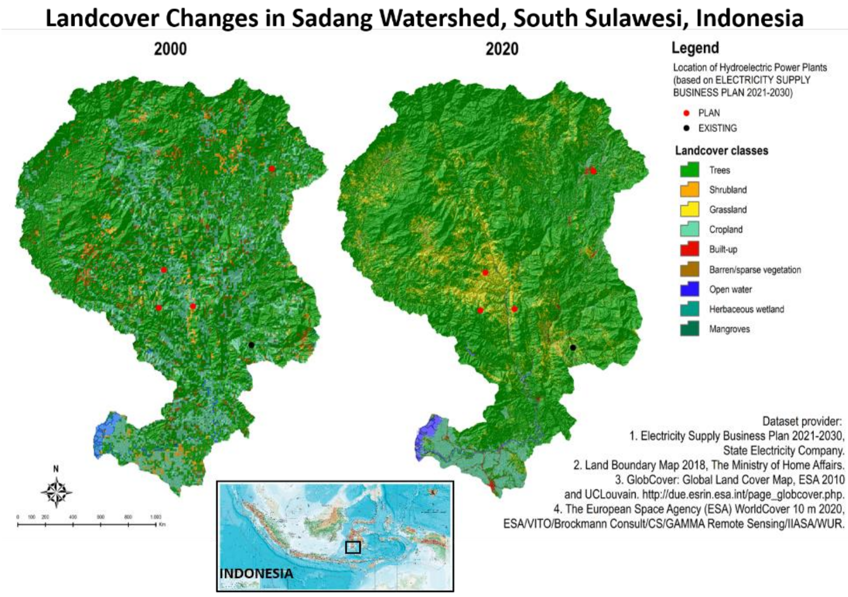
Investigating the Climate, Land-Use, Energy, Water Nexus for Hydropower Plants in South Sulawesi, Indonesia

Dwi Novitasari[1], Sarjiya[1]*, Sasongko Pramono Hadi[1], Rachmawan Budiarto[2], Deendarlianto[3]

Key Messages

- Hydropower plant planning as an option to meet new and renewable energy targets in Indonesia should not only be based on the demand, but also should be analysed with integrated climate and land-use changes that impact the water availability of the system.
- A case study of the Sadang watershed, Indonesia, shows that there was a 12% reduction of forest area in 2020 compared to 2000. Furthermore, consideration of precipitation data from 1980–2020 shows that three of four hydropower plants will not reach the planned capacity due to water availability issues in the location.



Landcover of Sadang watershed in 2000 and 2020. The red dots show the location of hydropower plant planning and the black dots shows the existing hydropower plants. There has been an increase of grassland at the expense of forests.

Introduction

Indonesia is targeting a new and renewable energy (NRE) share in the national energy mix of at least 23% in 2025 and 31% in 2050 [1]. The State Electricity Company (SEC) has two scenarios to achieve the NRE target: optimal and low carbon scenarios [2]. Hydropower plants become an option to meet these targets by considering their potential.

Utilizing hydropower plants in Indonesia is not a new idea. Indonesia's electricity system used hydropower plants to provide the baseload for more than three decades. However, the availability of water has decreased. For example, changes in water discharge for hydropower supply have occurred throughout 2012–2019. The affected hydropower plants include six in Central Java and four in the Central Sumatra system, which cannot operate optimally, especially during the dry season [3–5].

As an archipelagic country, the electricity system in Indonesia is currently not interconnected. It is separated by geographical concerns. There are five large electricity supply systems, called (1) Jawa–Madura–Bali, (2) Kalimantan, (3) Sumatera, (4) Sulawesi, and (5) Maluku and Papua. Each electricity supply system only provides electricity in its islands. For example, the Maluku and Papua system only provide electricity for customers in these two islands and do not provide electricity in the Jawa–Madura–Bali system, and vice versa. The Sulawesi system will become the largest system to develop hydropower plants in the future.

In 2018, the existing NRE share in the Sulawesi system was 23% [6]. Based on SEC planning in the Electricity Supply Business Plan [2], the hydropower plant annual electricity generation in the Sulawesi system is planned to increase from 3,212 GWh in 2021 to 7,992 GWh in 2030. In other words, it will grow from 22.07% to 32.29% from 2021 to 2030. However, in 2019 and 2020, the existing capacity of hydropower is still only 450.1 MW and 588.3 MW. The SEC forecast for the composition of the energy mix in the Sulawesi system is shown in **Figure 1**.

