0.72	0.56~0.72	0.56~0.72	0.56~0.66

[1,2] (IPCC, 2006), this value is assumed for wastewater at the discharge point from households.
[3] (Duncan Mara, 2004)
[4] Number calculated for ten people Johkasou tank with power capacity 101W operating throughout the year (Japan Environment Association, 2012)

According to population projection in the region until 2050, population growth rate was assumed to be at 0.5 % for all scenarios. Also, due to GDP increasing and lifestyle improvement in the region, BOD value in domestic wastewater increases from 40 to 60 g/cap/day. Upon baseline scenario, four mitigation options to reduce GHG emissions from wastewater discharge and treatment was proposed namely scenario 1 to scenario 4. About climate change scenarios developed for Vietnam, scenario 1 and 2 represents the medium emission scenario (B21), while scenario 3 and 4 represents the low emission scenario (B12).

The baseline scenario set until 2041, the proportion of the rural population have access to hygienic latrine was 80 %; there is no wastewater sewer to collect wastewater. The major source of methane emission was from wastewater treated in household latrines. In scenario 1, twenty % of rural population has access to a hygienic latrine, 10 % wastewater is collected by sewer, and 50 % is treated with conventional aerobic treatment. Scenario 2 and 4 exhibited that the Japanese Johkasou wastewater treatment could be introduced and served for 30 % of the rural households by the year 2041. The proportion of the rural population has access to hygienic latrine is 20 %. Sewer collected the distributions of 10 % and 20 % wastewater of the rural population wastewater and treated with aerobic treatment respectively. Scenario 3 assumed that 50 % of domestic wastewater discharged from the total population will be treated in Johkasou system.

Electricity consumption for wastewater treatment with conventional activated sludge is 30kWh/cap/year while energy consumption for Johkasou is 88kWh/capita/year. In scenario 3 and 4, energy consumption in Johkasou is reduced to 75kWh/capita/year, this reduction results from technology innovation and introducing of low energy Johkasou. The electricity source is from National Grid with emission factor of 0.56 to 0.72 tCO_2e in the year 2012 and 2041 respectively, except in scenario 4, emission factor is 0.66 tCO_2e in the year 2041. The grid emission reduction results from effectively implemented of

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[1]IPCC Forth Assessment Report, B2 family scenario: Continuously increasing population, but at a rate lower than A2; the emphasis is on local rather global solutions to economic, social and environmental sustainability; intermediate levels of economic development; less rapid and more diverse technological change than in B1 family (medium emission scenario).

[2]IPCC Forth Assessment Report, B1 family scenario: Rapid economic growth, but with rapid changes towards a service and information economy; global population reaches the peak in 2050 and declines thereafter; reductions in material intensity and the introduction of clean and resource-efficient technologies; the emphasis on global solutions to economic, social and environmental sustainability (low emission scenario).

Green Growth Strategy in the power sector; 8 % reduction compared with baseline projection.

Mapping GHG emission using ArcGIS

Two digital maps, DEM, and land use, in raster format, are needed to derive watershed characteristics. DEM resolution of 30 m was derived from Digital topographic map, scale 1:50000. Both land use and the topographic map were obtained from Quang Nam Natural Resource and Environment department. Watershed boundaries were extracted from DEM using ArcHydro (Figure 51, Figure 52). The study area boundaries were identified that covers 103 watersheds with a total area of 2,924 km^2.

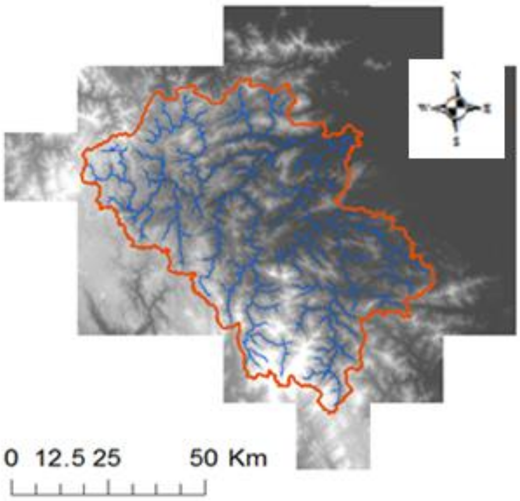


Figure 51 - Watershed Delineation using ArcHydro 9.1

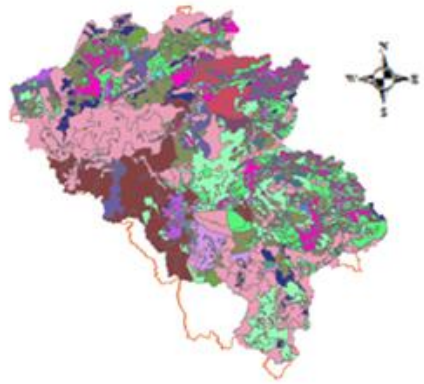
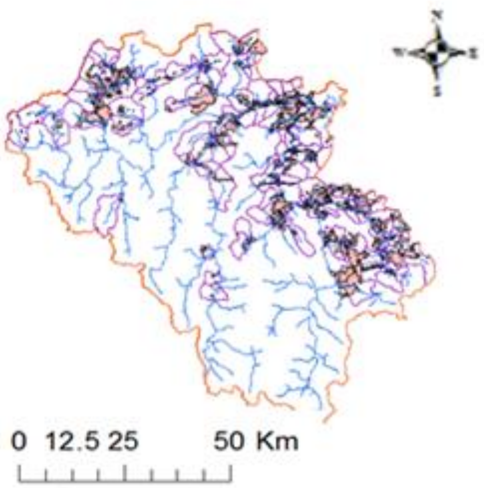


Figure 52 - Land Use Map



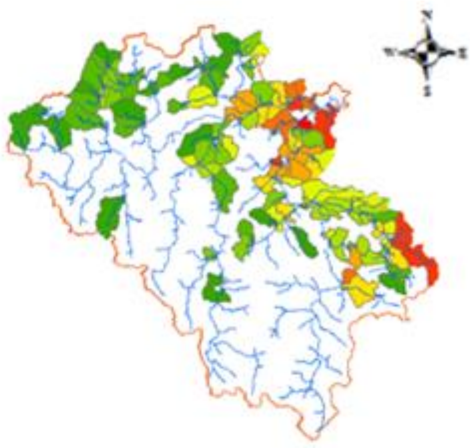


Figure 53 - Rural Settlement Designated in Watersheds

Figure 54 - Population Density Over Watershed Area

The land use map and the sub-watershed map was integrated so that the residential area were covered within the watershed boundaries (Figure 5-3 and Figure 53). The population was obtained at a communal level from Quang Nam Statistical Office. Then total population living in designated residential area in each of the watershed was calculated (Figure 54).

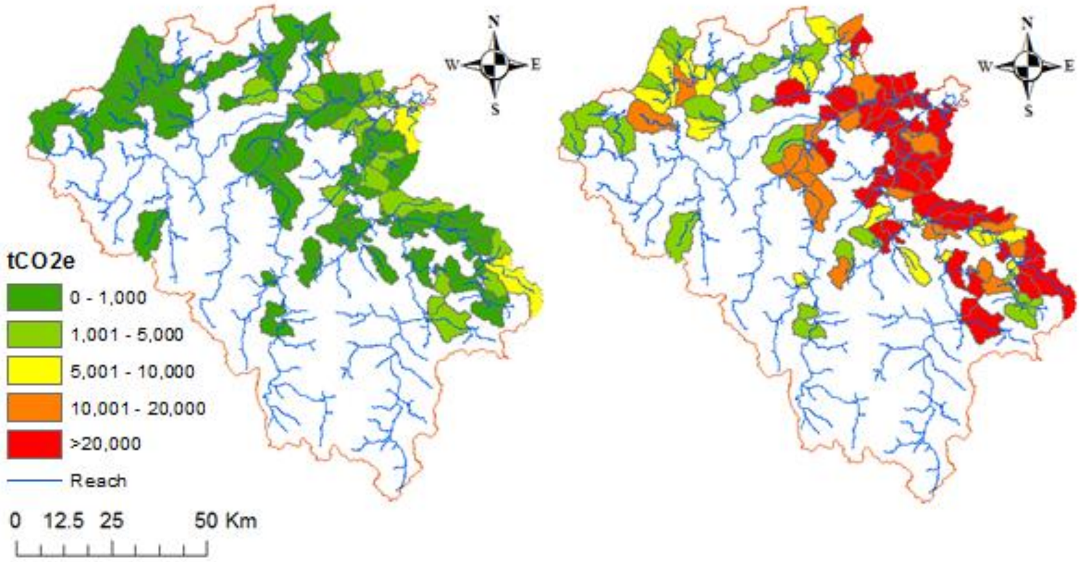
5.3 Results and discussion

A total number of 103 sub-watersheds were studied for GHG emissions from domestic wastewater discharged by the rural population living within the Vu Gia-Thu Bon River basin. The area of watersheds ranged from 2.4 to 93.2 km^2. Table 13 shows ten watersheds with the highest GHG emissions, in a period of 30 years. Even though these watersheds represented only 17 % of the total area, they attributed to 49 % of total GHG emissions from wastewater.

