Application of Geographical Information System in Environmental and Economic assessment of Run-of-river Hydropower in Central Vietnam

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Abstract. Conventional hydropower exploitation includes building large dams and reservoirs would pose significant impact to the environment. Recently there is trend to switch from building large hydropower plant to small and medium size, particular run-of-river hydropower plant. This study assesses the feasibility of installing run-of-hydropower scheme in the Vu Gia Thu Bon river basin with regards to the environmental and economic impact. The analysis was performed using GIS to identify the location of power plant that might have environmental constrains. The economic payback of each power plant was calculated and spotted on the digital maps. The methodology proposed in this study could be helpful for decision-makers in the preliminary identification of the most suitable locations to install run-of-river plants in the Vu Gia Thu Bon river basin.

1. Introduction
As of 2017, renewable energy accounted for an estimated 18.1% of total final energy consumption in the world(TFEC).The biggest share of the modern renewable was renewable thermal energy (an estimated 4.2% of TFEC), followed by hydropower (3.6%), other renewable power sources including wind power and solar PV (2%), and transport biofuels (about 1%) [1, 2]. According to the Vietnam master plan for energy and power development in the period of 2016- 2030 with the vision to 2030 [3], the government prioritize the development of renewable energy sources for electricity production;
increase the proportion of electricity generated from renewable energy sources (excluding large-scale, medium-scale and pumped storage hydro power) up to around 7% in 2020 and above 10% in 2030. The total of hydropower from all sources will be 21,600MW in 2020; and increases to 24,600MW in 2025 and 27,800MW in 2030. The proportion of electricity generation from hydropower is 29.5-20.5% and 15.5% of total electricity generation from renewable sources which will be 21,600 MW in 2020, 24,600 MW in 2025 and 27,800 MW in 2030.

Conventional hydropower exploitation includes building large dams and reservoirs would pose significant impact to the environment[4, 5]. Recently there is trend to switch from building large hydropower plant to small and medium size, particular run-of-river hydropower plant. The advantage of run-of-river hydropower is less environmentally damaging than storage hydropower schemes because they are normally built on, or make use of, existing weirs rather than involving the construction of large dams [6, 7]. The number of tools was developed to study and spot the potential of run-of-river hydropower but very few studies include the environmental and economic impact the proposed hydropower schemes [8-12].

The development of run-of-river hydropower in Vietnam not only to meet the need for development but also contribute to reduce greenhouse gases emission and climate change mitigation especially in the water sector. This study assesses the feasibility of installing run-of-hydropower scheme in the Vu Gia Thu Bon river basin with regards to the environmental and economic impact. The analysis was performed using GIS to identify the location of power plant that might have environmental constrains. The economic payback of each power plant was calculated and spotted on the digital maps. The results of GIS application in this study also benefit for decision-makers to select the most suitable site for run-of-river hydropower plants installation in the area.

1.1.1. The technical potential of Run-of-river hydropower in the Central of Vietnam

The Vu Gia-Thu Bon River Basin hosts some of the largest hydropower plants that play 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 [13]. Most of the hydropower plants sell electricity to national grids and locate upstream of the basin (Figure 1), therefore, in many areas; the people are not able to have access to electricity although the community locates very near to the plant.
According to the survey by Lan Huong [15], electricity demand of the rural household in the region at annual basis for one rural household is 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. However, electricity supply in this rural area is not stable, especially in dry season, electricity blackout often takes place. For some remoted areas without access to electricity, firewood, LP gas was seen as the main energy source. The potential of small hydropower in the representative river basin of Vietnam was analyzed in a study by Nguyen and Fukushi [16]. In this study, 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-of-river hydropower potential is 277.342 MW with an average capacity factor of 40.2 % (Figure 2).
2. Materials and methods

2.1. Environmental analysis
The Vu Gia Thu Bon (VGTB) watershed in Central Vietnam lies at the foothills of the Annamite Mountains in the north, west and south. This area is well known with rich biodiversity with high coverage of forest. But it is also threatened by the economic growth in the region, the agriculture expansion and the development of large scale hydropower plants. Raedig, Ho Dac [17] developed the species distribution models and show highest levels of potential tree species richness in the northwestern part of the watershed bordering Lao PDR, and in the highlands in the south at the border to Kon Tum Province.