The performance of hydropower is highly dependent on the availability of water in the watershed [7]. The priority for watershed management is maintaining forest area in the upstream area [8]. For example, in South Sulawesi, the total forest area has substantially reduced. In 2012, it had declined 94% compared to 2002, from 470.44 km^2 to 29.26 km^2 [9]. Meanwhile, current power plant planning does not consider water availability due to climate and land-use changes.

Accordingly, this policy brief aims to investigate the climate, land-use, energy, water nexus in Sulawesi. The result will help the government develop better planning by considering many more aspects correlated with hydropower planning. Moreover, the result will also show that hydropower plant planning is not only about the generated energy, but also about consideration of the sustainability of water availability.

Case Study Context

Sulawesi island has the fastest economic growth in Eastern Indonesia. The location is strategic as it is the main gateway to eastern Indonesia [10]. Unfortunately, the availability of electricity is one of the obstacles to the industrial development of eastern Indonesia [10]. Additionally, the energy demand is increasing. The most significant number of customers consists of households, followed by the business sector. Electricity in Sulawesi is predicted to increase in line with population growth [6]. The SEC's projection for all sectors is shown in **Figure 2**.

The case study in this brief regards the Sadang watershed. Based on the SEC planning, the watershed has five hydropower plants on a medium and large scale. In total, the potential, planned, and existing capacity until 2030 utilizing this watershed is 680.5 MW, as shown in **Table 1.**

Methodology

The research used the Cook method [11] to determine the water discharge from precipitation data. First data was collected on land-use changes in the Sadang watershed, of which

Table 1 Potential, existing, and planning of hydropower plant utilized the Sadang Watershed

Hydropower	Capacity (MW)	Planning
Malea	90	2021
Poko	124.5	2026
Bakaru 2	140	2025
Buttu Batu	200	2027
Bakaru 1	126	Existing
Total	**680.5**	

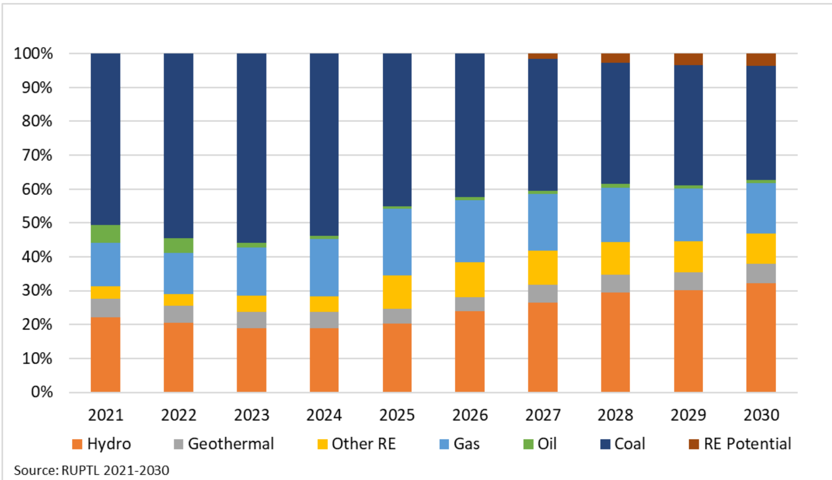


Figure 1 The projection of the energy mix composition in Sulawesi system [2]

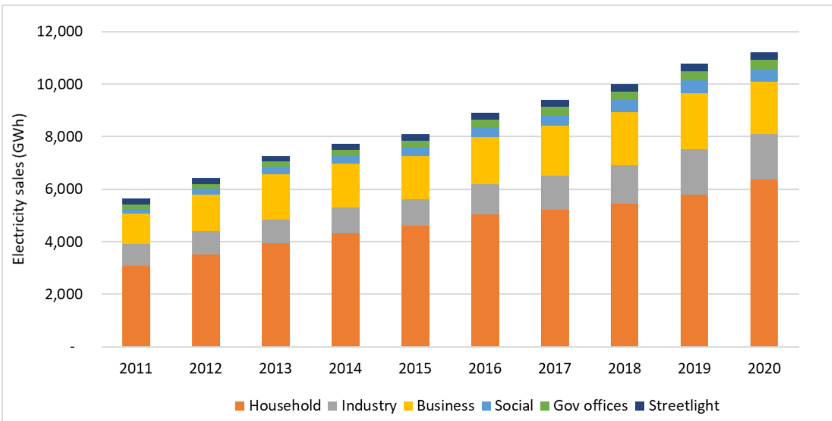


Figure 2 Electricity demand projection in Sulawesi [2]

the total area is 6,675 km^2. The runoff coefficient was determined based on land-use classification. For example, the runoff coefficient of forest is 0.15 and for building is 0.5. The larger the runoff coefficient, the faster the water flow, and the less water absorption to the soil. Furthermore, the water discharge (m^3/s) is calculated by multiplying the watershed area of each landcover category (km^2), rainfall intensity (mm/hour), and runoff coefficient.

