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Perspective

We Have Eaten the Rivers: The Past, Present, and Unsustainable Future of Hydroelectricity in Vietnam

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Abstract: Vietnam has one of the most intensively energy-exploited riverscapes in Asia with at least 720 hydropower facilities of various capacities currently in operation or in some stage of construction. These facilities represent about 26 GW of installed capacity. This degree of domestic exploitation is often overshadowed by the geopolitically contested manipulation of the waters of the international Mekong River. In contrast, the utilization of Vietnam's hydropower resources has unfolded gradually and largely unremarked for more than half a century. This perspective argues that the harnessing of rivers and streams for electricity generation is the result of not only the country's abundant hydrologic resources, but also its history, culture, and (geo)politics. The paper traces the processes that have produced this high level of river exploitation, its ambiguous history, and the uncertain future of hydropower in Vietnam in the context of sustainability. Further, the renewed interest in dam-building in recent years is part of a "theater of decarbonization" that masks the operation of powerful domestic and international lobbies with an interest in "heavy engineering" projects that will do little to meet the nation's rapidly growing electricity needs but will likely incur detrimental ecological and sociological impacts. The paper ends by positing that rather than forging ahead with the construction of additional small hydropower facilities, a more ecologically and socially equitable policy could instead critically examine the sustainability of existing capabilities, resolve the factors limiting the development of other renewable sources of energy, and face the fundamental challenge of curbing energy use.

Keywords: sustainability; energy security; hydropower; environmental degradation; Vietnam; decarbonization

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1. Introduction

In 1957, the anthropologist Georges Condominas used the phrase "We have eaten the forest" to translate indigenous understandings of swiddening, or the shifting agriculture practices of the Mnong people of central Vietnam [1]. Herein the phrase is adapted to describe hydropower development on rivers in Vietnam since 1945. Since independence, Vietnam has in a sense "eaten" many of its rivers. But unlike true forms of swiddening, which involve clearing forest for cultivation then allowing the land to regenerate back to high-quality forest, the manipulation of river systems for hydropower poses a near-permanent transformation to the ecologies of both human and natural systems. Today, few of Vietnam's rivers and streams remain to be exploited for power or water supply. And it's far from clear if, or even to what extent, the riverscape transformed through extensive damming and/or flow alteration might be regenerated.

Much of the concern regarding dam-building in mainland Southeast Asia focuses on large international river systems and the complex local and international politics of exploiting an abundant natural source of power at the expense of the wellbeing of local people and natural ecosystems [2–6]. Yet because of the focus on the more politically contested waters of international rivers like the Mekong, or the massive scale and scope of hydropower development in China, it is easy to overlook the reality that Vietnam's hydropower resources are some of the most heavily exploited in Asia, if not the world.

According to the International Hydropower Association (IHA), in 2022 Vietnam ranked fourteenth in the world in installed hydropower capacity and third in the East Asia and Pacific Region, after China and Japan [7]. However, simple hydraulic potential isn't enough to explain the scope, scale, and particular characteristics of hydropower development in Vietnam. Instead, the embrace of "hydro-developmentalism" by postcolonial governments was conditioned and shaped by important historical, political, and cultural factors. Over time, the resulting domestic "hydro-industrial complex" was joined by foreign and international engineering, financing, and consulting bodies that together have produced today's engineered riverscape.

The analysis that follows is original in that it traces the evolution of Vietnam's riverscape over time, and at both local- and national-scales. In general, analyses of hydropower development in Vietnam can be placed in two categories. First, accounts at the national scale tend to focus on political economy: electricity market regulation, for example, or processes of political devolution. By contrast, local-scale accounts, while rare, tend to explore the ecological or social impacts of hydropower development: for example, resettlement activities at specific dam sites, changes in environmental flows (e.g., water, sediment, nutrients), hazards risk, or impacts on biodiversity. Through the combined national- and local-scale lens one can see clearly that the cumulative result of hundreds of individual dams spread across the sloping lands of Vietnam has radically transformed the ecology of the entire nation. The result is an immense "organic machine" or "technonatural system" of vast scale and complexity that can only be grasped imperfectly [8,9].