Table 13- GHG emissions projection from 10 most populated watersheds

ID	Residential area,km2	Population projection 2041		CH4 emissions from wasteawter treatment & discharge, tCO_2e				
		people	people/ km^2	Baseline	S1	S2	S3	S4
1	9.95	79,620	8,003	336,508	258,197	270,273	317,945	269,425
2	14.26	73,418	5,149	310,295	238,084	249,220	269,721	248,438
3	5.12	26,389	5,149	111,533	85,577	89,580	96,949	89,299
4	8.54	23,885	2,798	100,949	77,456	86,943	87,749	85,716
5	10.70	22,013	2,057	93,461	71,361	80,104	80,847	78,973
6	25.09	19,426	774	79,625	63,773	68,233	68,888	67,236
7	7.69	15,813	2,057	67,488	51,219	57,500	58,034	56,688
8	28.85	15,067	522	62,165	49,870	53,329	53,837	52,556
9	4.10	14,668	3,578	61,994	47,567	53,393	53,888	52,639
10	7.24	14,895	2,057	61,370	49,216	52,636	53,139	51,871

Baseline scenario: Based on the model emission output, total GHG emissions from wastewater in the area was 2.7 million tCO_2e for the 30 years project. An emission from wastewater per capita per year was 2.7 % of total GHG emissions projection per capita in 2030 which is 5.0 tCO_2eq (Vietnam's second National Communication to UNFCCC, 2010).



(a) (b)

Figure 55-GHG Emissions from Domestic Wastewater Discharge
(a) The inventory year 2012; (b) Baseline scenario for period 30 years

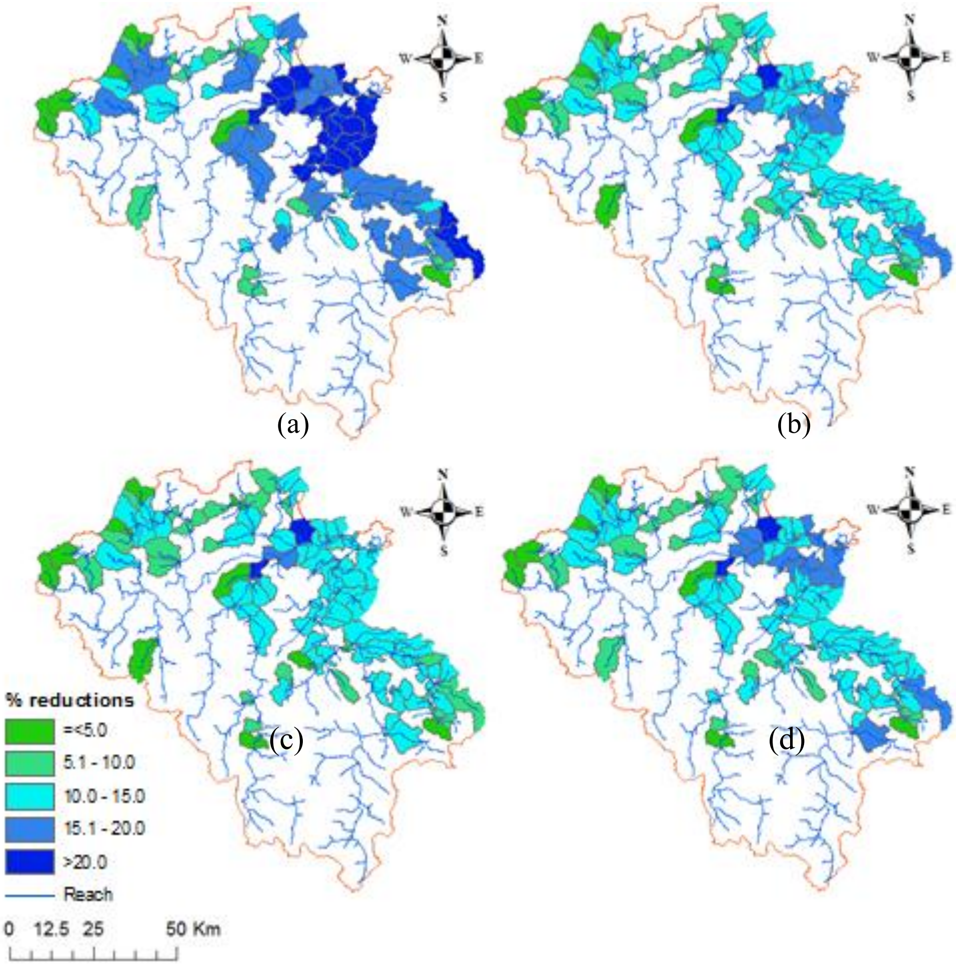


Figure 56 - GHG Emissions Reduction with Baseline (in percentage) From Domestic Wastewater Treatment
(a) Scenario 1; (b) Scenario 2; (c) Scenario 3; (d) Scenario 4

Table 14- Total GHG emissions from 103 watersheds

Parameters	Baseline	S1	S2	S3	S4
Total emission, mil tCO2e	2.76	2.17	2.33	2.42	2.31
Emission reduction with baseline, mil tCO2e	-	0.59	0.42	0.33	0.45
Emission reduction with baseline, %		21	15	12	16
Emission per capita, tCO2 per capita per year	0.15	0.11	0.12	0.13	0.12

Project Scenario 1: shows that, by 2041, the major source of GHG emissions was from wastewater treated in household latrines, with some proportion of methane gasses emits from the sewer. Total emission from wastewater in the area was 2.17 million tCO_2e for the total 30 years simulation. An emission from wastewater per capita per year was 0.11 tCO_2e. By treatment of wastewater, the total methane emission reduction was 0.59 million tCO_2e, which is 21 % reduction compared with the baseline scenario.

Project Scenario 2: indicates that sources of GHG emissions were from wastewater treated in household latrines, GHG emitted from the sewer and Johkasou treatment system. Total emission from wastewater in the area was 2.33 million tCO_2e for the total 30 years simulation. Emissions from wastewater per capita per year were 2.3 % of total GHG emissions per capita in 2030, and the GHG emissions reduction for this project scenario was 12 % compared with baseline scenario.

Project Scenario 3: shows that the total amount of GHG emissions from wastewater in the area for the period of 30 years was 2.42 million tCO_2eq. Compare with baseline scenario, emissions reduction for 30 year simulation period was 0.33 million tCO_2e accounted for 12 %.

Project Scenario 4: indicated the major source of GHG emissions was from wastewater treated in household latrines, sewer and from Johkasou treatment system. The total emission amount of methane emission from wastewater in the area for 30 years was 2.31 million tCO_2e. Compare with baseline scenario, emissions reduction for project period was 0.45million tCO_2e and the GHG emissions reduction per capita per year from wastewater was 0.12tCO_2e.

Uncertainties

The IPCC guideline employed in this study suggested several parameters in the model, which were believed to be very uncertain such as maximum CH_4 producing capacity, the collection of additional industrial BOD discharged in the system. In additional, the wastewater treatment pathways in the areas were assumed however it is highly uncertain with public acceptance. Therefore, acceptance of having Johkasou system install in household or group of households that replaced local household latrines was considered. With uncertainty level of ±10 % of population acceptance to install Johkasou instead of conventional household latrines, total GHG emissions are estimated to range from ±2 % (scenario 2 and 3) to 15-22 % (scenario 4).

Discussion

GHG emissions can be reduced up to 21 % compared to the baseline scenario for 30 years of the project period. However, this centralized wastewater treatment scenario requires the largest investment and thus not feasible for the region. We propose scenario four is the most applicable for the region with 16 % in GHG reductions. In this scenario, the Japanese Johkasou system could serve 30 % of the total rural household especially in the mountainous areas in the up and a middle stream of the Vu Gia-Thu Bon River basin, where the population density is relatively lower than the downstream. In populated areas downstream, centralized or semi-centralized wastewater treatment system is favored and more efficient. In additional, the investment cost for this system is lower than compare with the centralized system. Regarding financial aspect of investment in wastewater treatment facilities, the main budget comes from external assistant Official Development Assistance (ODA) in the form of grants, technical assistance and loans; and the priority is to invest in urban wastewater treatment. Therefore, the obstacle for installation of Johkasou and wastewater treatment system in the rural and less developed area remains as one of the biggest challenges. Nevertheless, this treatment scheme, besides environmental conservation, a substantial amount of GHG emissions can be reduced. With existing Carbon trading schemes, this system has potential to attract carbon finance from Clean Development Mechanism (CDM) or Joint Crediting Mechanism (JCM) projects.

5.4 Conclusions

GHG emissions reduction can be achieved through treatment of domestic wastewater to achieve low-carbon watershed. Compared with baseline scenario, a maximum 16 % of total GHG emissions can be reduced in Scenario 4, in which Japanese Johkasou replace 30 % of household latrines and 20 % of domestic wastewater is treated by conventional activated sludge based on the projection. Emissions reduction from wastewater treatment can be credited to existing carbon-trading scheme, to minimize the initial cost of system construction including installation of Johkasou. On the other hand, GHG emissions can also be reduced utilizing renewable energy for wastewater treatment eliminates grid emissions. The high uncertainty of emission calculation can be minimized by the accessibility of local data or existing empirical data.

The research finding indicates government's GHG emissions reduction target in the wastewater sector can be set up to 16 %. Moreover, a method to develop emission inventory for wastewater treatment in rural areas of developing countries from the watershed approach is proposed. Also, this study raises the potential of utilizing existing carbon emission trading schemes for an initial investment of the wastewater treatment facilities through carbon credit.

6 THE INTEGRATED MECHANISM - SOCIAL AND FINANCIAL CONSIDERATIONS

In this chapter, the second and third pillar of sustainable development namely social and economic sustainability is addressed through household questionnaire survey and financial analysis. This chapter first examined electricity demand for a typical rural household by employing questionnaire survey. The total number of household respondents was 146 households. The financial analysis consists of estimating the investment cost, operation and maintenance cost, levelised cost of electricity generation, and abatement cost. The result of questionnaire survey reveals that average electricity consumption of a rural household is 960 kWh per annual. The total electricity demand for the river basin is 0.14 million MWh/year in 2012 and will increase to 2.3 million MWh/year in 2041. Also, emission reduction potential can be reduced by 17.52 mil.tCO_2 and 11.03 mil.tCO_2 for diesel generator based case and grid based case respectively.