Results and Discussion

Data availability of the land-use on Sadang watershed is from 2000 and 2020. Eight types of landcover that are used in the analysis. The forest decreased 12% by 2020 compared to the condition in 2000 and the grassland increased 13% by 2020 compared to the condition in 2000. Additionally, forest, shrubland, cropland, barren, and open water categories of land use are declining. Meanwhile, the amount of grassland and built-up area is rising. The composition of land-use type is shown in **Table 2**.

Table 2 Landcover in Sadang watershed in 2000 and 2020

Landcover	Landcover coefficient (C)	Area (km2)		*CiAi*		Area (%)	
		2000	2020	2000	2020	2000	2020
Forest	0.15	6,156.11	5,324.06	923.42	798.61	92%	80%
Shrubland	0.4	7.99	6.73	3.20	2.69	0%	0%
Grassland	0.3	-	834.65	-	250.39	0%	13%
Cropland	0.15	367.02	366.89	55.05	55.03	5%	5%
Built-up	0.5	0.09	38.44	0.04	19.22	0%	1%
Barren/sparse vegetation	0.4	42.91	42.89	17.16	17.15	1%	1%
Open water	0	93.70	54.16	-	-	1%	1%
Herbaceous wetland	0.15	7.29	7.29	1.09	1.09	0%	0%
Total		**6,675.10**	**6,675.10**	**999.97**	**1,144.20**	**100%**	**100%**