Herein, the paper traces out many of the factors that drove hydropower development after 1945 and explores how they have shaped the nation's riverscape. It is argued that the legacy of this hydropower development is ambiguous, and that many of the goals that originally drove the intensive exploitation of hydropower were either never realized or are no longer capable of being met given the changed national, regional, and global political economy of energy. By contrast, the social and ecological costs of intensive water damming and diversion are real and persistent. Today, when most of river systems in Vietnam have already been "eaten," renewed interest in dam-building reflects less the hydrologic or economic realities than the persistence of powerful internal and external construction and finance lobbies combined with a "theater of decarbonization" that may or may not adequately address the salient concerns of climate change. In foreshadowing the conclusions: a more sustainable and equitable approach might be to reconsider the role of hydropower expansion in the energy production portfolio and to address the sustainability of relentless growth in electricity consumption.

2. Eating the Rivers

2.1. Background

Vietnam, with the steep terrain of the elongated Annamite mountain range, relatively wet climate regimes, and more than 3400 rivers and streams, has great potential for hydropower generation [10–12]. The International Hydropower Association (IHA), an organization devoted to the promotion of hydropower development worldwide, estimates the total technical potential of Vietnamese hydropower is 35 GW. Much of the potential is concentrated in three river basins: the Đà in the country's North; the Đồng Nai in the south; and the Sê San in the Central Highlands [13].

Since 1975, the Vietnamese state has overseen the aggressive exploitation of the nation's hydropower resources to first stimulate and then sustain the nation's economic growth. Since 1994, Vietnam has had the most powerful HPFs in Southeast Asia, measured by installed capacity. Since then, the size and scope of hydropower development has only grown. Thanks in part to very large hydropower facilities like Hòa Bình (1920 MW; completed in 1994), Sơn La (2400 MW; 2012), and Lai Châu (1000 MW; 2016), Vietnam currently ranks third in East Asia and first in Southeast Asia in installed hydropower capacity—approaching 22,400 MW by our estimate (Table 1; see below). Annual power generation by Vietnam's vast network of hydropower facilities (HPFs) is an estimated 93 TWh (range = 74–112 TWh) of electricity per year, depending on annual variability which is influenced by rainfall, the state of maintenance, and/or operational protocols of HPFs.

Table 1. Information related to the installed capacity (IC) of hydropower facilities (HPFs) operational in Vietnam as of late 2022.

Nominal Category	IC Range (MW)	Number of HPFs	Fraction of Total HPFs	IC Total (MW)	Median IC (MW)	Fraction of Total IC	Power Generation (TWh) *
Mega	>=1000	3	0.01	5520	1920	0.25	26 (20–31)
Very Large	300–999	9	0.02	3602	18	0.16	14 (11–17)
Large	100–299	29	0.05	4914	11	0.22	21 (17–25)
Medium	30–99	79	0.15	4109	15	0.18	16 (12–19)
Small (Large)	8–29	219	0.41	3435	12	0.15	14 (11–16)
Small (Small)	<8	193	0.36	802	10	0.04	3.2 (2.6–3.8)
Total	NR	532	NR	22,383	12	NR	93 (74–112)
Total (all) **	NR	721	NR	26,161	NR	NR	NR

* See Supplementary File "Notes" for listing of all HPFs and discussion on how power generation was determined. ** The total includes 172 (3550 MW) HPFs that are in some stage of construction within a river channel (e.g., in progress, delayed, etc.) and 17 (~170 MW) more could not be verified, but were recognized by the MNRE (2022) document. Locations of the 172 HPFs are also shown in the map (Figure 1) and listed in the Supplementary File "Database". "NR" means not relevant.