6.1 Introduction

To understand the potential of integrating renewable energy supply and wastewater treatment in a rural context, this chapter was to analyze the current status of electricity demand and the necessity of having wastewater treatment system. Chapter 4 and 5 addressed the potential of renewable electricity for rural communities and potential of GHG emissions reduction through wastewater treatment. However, to implement the scheme, social and financial context has to be carefully considered including electricity demand and projection, investment cost to build the system and willingness to have wastewater treatment system.

In the case of electricity demand, many studies have indicated the need for accessing to off-grid electricity although it is much costly to compare to national grid thus indicate people are willing to pay a higher price to gain electricity accessibility. Wastewater treatment service is, on the other hand, often got less priority. Therefore lowering the cost for wastewater treatment to meet the willingness of the rural people is fundamental. This study takes the bottom-up approach to ensure sustainable development in the rural areas by taking rural electrification and wastewater treatment as a case study. In this chapter, the second and third pillar of sustainable development namely social and economic sustainability is addressed through household questionnaire survey and financial analysis.

6.2 Materials and Methods

6.2.1 Household questionnaire survey

Household data were collected from 146 respondents living in watershed downstream of Vu Gia-Thu Bon River basin. These households represent the rural community in the basin that resides in the countryside and towns. The survey covers three communes Dai Quang, Dai Lanh (rural) and Dai Nghia (town) in Dai Loc district (Figure 57). Household respondents were randomly selected from map and GPS device (Figure 58). Household questionnaire was conducted from *4th to 8th February 2015*. The team included author and five students from the Danang University of Technology. The team divided into three groups of 2 people to approach household respondents and interview them.

The household questionnaire was designed in 4 parts of 28 questions, included yes/no, multiple choice, open answers as followed:

- Part 1: General information of the household respondent
- Part 2: Electricity consumption pattern
- Part 3: Household water supply and sanitation status
- Part 4: Household willingness to participate in wastewater treatment projects

The questionnaire was translated into Vietnamese including a questionnaire sheet and an answer sheet (see Annex 1).

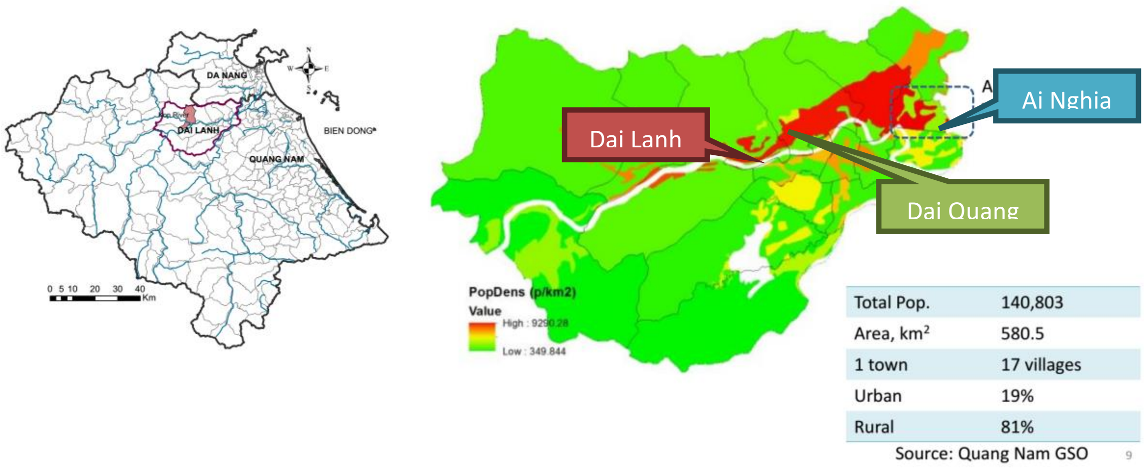


Figure 57 - Dai Loc District and the Surveyed Communes and Town

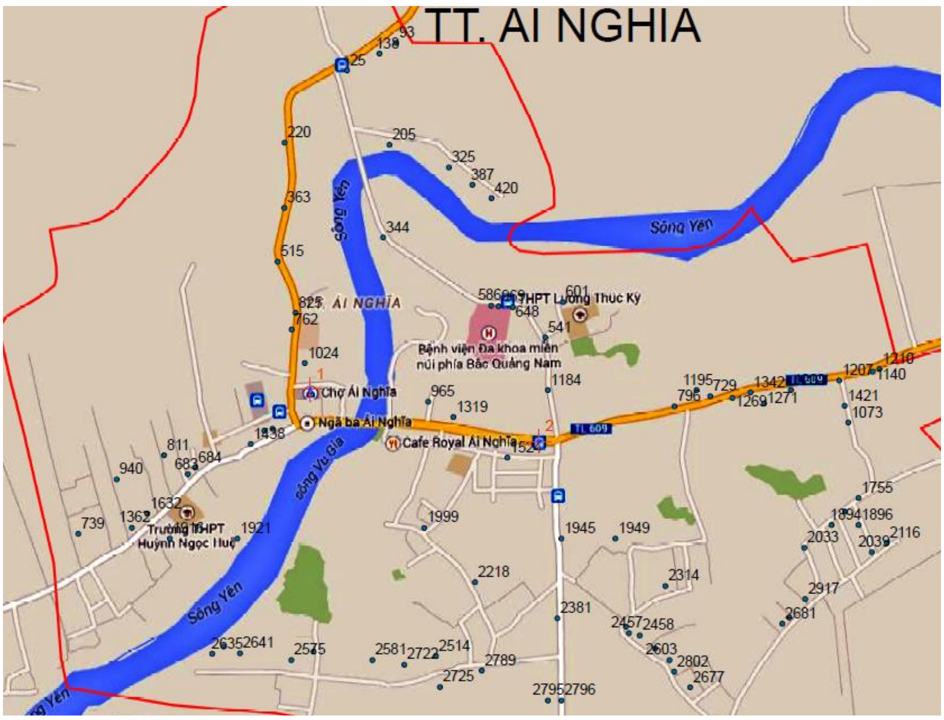


Figure 58 - Household Sampling Locations (Ai Nghia Town)

6.2.2 Household electricity demands analysis

In the household survey, electricity consumption data at the household level, the number of electrical appliances as well as their usage was collected (indicated in questionnaire part 2).

Based on the data collected, we estimate the electricity load by identifying the electricity appliances and the times of usage. The average electricity consumption per month for one household is calculated as followed:

$$\textbf{\textit{Electricity consumption (kWh/ mo)}} = \gamma * hr/d * W * 30 \qquad [18]$$

Where

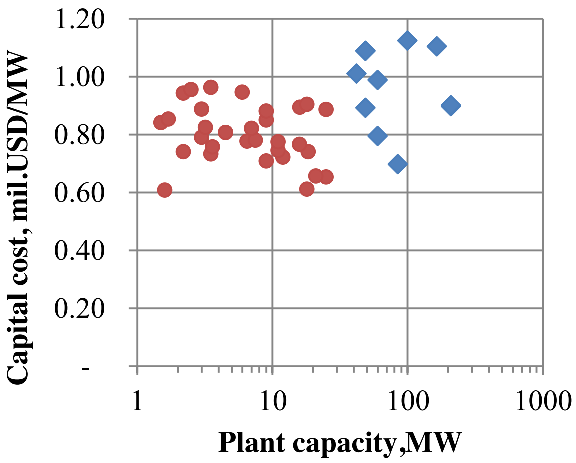
γ is number of electricity appliances per household;

hr/d is usage duration per day (hour/day);

W is electricity consumption for each appliance (W).

6.2.3 Financial analysis

The cost of installing small hydropower is very site specific and depending on the size of the plant. We collect investment data to existing and planned small hydropower schemes in the Vu Gia-Thu Bon River basin (Figure 59 and Figure 60). Regarding O&M cost, the number is often quoted as 1.5 % of the total investment cost per year.



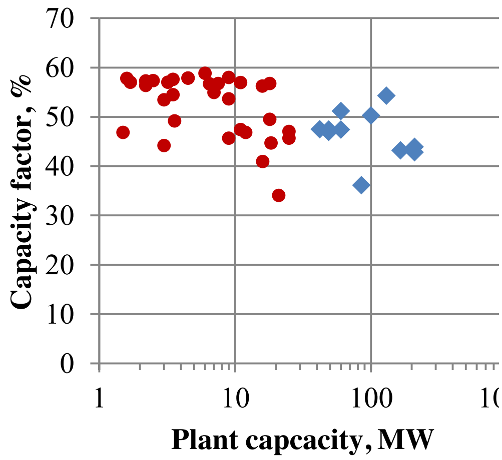


Figure 59 - Hydropower Plant Capital Cost. Source: ICEM (2008a)

Figure 60 - Hydropower Plant Capacity Factor. Source: ICEM (2008a)

Investment for various wastewater treatment schemes in the country was collected from different sources as presented in able 15. The analysis based on the investment per year for the 30 year lifetime.

Table 15 - Investment (capital expenditure - CAPEX and O&M - OPEX) for the various wastewater treatment systems

Type	CAPEX USD/person/year	OPEX	Note
Latrines	3	0	Common pour-flush latrine type, no sludge removal
Sewer	22	5	Source: Hydroconceil, 2012 Estimated Sewer CAPEX equals to 1.6 times wastewater treatment plant CAPEX
Conventional Activated Sludge (CAS)	14	12	Source: (WHO et al., 2012) 1USD= 22,500VND (2015) Wastewater discharge 150litre/capita/d Value for small scale wastewater treatment plant with CAS (A2O) Capacity <10,000 m^3/d
Johkasou	17	6	Source: (Hactra Vietnam, 2016). Domestic Johkasou system for five persons

6.2.4 Abatement cost analysis

Levelised Cost of Electricity (LCOE) from off-grid ROR hydropower scheme is as followed:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} (\mathrm{USD/kWh}) \quad [19]$$

Where

I_t is the investment expenditure;

M_t is O&M expenditure,

n is the system lifetime;

E_t is the electricity generation in the year t.