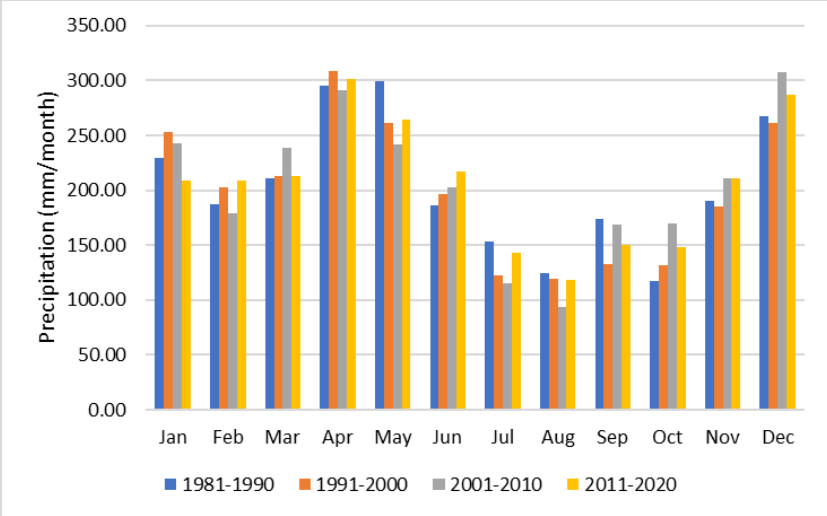


Figure 3 Precipitation in Sadang watershed period 1980-2020

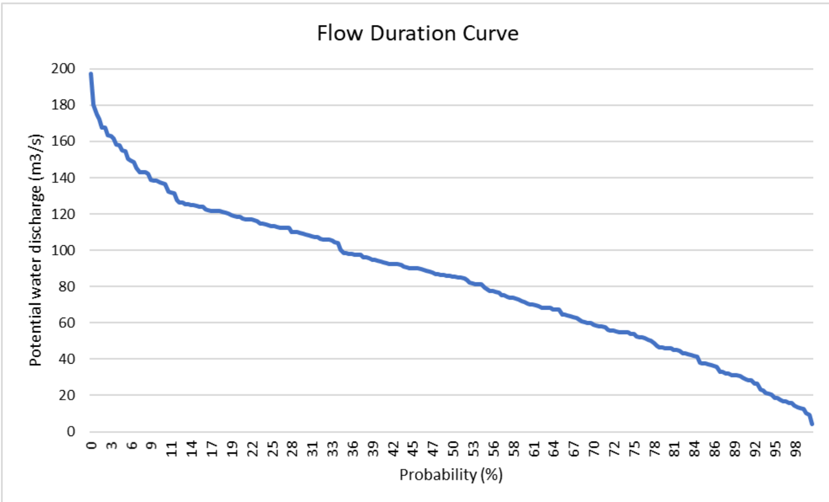


Figure 4 Flow duration curve of Sadang watershed

$$C = \frac{\sum C_i A_i}{\sum A_i} \qquad (1)$$

The runoff coefficient (C) is calculated with equation (1). The sum of multiplying each landcover area (A_i) and each landcover (C_i) divided by total area ($\sum A_i$). Based on the calculation, the runoff coefficient in 2000 is 0.15 and 0.17 in 2020. The higher runoff coefficient means the water flows faster and is not stored in the ground/soil. It also has the potential to flood on the lower area of watershed.

On the other hand, the trend of precipitation in Sadang watershed is shown in **Figure 3**. The data provided concerns the years 1980–2020. To see the trend, the data is classified per decade with an average value for each month. It is known that the minimum precipitation in the last four decades is in August. However the highest precipitation is in April–May, except in the 2001–2010 period when the highest precipitation was in December.

By collecting precipitation data (mm), and the runoff coefficient based on land-use classification, the water discharge (m^3/s) can be calculated. The power potential of a hydropower plant depends on two variables, the water discharge and head (the height of water fall in vertical measurement).

Table 4 Head of hydropower plant planning

Hydropower plant	Head (m)
Malea	19
Poko	27
Bakaru 2	480
Buttu Batu	31

Table 3 Hydropower plant capacity potential based on condition in 2020

Potential water discharge (m^3/s)		Potential power production (MW)			
		Malea	Poko	Bakaru 2	Buttu Batu
Q60	71.8	9.4	13.3	236.5	15.3
Q70	59.0	7.7	10.9	194.4	12.6
Q80	46.1	6.0	8.5	151.9	9.8
Q90	29.5	3.9	5.5	97.3	6.3
Q100	9.4	1.2	1.7	31.0	2.0

The flow duration curve (FDC) in **Figure 4** (previous page) shows the probability of water discharge in a year. For example, the probability of 60% means there are 219 days when the water discharge is 71.8 m^3/s or less in a year.

In the analysis, we use a probability of 60%–100%. Furthermore, the head of the hydropower plant based on location on the SEC map is shown in **Table 3**. The head is measured based on the location mentioned in Electricity Supply Business Plan 2021–2030 [2].

The calculation of potential power produced by hydropower plant is shown in **Table 4**. This condition occurred in 2020.

Compared to SEC planning, this result indicates that Malea, Poko, and Buttu Batu hydropower plants cannot meet the planned capacity. The potential is in the range of 1.2–9.4 MW for Malea, 1.7–13.3 MW for Poko, and 2–15.3 MW for Buttu Batu, whereas the planned capacity is 90 MW, 124.5 MW, and 200 MW, for Malea, Poko, and Buttu Batu, respectively. However, for Bakaru 2, which is 140 MW, the calculation predicted 31–236.5 MW.

To predict the future condition of water availability in Sadang watershed, we used two sets of data. Firstly, land changes come from the analysis. It is known that during 2000 to 2020, the runoff coefficient has changed as much as 0.02. Second, the precipitation is predicted to increase 0.624% per decade [12].

These data show the water discharge only changed 0.01 in 20–30 years. The water discharge potential also has almost no impact in 2030–2050 compared to the condition in 2020.

However, besides the water discharge, the potential of a hydropower plant depends on the head. This calculation can have different results if the head of the hydropower plant is different from the calculation in this paper. Moreover, this paper also did not consider the growth of population and economy that also impact the land-use changes.

Recommendations

The recommendations of this research are as follows:

- The Indonesian government's commitment to developing hydropower to reach the renewable energy target should be accompanied by an analysis of climate and land-use change, which impact water availability.
- Sulawesi island has abundant hydro potential that can be utilized for hydropower, Especially for South Sulawesi, which has five hydropower plants in a watershed, the climate, land-use, energy, and water (CLEWs) nexus needs to be considered. Moreover, the following factors should be considered: the growth of population, economy, and potential of land-use changes in the future based on government planning.
- Based on the analysis of hydropower plants in the Sadang watershed, South Sulawesi, there are no significant power potential changes of hydropower plants in the next 30 years. However, based on the calculation, the capacity of three hydropower plants will not reach the planned capacity.
- The recommendation for future work is to add a more detailed analysis of the CLEWs nexus by modelling scenarios relevant to the context. The modelling result can be an input for stakeholders to develop a suitable policy that considers the CLEWs nexus.
- Furthermore, Indonesia needs long-term power generation planning from a broader perspective. Consideration is needed of not just how much power is generated yearly based on demand, but also the resources, especially natural resources, needed to support the development of renewable energy.