Because of the lack information about the aquatic biodiversity that is specific to the VGTB river basin, we gather information and map of the network of protected areas in the VGTB watershed. The protected areas located in the southwest of the watershed consist of the Song Thanh Nature Reserve, which is the largest nature reserve in the VGTB watershed. Song Thanh Nature Reserve is home to the globally endangered tiger (Panthera tigris) [18]. The Ngoc Linh NR, have been shown to be important for a number of globally threatened and restricted-range bird species, including two recently discovered species: the golden-winged laughing thrush (Garrulax
ngoclinhensis) and the black-crowned barwing (Actinodura sodangorum). The Sao La (Pseudoryx nghetinhensis) reserve lies at the border to the northern neighboring province of Thua Thien-Hue is known as the protect area of one of the world's most endangered and most elusive mammals.

The National Protection Area GIS map was obtained from the Department of Nature Conservation Vietnam Administration of Forestry and import to Arcgis Pro (Figure 3). We employ mapping overlay technic to identify the environmental sensitivity of the Run-of-river hydropower plant and the level of environmental impact. We categorize the potential plants in to 4 groups: high output-high environmental impact, low output-low environmental impact, low output-high environmental impact and high output-high environmental impact.

![Figure 3. Map of National Protection area and Protection Forest in Quang Nam Province](image)

**2.2. Economic analysis**

The cost of installing small hydropower is very site specific and depending on the size of the plant, the average investment cost for small hydropower plant is calculated as 1000 USD per Kilowatt of plant capacity. The O&M cost is 1.5 % of the total investment cost per year.
To estimate the economic impact of the proposed Run-of-river hydropower plant, the authors employ the simple payback period. This is simply by dividing the total investment with the annual revenue.

\[
\text{Payback period} = \frac{\text{Total investment cost}}{\text{Annual revenue}} \quad \text{(years)} \quad (1)
\]

The hydropower project is considered as financial feasibility when the payback period is less than 8 years.

Levelized cost of electricity (LCOE) represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle [19]. Levelised Cost of Electricity (LCOE) from off-grid ROR hydropower scheme is as followed:

\[
\begin{align*}
LCOE &= \frac{\sum_{t=1}^{n} I_t + M_t}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}, \quad \text{(USD/kWh)} \quad (2)
\end{align*}
\]

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 the electricity retail price is 0.07 USD/kWh

3. Results and discussion

3.1. Environmental sensitivity

The level of environmental sensitivity versus hydropower output is shown in Figure 4. There was only 5 out of 111 potential locations fell into the category high sensitivity and 3 locations fell into the category “low output x high sensitivity”. These sites are less attractive to developers as the potential income will be low and the cost for environmental is high because they are located in the national protected area of Nui Thanh and Sao La. There was 37.85% of total number of the sites is categorized as high output and low sensitivity which is highly attractive to invest.
Figure 4. Environmental sensitivity of proposed run-of-river hydropower locations

3.2. Economic viability

The LCOE for hydropower electricity generation was calculated as 0.03USD/kWh. This number agrees with findings from other cases in the developing countries with the cost range from 0.012 to 0.27 USD/kWh [20]. The cost for small hydropower generation is far cheaper than the retail tariff currently at 0.7 USD/kWh.

The payback period value was calculated and spotted on the maps in Figure 5. In this case, the dependable flow used for calculating plant capacity was at Q25%. There have been 100 potential locations out of 111 identified as financially feasible of installing a run-of-river power plant (payback period less than 8 years). Among 50% of locations, the payback period was less than 6 years. There was 21 location spotted in the Nong Son sub-basin with payback period less than 7 years. The total run-of-river hydropower potential was 309MW and estimated power generation over one year was 1,063,736 MWh. Most of the new proposed location is located near to the rural residential areas. This makes the advantage of accessibility to local community and also reduces the electricity loss and investment in transmission line.
4. Conclusions
This study employed combination of methods to develop the feasibility of run-of-river hydropower at the Vu Gia Thu Bon river basin of Vietnam that taken to account the environmental impact and economic benefit. GIS mapping tools have proven to be effective method to visualize the distribution of potential plant.

The environmental sensitivity was performed and sensitivity map for run-of-river hydropower was constructed. There has been 37.85% of the total number of spotted locations that fall within the low environmental impact and high power output.

The LCOE value and economic payback for the potential sites was calculated and spotted on the map. The location with high economic payback (less than 7 years) is highlighted which shows interest for developers.

To conclude, the methodology we propose could be helpful for decision-makers in the preliminary identification of the most suitable locations to install run-of-river plants in the Vu Gia Thu Bon river basin. However for further exploitation of run-of-river hydropower plant, surveying and technical calculation of specific sites is needed.

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