We assume the system lifetime is 30 years, the discounted value of electricity sold r is 10%, and electricity generated meet 100 % demand for domestic use.

The abatement costs (AC) was calculated to compare the difference between the ROR hydropower scheme and diesel based electricity generation as followed:

$$AC = \frac{LCOE_{Off\ grid\ hydropower} - LCOE_{Diesel}}{Emissions_{Diesel} - Emissions_{Off\ grid\ hyropower}} \text{(USD/kWh)} \quad [20]$$

6.3 Results and Discussion

6.3.1 Household questionnaire survey

6.3.1.1 Household respondent characteristics

The number of household respondents is 146. The proportion of male and female respondents was 46 % and 54 % respectively (Figure 61). The majority of respondent were at the age from 20 to 60; there were three respondents under 20 years old and 18 respondents over 60 years old (Figure 57). Regarding occupation of respondents, the majority were farmers (47 %); another 46 % of respondent were involving in other occupation including mason, carpenter, homemaker, household business or retired. There were only 7 % of respondent were paid workers (Figure 63 and Figure 64).

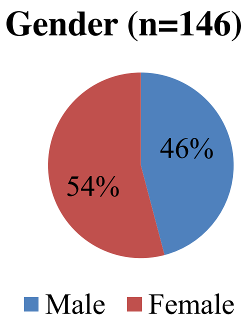


Figure 61 - Gender of Household Respondents

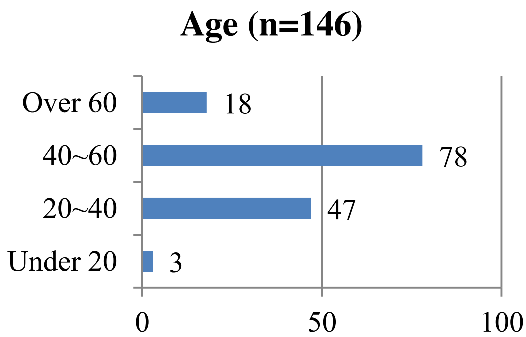


Figure 62 - Age of Household Respondent

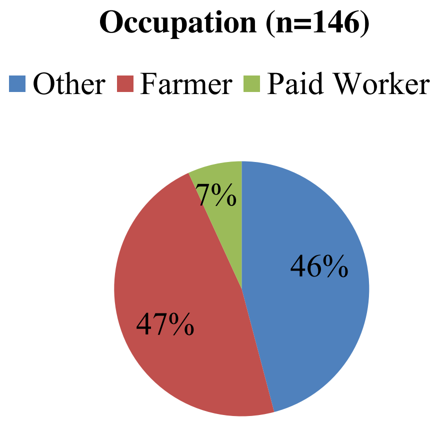


Figure 63 Occupation of respondents

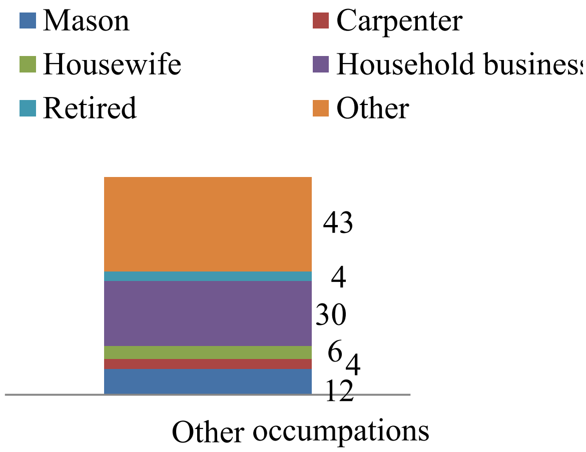


Figure 64 Number of respondents involved in other than the farmer of paid worker occupation.

6.3.1.2 Household energy sources

Firewood, LP gas, and grid electricity were seen as the main energy source for daily activities of the households in the region. All of the household respondents have access to grid electricity which is higher than the average of the region (95.57%). The energy source for lighting and daily activities (other than cooking) come from grid electricity (Figure 65). In the case of cooking, the household usually has various energy sources, as shown in Figure 66 both firewood and gas were used for boiling water and cooking dishes.

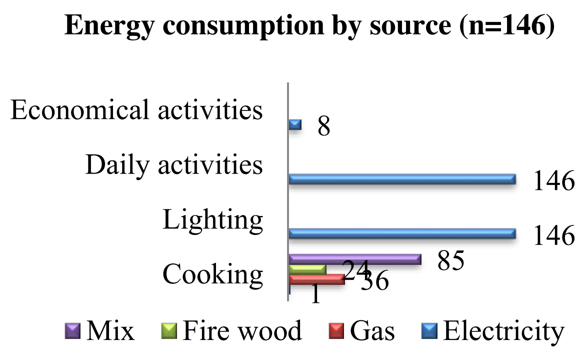


Figure 65 - Energy Consumption By Source (number of respondents)

Figure 66 - Various Energy Sources for Cooking (photo taken by author)

6.3.1.3 Household water supply and sanitation

The water supply comes from four different sources including dug well, drilled well, tap water and bottled water (figure 67). Tap water is the main source of drinking and cooking with a proportion of 55 %. There were 44 % of the households have no access to tap water. In few areas, there was a problem with tap water quality (such as odor or color), purified or bottled water was used for drinking (Figure 68).

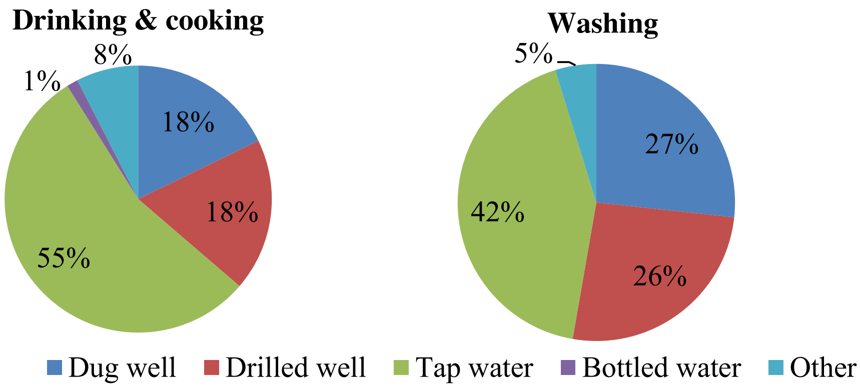


Figure 67 - Water Supply Sources for Household Activities

(a) (b) (c)

Figure 68 - Water Supply Sources
dug well (a); drill well with pump (b); purified water (c)

Wastewater from the kitchen was discharged to backyard or town sewer (Ai Nghia Town), while blackwater from the toilet was collected in septic tanks. There was a household practice open defecation because of lacking financial to build a toilet. The most common toilet type found in the area was a flush toilet with septic tanks. The cost for building toilet varies from 200 US dollars to 800 US dollars. Many of the households with financial difficulties have access to micro credits provide by the Women Associations; the maximum allowance is 600 US dollars for each household with no interest.

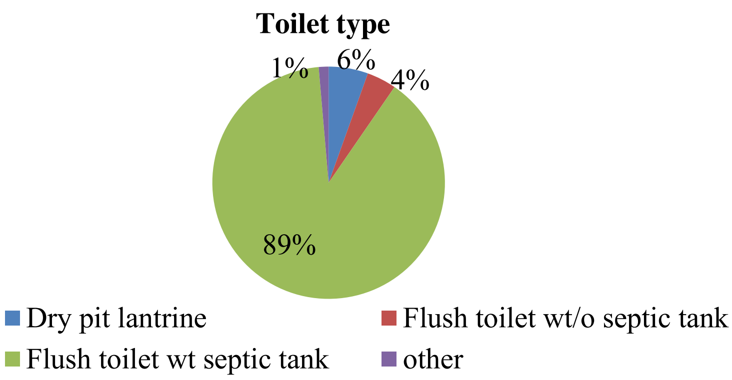


Figure 70 - Toilet Type

Figure 69 - Flush Toilet with Septic Tank

The majority of respondent households discharge wastewater (greywater) directly to backyard (Figure 71). In most of the cases, there were no existing sewers. However in Ai Nghia town, even sewers were built, many households refused to connect to the sewer due to the high cost of connection. There were two households installed biogas tank to treat wastewater from piglets.

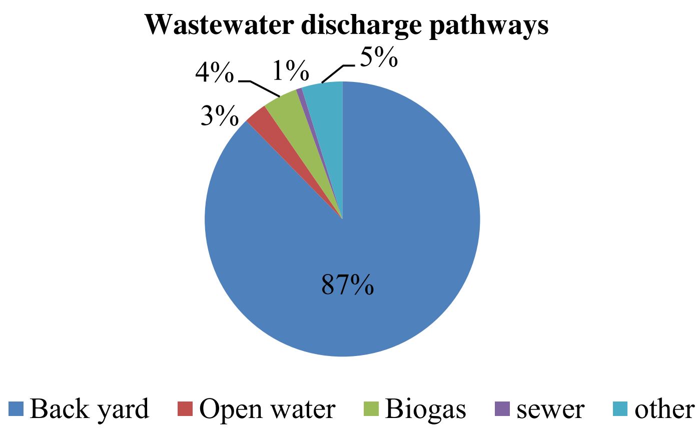


Figure 71 - Wastewater Discharge from Households

6.3.2 Household electricity demand

All of the surveyed households have access to grid electricity. The main electrical appliance by number and usage hour in a particular day were shown in Figure 72 and Figure 73 respectively.