References

[1] President of the Republic of Indonesia. Republic of Indonesia Government Regulation No 79/2014 concerning National Energy Policy (Peraturan Pemerintah Republik Indonesia No 79/2014 tentang Kebijakan Energi Nasional) 2014.

[2] State Electricity Company (PT.PLN (Persero)). Electricity Supply Business Plan (Rencana Usaha Penyediaan Tenaga Listrik) 2021-2030. Jakarta: 2021.

[3] Dabu P, Amri A. Banyak PLTA di Pulau Jawa Berhenti Beroperasi. KontanCoId 2012. https://industri.kontan.co.id/news/banyak-plta-di-pulau-jawa-berhenti-beroperasi (accessed January 6, 2021).

[4] Susanto R, Arista B. Debit Air Turun , PLTA Sempor Berhenti Beroperasi. GatraCom 2019. https://www.gatra.com/detail/news/438946/ekonomi/debit-air-turun-plta-sempor-berhenti-beroperasi (accessed January 6, 2021).

[5] Pembangkit Listrik Tenaga Air PLN Berhenti Beroperasi Gara-gara Kemarau. DetikCom 2013. https://finance.detik.com/energi/d-2353290/pembangkit-listrik-tenaga-air-pln-berhenti-beroperasi-gara-gara-kemarau (accessed January 6, 2021).

[6] State Electricity Company (PT. Perusahaan Listrik Negara). Electricity Supply Business Plan (Rencana Usaha Penyediaan Tenaga Listrik) 2019 - 2028. Jakarta: 2019.

[7] ADB. Asian Water Development Outlook 2016, Description of Methodology and Data. 2016. https://doi.org/10.22617/RPT178628-2.

[8] Paimin, Pramono IB, Purwanto, Indrawati DR. Sistem Perencanaan Pengelolaan Daerah Aliran Sungai. Bogor: Pusat Penelitian dan Pengembangan Konservasi dan Rehabilitasi (P3KR); 2012.

[9] Indonesian National Carbon Accounting. Net GHG Emissions Net GHG Emissions by Carbon Pool (Emisi bersih GRK Emisi bersih GRK berdasarkan Pool Karbon) 2015. http://incas.menlhk.go.id/id/data/south-sulawesi/ (accessed March 25, 2021).

[10] Sosilowati, Handayani A, Wahyudi AR, Massudi W, Febrianto S, Suhendri NA. Sinkronisasi Program Dan Pembiayaan Pembangunan. Jakarta: Pusat Pemrograman dan Evaluasi Keterpaduan Infrastruktur PUPR; 2017.

[11] Setiyono RY, Hastuti AY, Widayani P. Estimasi Debit Puncak Melalui Metode Manning dan Metode Cook Berbasis Penginderaan Jauh dan Sistem Informasi Geografi di Sub DAS Gesing, Kabupaten Purworejo (Estimation of Peak Discharge Using the Manning Method and Cook Method Based on Remote Sensing and. Semin Nas Kebumian Ke-10 Peran Penelit Ilmu Kebumian Dalam Pembang Infrastruktur Di Indones 2017:1683–700.

[12] Meteorology Climatology and Geophysics Council. Climate Change-Rainfall Trends (Perubahan Iklim-Tren Curah Hujan). 2021:1–5. https://www.bmkg.go.id/iklim/?p=tren-curah-hujan (accessed December 10, 2021).

[13] Central Bureau of Statistic South Sulawesi Province. Rainfall in South Sulawesi. Makassar: 2015.

Notes

Climate-Compatible Growth (CCG) programme: CCG is funded by the UK's Foreign Development and Commonwealth Office (FCDO) to support investment in sustainable energy and transport systems to meet development priorities in the Global South.

Acknowledgements

The authors would like to thank the Department of Electrical and Information Engineering and Center for Energy Studies, Universitas Gadjah Mada, for the support.

Author Information

Affiliations

[1] Department of Electrical and Information Engineering, Universitas Gadjah Mada

[2] Department of Nuclear Engineering and Engineering Physics, Universitas Gadjah Mada

[3] Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada

All authors: Center for Energy Studies, Universitas Gadjah Mada

**corresponding author*

Email: sarjiya@ugm.ac.id