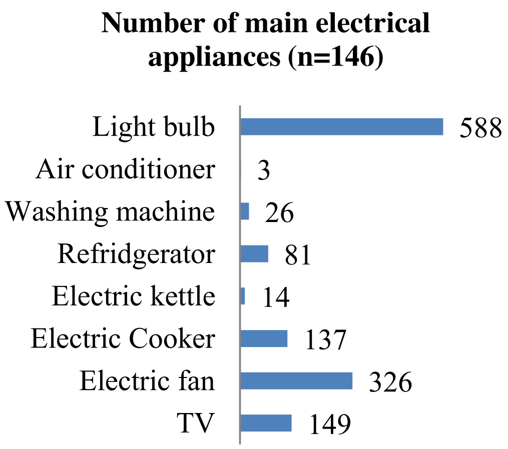


Figure 72 - Main Electrical Appliances

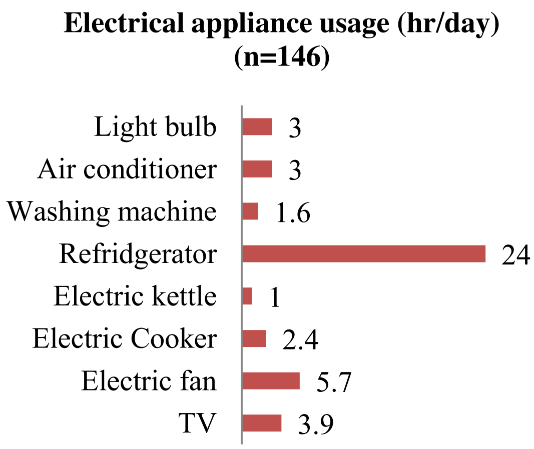


Figure 73 - Electrical Appliance

The average size of the surveyed households is 4.2 people. The most common electricity appliances in this household are light bulbs, electric fan, television and electric rice cooker. In some wealthy family, there are air conditioners and washing machines. According to the survey results, one average household would consume 67 kWh and 93 kWh per month depending on the season. On a yearly basis, average electricity consumption is 228 kWh per capita. With current billing system, it costs 4.4 USD to 6.6 USD per month for each household. In comparison with household income, the price is affordable. However, electricity supply in this rural area is not stable, especially in dry season, electricity blackout often takes place.

Table 16 - Typical Electrical Appliances and Electricity Consumption for Households

Electrical appliance	Quantity	Quantity per household	Usage duration per day	Power consumption	Power consumption per month
	n	γ=n/N	hr/d	W	kWh/ mo
Color TV	149	1.02	3.9	50	4.78
Electric fan	326	2.23	5.7	30	9.16
Electric Cooker	137	0.93	2.4	500	27.02
Water boiler	14	0.10	1	1000	2.30
Refrigerator	81	0.55	24	100	31.96
Washing	26	0.18	1.6	200	1.37
Air conditioner	3	0.02	3	1000	1.48
Light bulb	588	4.00	3	50	14.50
Monthly Electricity consumption (kWh)					93(67[1])
Monthly Electricity payment (US$) (1US$= 22,500VND)					6.1(4.4[2])

[1,2]Due to seasonal variation, we assume no use of AC and electric fan during the rainy season. The number reflects the electricity consumption in the rainy season.

Electricity consumption projection

Many studies have been analyzed the causal relationship between economic development and electricity consumption (Chen, Kuo, & Chen, 2007). Ghosh (2002) pointed out the increase in economic growth may result in a permanent increase in electricity consumption. Similar studies found the relationship between energy consumption and economic growth in Vietnam (Canh Le, 2011; Tang, Tan, & Ozturk, 2016). In the year 2012, electric power consumption per capita in Vietnam is at 1273 kWh (38% is for residential electricity consumption) with GDP per capita 1755.3 USD (World Bank, 2015). The latest projection from HSBC, GDP per capita in Vietnam will reach to 4335 US dollar (constant 2000 US dollar) by the year 2050(Karen Ward, 2012). According to projection, electricity per capita will increase by 10% by each year. With population projection in the region until 2050 is 648,000 people, total electricity consumption for a household is the Vu Gia-Thu Bon River basin is projected to increase to 2.3 million MWh per year.

6.3.3 Financial analysis

6.3.3.1 Investment for various wastewater treatment system

The study proposed four scenarios with different wastewater treatment system as discussed in section 4.2. Table 17 indicates the baseline scenario requires largest initial investment, but the operation and maintenance cost were not considered. Therefore, in total investment (CAPEX and OPEX) the BAU scenario requires the smallest investment. Whereas scenario 1 with centralized wastewater treatment requires the largest investment. The combination system comprises of the decentralized system (Johkasou and latrines) in the upper streams and centralized system (sewer and wastewater treatment plant) in the populated down streams of the Vu Gia-Thu Bon River basin as suggested in Scenarios 2, 3 and 4, can reduce investment cost to 9-13 million USD per year.

Table 17 - Investment Expenditure for Various Wastewater Treatment System Scenarios

	CAPEX (mil.US Dollar)	**OPEX (mil.US Dollar/year)**
BAU	384.95	-
Scenario 1	188.70	5.66
Scenario 2	149.07	3.59
Scenario 3	349.09	2.20
Scenario 4	149.07	3.59

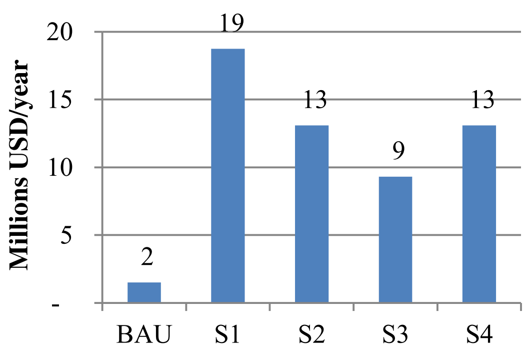


Figure 74 Investment for wastewater treatment system

6.3.3.2 Levelised Cost of Electricity and Abatement Cost

The LCOE for run-off-river hydropower supply scheme in the river basin was calculated with an average electricity consumption of 0.96 MWh per year per household in 2012 and 15.1 MWh per year per household with average size 4.2 people per household as projected in session 6.3.2. The total electricity generated and supply to the community is 136,320 MWh/year in 2012 and will increase to 10^6 MWh/year in 2041. The roadmap for power plant installation is divided into five years period as shown in Figure 75.

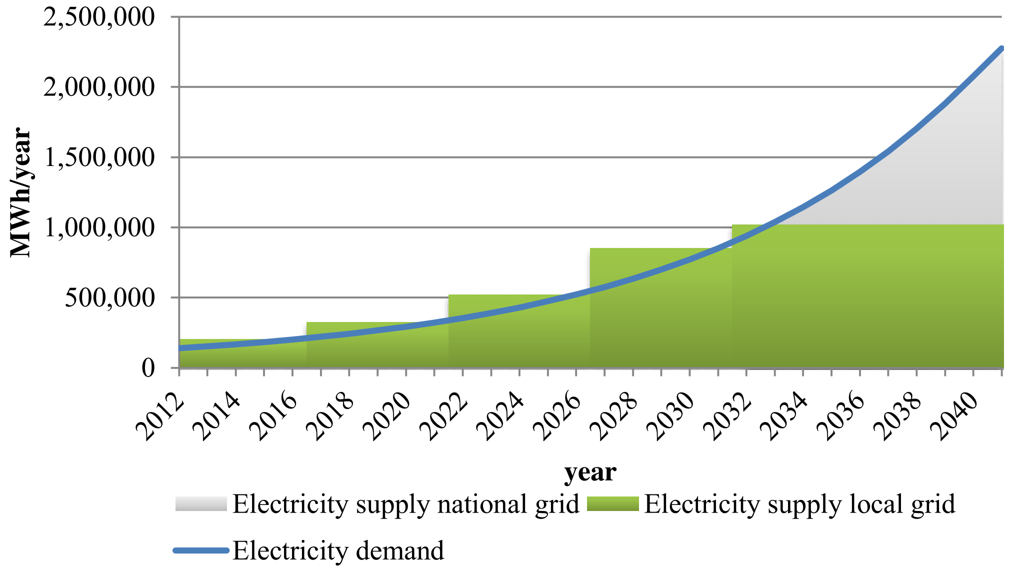


Figure 75 - Electricity Supply Projection (2012 to 2041)

The installed capacity of the total system at the first five-year is 72 MW with average capacity factor is 40.2%; annual O&M cost is 0.0002USD/kWh year (1.5% of total investment cost). Table 18 shows the cost of electricity generation by various sources. The cost LCOE of small hydropower and diesel generator was calculated. The cost for electricity generation from national grid was 0.053 USD/kWh.

Table 18 - Cost of electricity generation by sources

Type of cost	Unit	Value	
		Small hydropower	Diesel generator[1]
Capacity factor	%	40.2	80
CAPEX	USD/kW	1000	640
OPEX	USD/kWh	0.00022	0.19
LCOE	USD/kWh	0.030	0.199

[1] ESMAP(2007)

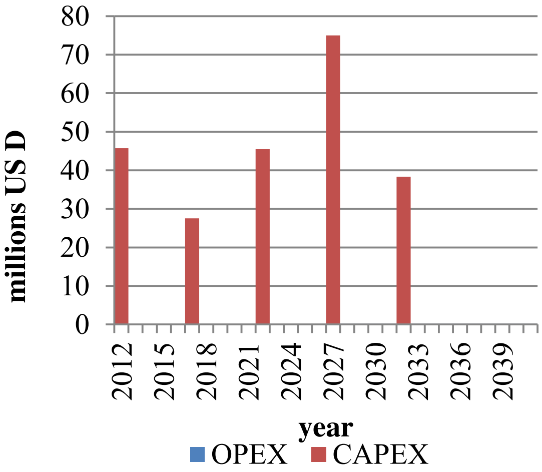


Figure 76 - ROR Hydropower Capital and O&M investment

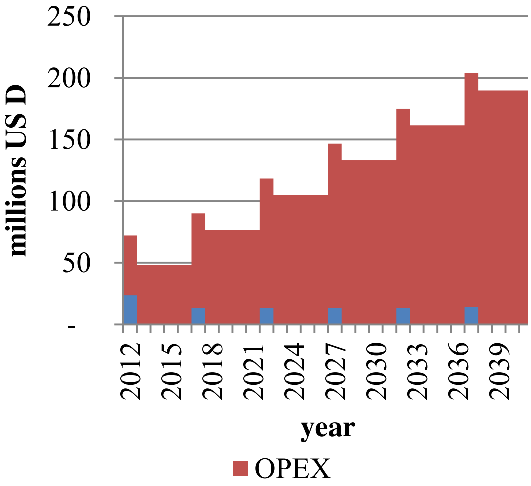


Figure 77 - Conventional Diesel generator Capital and O&M investment

As shown in Figure 76 and Figure 77, the capital investment is paid in every five year period to upgrade the system according to the electricity consumption projection. The total capital investment for ROR hydropower system is higher than Diesel generator. However, the cost of operation and maintenance is much lower. In result, the cost for electricity generation from ROR hydropower is lower than from Diesel generator.

The LCOE calculated shows that, in conventional diesel generator baseline the cost for energy generation is 0.199USD/kWh, this number reflect the high cost of conventional electricity generation, since the diesel price is highly dependent on world fuel price. When considering the retail electricity price sold at 6.6 cents/kWh, the cost for electricity generation from diesel fuel is 3.1 times higher. If the diesel generator is replaced by the hydro turbine, the cost of electricity generation can be reduced by 94 %.

We found that LCOE calculated are similar to other findings by (Blum, Sryantoro Wakeling, & Schmidt, 2013) in the Indonesian village context. The result indicated that diesel power system is expensive for off-grid villages. Small hydropower, on the other hand, has low LCOE compared with a diesel generator, also the lowest compared to other technologies for off-grid electricity (ESMAP, 2007). The LCOE for hydropower electricity generation calculated in this study agrees with findings from other cases in the developing countries with the cost range from 0.012 to 0.27USD/kWh (IRENA, 2012). The cost for small hydropower generation is far cheaper than the retail tariff as well as LCOE diesel generator; these shows that the replacement of hydro turbine is much more economical than compare with a diesel generator.

The results of total emission reduction potential and abatement cost for small hydropower system installed in the river basin is calculated and showed at Table 19. The abatement cost was calculated based on the two reference cases: substitute diesel generator and supply to the national grid. The calculated abatement cost for both small hydropower over diesel generator and grid-based electricity shows a negative value. The value implies that the cost of CO_2 mitigation can be saved by small hydro technology. Also, emission reduction potential can be reduced by 17.52 mil.tCO_2 and 11.03 mil.tCO_2 for diesel generator based case and grid based case respectively

Table 19 - Abatement Cost and Emission Reductions Potential of Small Hydropower Compared to Conventional Diesel Generator and Grid Electricity Baseline

	Unit	**Small hydropower**	**Diesel generator**	**Grid**
Emission factor	tCO_2/MWh	0	0.89[1]	0.56[2]
Total electricity generated	TWh	19.68	19.68	19.68
Total emission reduction	mil.tCO_2	17.52	-	11.03
Abatement cost	USD/tCO_2	-195.51	-	-48.19

[1,2] Source: Ministry of Natural Resources and Environment (MONDRE, 2012)

6.4 Conclusions

The electricity demand for domestic purpose study revealed that at annual basis one rural household consumes 960 kWh, which is lower than the country's average. The total electricity demand is 0.14 million MWh/year in 2012 and will increase to 2.3 million MWh/year in 2041.

The small hydropower system has a lower cost compared with conventional diesel generator based system, and even lower than the retail electricity tariff from the government. This economic advantage can interest private entities to invest in rural electrification even without government subsidies. The cost advantages of implementing on/off-grid hydropower than other renewable energy such as the wind or solar PV.

The negative abatement cost for small hydropower over conventional diesel generator and grid based indicates that cost for CO_2 mitigation can be saved. Although this result is vary depending on the fuel price projection as well as plant capacity and discounted value of electricity sold, the similar negative value is observed from other developing countries.

The lower cost for ROR hydropower generation over conventional diesel generation indicates that rural electrification through renewable energy is economically feasible. Besides, the investment in both electricity generation and environmental conservation with wastewater treatment ensures environmental and social sustainability.

7 DEMONSTRATION OF THE INTEGRATED MECHANISM - SCENARIO ANALYSIS

This chapter presents the scenario-based analysis of the integrated mechanism under different input parameters. The policy framework was assumed following the development of one base case and five scenarios. The benchmarking analysis of project investment was performed to demonstrate profitability of the financial investment under the integrated mechanism. The sensitive analysis was then performed. The environmental co-benefits assessment was achieved by referring with findings from chapter 5.

7.1 Scenarios assumptions

The policy framework assumed in the analysis included the three main policies: climate change mitigation; power sector policy and the international carbon pricing.

- ***Climate change policy***: Vietnam government actively participates in Nationally Appropriate Mitigation Actions (NAMAs). The government establishes policies, programs, and projects to monitor and reduce greenhouse gas emissions especially in energy and waste sector.
- ***Power sector policy***:

  (1) The government provides incentives for renewable electricity generation (including small hydropower development) through issuing the Avoided Cost Tariff (ACT) Regulation. ACT is calculated as the production cost per kWh of the most expensive power generating unit in the national power grid that would be avoided if the buyer purchases one kWh of electricity from a small renewable energy power plant (MOT, 2008).

  (2) The government implements competitive electricity market where wholesale companies could compete in buying electricity before distribution, and the consumers could choose their power suppliers. The electricity price is regulated by the government but can be adjusted based on actual conditions including socio-economic issues.
- ***International carbon pricing:*** is implemented in most OECD countries including EU and Japan including carbon taxes and carbon markets. All trading schemes have access to carbon offsets (JCM, CDM). Non-OECD countries participate in carbon crediting schemes as host countries.

7.2 Methodology for co-benefits assessment

It is important to ensure that all the small hydropower projects developed under the integrated mechanism reduces net emissions and contributes to alleviating environmental pollution in the host countries. Since it is difficult to monitor the emission from CO_2 reduction from baseline for credit approval, the monitored parameters are the amount of electricity supply to grid and supply to wastewater treatment facilities. Therefore, the eligible criteria were determined as followed:

- Criteria 1: Supply electricity to the local or national grid.

- Criteria 2: Surplus electricity generated from small hydropower plant is obligated to distribute to wastewater treatment facility with zero tariffs.

To demonstrate co-benefits of the financial investment under the integrated mechanism, the benchmarking analysis of project investment was performed. This analysis takes the project IRR value of 10% as the benchmark IRR (equal to the maximum interest rate from a commercial bank in Vietnam at the time of analysis).

The five scenarios were developed for the cash flow analysis, and sensitivity analysis was performed.

7.3 Cash flow analysis

The scenarios were developed with the following descriptions:

(1) **Base case**: Small Hydropower Project (SHP) developed under domestic conditions (Figure 78)

The project is to be implemented by the developer to invest in small SHP in the Vu Gia-Thu Bon River basin. The contractors provide equipment and construction for SHP. The ratio between debt and equity is 30% and 70%. The interest rate from a commercial bank is 10% with tenor for ten years. Electricity generated from small hydropower plant will supply to the national grid. Electricity tariff is negotiated between the project developer and Vietnam Electricity Company (EVN) based on the acceptable payment for the whole project life, assuming EVN would purchase with the highest price at 5.3 US cents/kWh. Rural household connected to national grid pay at the retail price set by EVN.

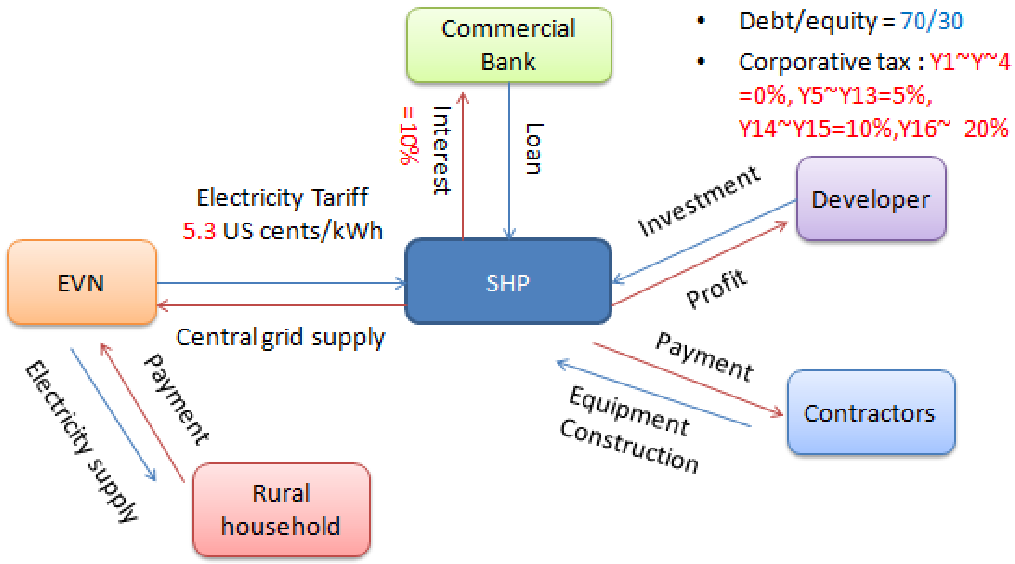


Figure 78- Base case: Small hydropower projects (SHP) implemented by developers.

(2) **Scenario 1**: Small Hydropower project implemented under the integrated mechanism scheme with 50% equipment grant (Figure 79).

Vietnam government and donor government sign an agreement to implement the project under the integrated mechanism. The donor provides loan with low-interest rate (5%/year), and tenor duration is ten years. The ratio between debt and equity is 70% and 30%. Donor contractor provides high quality and durable hydro turbine with additional 50% equipment grant and provides capacity building for a local contractor. In return, 50% of total carbon emission reductions generated by the project will be given to Japan government. As a result, capital cost reduced by 15%. The remainder carbon emission reductions will be utilized by Vietnam government in the future. Therefore, the price of CER is not considered. The crediting period is for ten years. The cost for monitoring, verification, and report (MRV) for the project is paid by the donor contractor and was not included in the project financial calculation. Electricity generated will be provided to the local community and wastewater treatment facilities. Electricity tariff is negotiated between the project developer and Vietnam Electricity Company (EVN) based on the acceptable payment for the whole project life. The electricity generated from SHP sell to the grid at 5.3 US cents/kWh. The corporate income tax for the first four years of the project is waived, the fix tax rate is 10% because its contribution to environmental conservation through supplying electricity for wastewater treatment facilities.

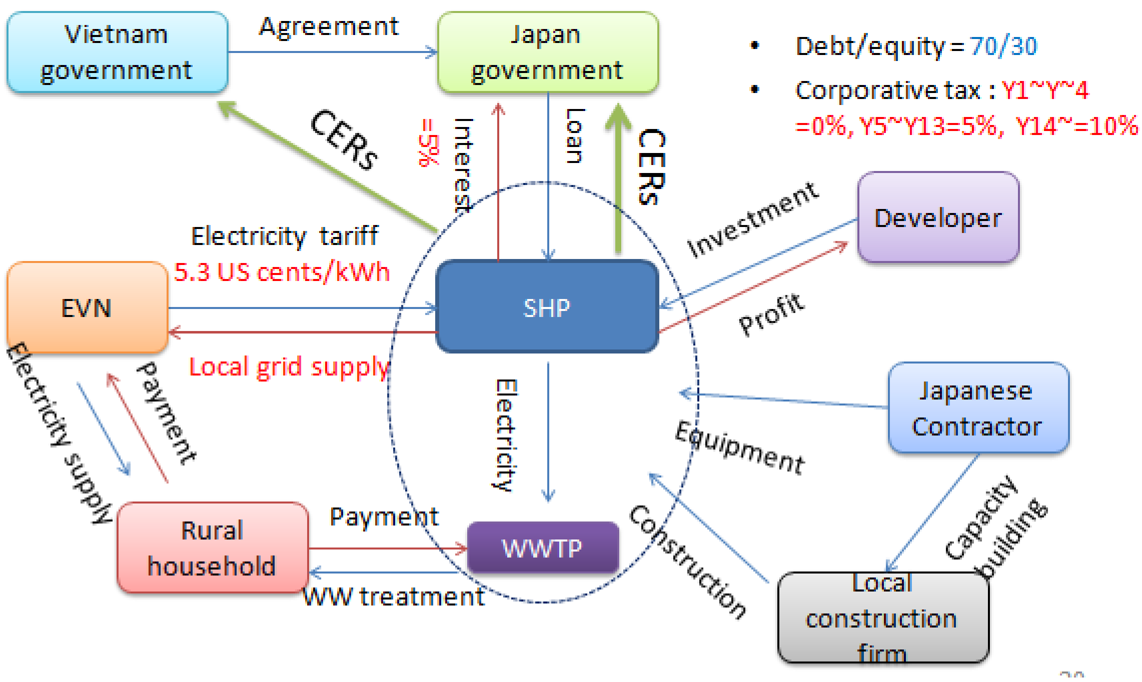


Figure 79 - Scenario 1: Small Hydropower project implemented under the integrated mechanism scheme

(3) **Scenario 2**: Small Hydropower project implemented under the integrated mechanism scheme with 100% equipment grant in which 50% grant from JCM and 50% from ODA.

The assumption conditions were similar to scenario 1. The adjustments were: the total capital investment reduced by 30%.

(4) **Scenario 3**: Small Hydropower project implemented under the integrated mechanism scheme with 50% equipment grant and highest CER price at 150 USD/tCO2

The assumption conditions were similar to scenario 2. The adjustments were CER price, electricity sold at 3.5 US cents/kWh.

(5) **Scenario 4**: Small Hydropower project implemented under the integrated mechanism scheme with 50% equipment grant.

The assumption conditions were similar to scenario 1. The adjustment was: the interest rate issued by the bank is 8%.

(6) **Scenario 5**: Small Hydropower project implemented under the integrated mechanism scheme with 50% equipment grant.

The assumption conditions were similar to scenario 1. The adjustment was: the corporative income tax from year 16 is applied at 20%.

The result of profitability analysis (Table 21) shows that without implementation of the proposed scheme, the project will likely not happen even with the existing ACT regulation.

Table 20 - Cash Flow analysis assumptions

Assumption parameters	Base case	Scenarios				
		50% Grant	100% Grant	3.5 c/kWh	8% interest	20% tax
Initial cost (CAPEX, mil USD)	289.55	246.12	202.69	246.12	246.12	246.12
- Equipment cost	86.87	86.87	86.87	86.87	86.87	86.87
O&M cost (OPEX, mil USD)	4.34	4.34	4.34	4.34	4.34	4.34
Total electricity supply to grid (TWh)	19.7 TWh	19.7 TWh (0.5 TWh supply to wastewater treatment facilities)				
Electricity selling price (US cents/kWh)	5.3	5.3	5.3	2.8	5.3	5.3
Dept	Vietnam commercial bank	Foreign bank				
Interest rate (%)	10	5	5	5	8	5
Corporate income tax	year 1~ year 4: 0% year 5 ~ year 13: 5% year 14 ~ year 15: 10% year 16~20%	year 1~ year 4: 0% year 5 ~ year 13: 5% year 14 ~: 10%				same as the base case
Price of CERs (USD/tCO_2)	-	0	0	200	0	0

Note: The proportion of debt/equity is 70/30. The tenor period is ten years applied for all scenarios.

Underlined letters indicate adjustment conditions.

Table 21- Result of Profitability Analysis

		Base case	50% Grant	100% Grant	3.5 c/kWh	8% interest	20% tax
Investment	**Total**	**293.89**	**293.89**	**293.89**	**293.89**	**293.89**	**293.89**
	CAPEX	289.55	246.12	202.69	246.12	246.12	246.12
	Equipment Grant	0	43.44	86.87	43.44	43.44	43.44
	OPEX	4.34	4.34	4.34	4.34	4.34	4.34
Expense	**Total**	**323.85**	**158.51**	**144.3**	**131.65**	**224.78**	**220.37**
	Interest	203.14	86.37	71.17	86.37	138.19	86.37
	Corporate Tax	120.71	72.14	73.13	45.61	86.59	134.00
Income	**Total**	**1025.81**	**1025.81**	**1025.81**	**1139.43**	**1025.81**	**1025.81**
	Selling electricity	1025.81	1025.81	1025.81	677.42	1025.81	1025.81
	CERs	-	-	-	462.01	-	-
Project IRR (%)		**8.50**	**19.47**	**26.57**	**10.40**	**16.60**	**19.07**
Payback period (years)		**18.39**	**8.12**	**7.31**	**18.32**	**12.37**	**8.12**

Figure 80 shows the cumulative cash flow graph constructed for the base case with 30 year project period. The return period is 18.39 years, and IRR is 8.5 %. The IRR for base case is smaller than the benchmark IRR which is 10% indicates that this project would likely not happen.

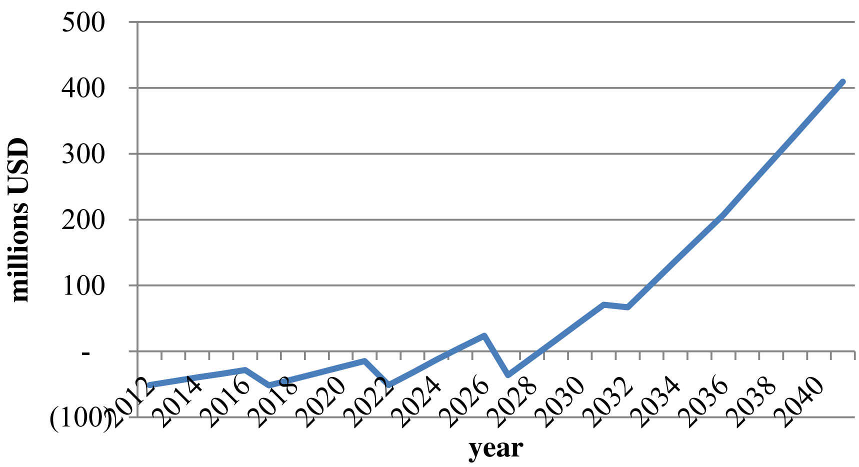


Figure 80 - Cumulative Cash Flow Graph for Base Case

Figure 81 shows the cumulative cash flow graph for the proposed scenarios with 30 year project period. The payback period is from 7.31 years to 18.17 years, and IRR is from 10.04% to 26.57%. The IRR value is greater than the benchmark IRR of 12% indicates these projects generate acceptable profit.

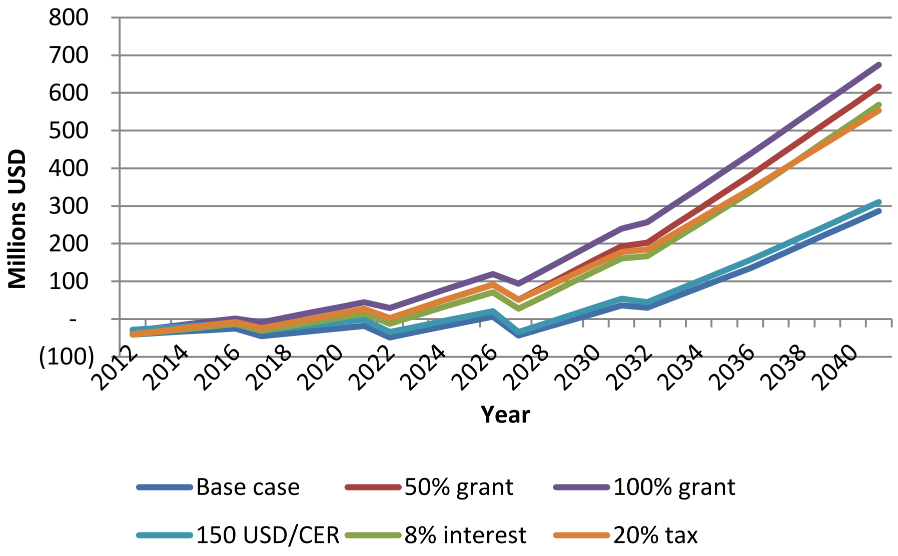


Figure 81 - Cumulative Cash Flow Graph for the Proposed Scenarios

7.3.1 Sensitivity analysis

The sensitivity analysis was performed with the chosen parameters that have an influence on the project implementation based on scenario 1. The range of sensitivity parameters was shown in Table 22.

Table 22 - Sensitivity Analysis

Parameters	**Unit**	**Range**	**ΔIRR**
Electricity selling price	US cents/kWh	±5%	+8.37% ~ -8.68%
Capital cost	millions USD	±5%	-8.17% ~ +8.99%
Interest rate	%/year	±5%	-1.23% ~ +1.28%

Electricity selling price and capital cost were found as the most sensitive parameters to affect project IRR. It is notable that, even if without selling CER, the project implementation is still feasible when the electricity selling price is higher than 3.92 US cents/kWh. In this case, Vietnam government would use CERs for future carbon offset projects.

7.4 Co-benefits Analysis

The main benefit of the project is GHG emission reductions. Besides, the implementation of the integrated mechanism will generate multiple co-benefits. Having the small hydropower plant and wastewater treatment system together would improve rural livelihoods and alleviate water pollution.

Table 23 presents the evaluation indicators for the co-benefits of project implementation under the integrated mechanism.

The Biochemical Oxygen Demand (BOD) was selected as the indicator for evaluating the co-benefits of the mechanism because it indicates the water-borne organic matter that causes water pollution. The reduction of BOD in the discharged wastewater indicates the improvement of the water environment.

Besides from the quantitative co-benefits assessed above, qualitative benefits would be the improved odors generated from untreated wastewater; reduce assess time to cleaner water source or reducing cost of drinking water purification.

Table 23 - Co-benefits Affects other than GHG Emission Reductions

Co-benefits		Unit	Value	Monetized benefit (bil.$)
Social Economic co-benefits: improved energy security, prevention from blackout brownout.	Reliable electricity supply	TWh	19.5	1.03
Environmental co-benefits: - Water pollution alleviation: reduce ground water pollution from untreated domestic wastewater	Removal of BOD in domestic wastewater	kgBOD	$0.18x10^9$	0.26
- Water resource conservation: improved groundwater quality for domestic purposes				-

7.5 Conclusions

The scenario-based analysis to demonstrate the co-benefits of the integrated mechanism were performed. The result shows that under domestic conditions the project return period is 18.39 years, and IRR is 8.5 %. The IRR for base case is smaller than the benchmark IRR, which is 10% indicate that this project would likely not happen. If the project is implemented under the integrated mechanism, the project payback periods are from 7.31 years to 18.17 years and IRRs are from 10.04% to 26.57%.

The result from sensitivity analysis indicates the most sensitive parameters are a capital cost, electricity selling price, and interest rate. With the assistant of the donor, capital cost and interest rate can be reduced for the host country. As a result, the project revenue increases. On the other hand, water pollution from domestic wastewater will be alleviated by the operation of wastewater treatment facilities.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Research significance

The result of our study highlighted that run-off-river hydropower potential has potential to fulfill the electricity demand for the rural villages in the Vu Gia-Thu Bon River basin, especially remote communities without access to the grid with the total capacity 277 MW with a capacity factor of 40.2 %. Also, off grid hydropower can serve as alternative electricity source to ensure the reliability of the grid by reducing grid load, prevent from blackout and brownout. Besides, renewable electricity generation from ROR hydropower scheme will provide power for decentralized wastewater treatment facilities within the watersheds.

The author proposes scenario four is the most applicable for the region with the GHG reduction amount of 0.45 mil.tCO_2eq . In this scenario, the Japanese Johkasou system could serve 30 % of the total rural household especially in the mountainous areas in the up and middle stream of the Vu Gia-Thu Bon River basin, where the population density is relatively lower than the downstream. In populated areas downstream, centralized or semi-centralized wastewater treatment system is favored and more efficient.

Full implementation of ROR hydropower generation and wastewater treatment system would reduce the total amount of 0.38 million tCO_2e per year (on-grid) and 0.60 million tCO_2e per year (off-grid).

Regarding financial aspect of investment in wastewater treatment facilities, the main budget comes from external assistant Official Development Assistance (ODA) in the form of grants, technical assistance and loans; and the priority is to invest in urban wastewater treatment. Therefore, the obstacle for installation of Johkasou and wastewater treatment system in the rural and less developed area remains as one of the biggest challenges. Nevertheless, this treatment scheme, besides environmental conservation, a substantial amount of GHG emissions can be reduced. With existing Carbon trading schemes, this system has potential to attract carbon finance from Clean Development Mechanism (CDM) or Joint Crediting Mechanism (JCM) projects.

Emissions reduction from wastewater treatment can be credited to existing carbon-trading scheme, to minimize the initial cost of system construction including installation of Johkasou. On the other hand, GHG emissions can also be reduced utilizing renewable energy for wastewater treatment eliminates grid emissions. The high uncertainty of emission calculation can be minimized by the accessibility of local data or existing empirical data.

The research finding indicates government's GHG emissions reduction target in the waste sector can be set up to 16 %. Moreover, a method to develop emission inventory for wastewater treatment in rural areas of developing countries from the watershed approach is proposed. Also, this study raises the potential of utilizing existing carbon emission trading schemes for an initial investment of the wastewater treatment facilities through carbon credit.

Also, the small hydropower system has a lower cost compared with conventional diesel generator based system, and even lower than the retail electricity tariff from the government. The economic advantage can interest private entities to invest in rural electrification even without government subsidies. Therefore, creates advantages for implementing on/off-grid hydropower than other renewable energy such as the wind or solar PV.

The negative abatement cost for small hydropower over conventional diesel generator which is - 195.51 USD/tCO_2 (off grid) or -48.18 USD/ tCO_2 indicates that cost for CO_2 mitigation can be saved. Although this result is vary depending on the fuel price projection as well as plant capacity and discounted value of electricity sold, the similar negative value is observed from Blum et al., (2013).

Finally, the demonstration of co-benefits was performed by scenario-based analysis. The result shows that under domestic conditions the project return period is 18.39 years, and IRR is 8.5 %. The IRR for base case is smaller than the benchmark IRR, which is 10% indicate that this project would likely not happen. If the project is implemented under the integrated mechanism, the project payback periods are from 7.31 years to 18.17 years and IRRs are from 10.04% to 26.57%.

Our study also emphasizes the potential of ROR hydropower development for rural electrification in the context of Vu Gia-Thu Bon River basin. This study employed the holistic approach to providing private entities as well as foreign investors with a comprehensive assessment of demand, supply, and economic values. The results from this study may assist the private sector to make the decision for investment in rural electrification projects.

The study provides quantitative evidences for the government of Vietnam, policy makers as well as developers. There is a potential to establish and implement an integrated mechanism for sustainable energy supply and rural development by utilizing existing emission trading schemes such as CDM co-benefits or JCM

8.2 Recommendations

(1) Greenhouse Gas emissions analysis

The IPCC guideline employed in this study suggested several parameters in the model, which were believed to be very uncertain such as maximum CH_4 producing capacity, the collection of additional industrial BOD discharged in the system. In additional, the wastewater treatment pathways in the areas were assumed however it is highly uncertain with public acceptance. Therefore, access to local data such as measurement of wastewater discharge from households; agricultural and industrial wastewater discharged to combined sewers; public acceptance shall be included.

(2) Run-off-river hydropower potential projection

Run-off-river hydropower generation is highly independent of river water flow. Climate change has resulted in a change of river regimes in the long run. Therefor projection of climate change impact on ROR hydropower generation shall be considered for long term prediction.

(3) The importance of studying the mechanism to integrate small hydropower to grid system: optimizing operation, decentralized management.

(4) Transition management is needed to transform the energy sector from fossil fuel based to renewable based accounting social, political and technical aspect.

(5) Implement the model JCM to other Annex 1 countries.

(6) Establish guidelines to non-Annex 1 countries to implement the mechanism for local sustainable development

(7) The importance of research on other co-benefits aspects of small hydropower development projects.

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ANNEX 1

HOUSEHOLD QUESTIONNAIRE