Large hydropower facilities like Hòa Bình and Sơn La are highly "visible" owing to the technical prowess and massive investment they demand, the forest and productive land they flood, and the thousands of people they displace. Yet their power—both in terms of electricity produced and as symbols of national development—can obscure how extensively the entire realm of Vietnam's riverscape is exploited. The IHA (2019), for example, estimates that as much as 10 percent of Vietnam's total economic hydropower potential could be exploited as micro-hydropower (<0.1 MW or <100 kW). While scores of such small facilities are already in existence but largely undocumented, harnessing this full potential would require installing thousands more small generation units on hundreds of rivers and their tributaries in the highlands. Thus, within this vision, large iconic dams are simply the most salient elements of a national web that includes HPFs with installed capacities spanning several orders of magnitude (~0.005 to 2400 MW). Collectively, this system, along with thousands of multi-use reservoirs, ponds, barrages, and canals, have reshaped contemporary Vietnam's riverscape over the last half century.

While overall statistics on installed capacity and annual hydropower production are available, reports of the precise number of HPFs in Vietnam vary; and the exact locations of small facilities can be difficult to verify. Since 2006, when the central government devolved planning and approving for small and medium hydropower to the provincial level, there has been an explosion of dam building, driven as much by investment interest as strategic planning, but without a readily accessible centralized public accounting of the outcome. Decision No. 1609/QD-BTNMT of the Ministry of Natural Resources and Environment lists more than 600 hydropower/irrigation dams for which minimum flow discharges downstream of the structure should be maintained [13]. Absent from all available lists is information on micro-scale facilities that would boost the total number greatly, but without making a significant contribution to national generation capacity.

2.2. Installed Hydropower in Vietnam

Table 1 summarizes the installed capacity of HPFs in Vietnam as of late 2022. Details on the facilities are listed in Supplementary File "Database". Construction of the database for the analysis herein began prior to the publishing of Decision 1609/QD-BTNMT by incorporating information in other available forms on the internet or in the literature, then verifying their existence using optical remote sensing images within applications such as Google Earth, Planet.com, openstreetmap.org, etc (see Supplementary File "Notes" for more details). Excluded are micro-scale HPFs (<100 kW) because of insufficient information and the difficulty of locating them. The smallest installation in the database is the 0.11-MW facility at Yang Trung in Gia Lai province (Supplementary File "Database").

As shown in Table 1, facilities are classified following the Vietnamese practice of defining "small" hydropower as HPFs of less than 30 MW installed capacity, but a further distinction is made between "Small (Large)" HPFs of between 8 and 29 MW and "Small (Small)" facilities of less than 8 MW, which is the median size of 'all' small HPFs in Vietnam. This distinction somewhat aligns with international classification systems (US DOE, European Small Hydropower Association) that define small HPFs as having less than 10 MW installed capacity; and it is consistent with recent decisions to eliminate very small HPFs from consideration in some provinces in Vietnam.

Listed in the database are 532 operational HPFs with an installed capacity of 22,383 MW (Table 1; Figure 1). Another 172 (3550 MW) facilities are in some stage of construction within the riverscape. Also included are 17 more HPFs that were listed in Decision 1609/QD-BTNMT, but their presence cannot be verified (estimated capacity of 170 MW). Collectively, this network totals to 721 facilities of 26,161 MW installed capacity (the error is on the order of 5–10%; see Supplementary File "Notes"). Of the 532 operational HPFs, only three are truly megaprojects (>1000 MW), with 5520 MW of combined installed capacity Table 1). These three facilities all have dams with large reservoirs on the Đà River and comprise a full quarter of the nation's total hydropower capacity (Table 1). Another nine have installed capacities $\geq$ 300 MW (3602 MW total). Large (100–299 MW) and medium (30–99 MW) plants total 29 and 79, respectively, with a combined capacity of 9023 MW.

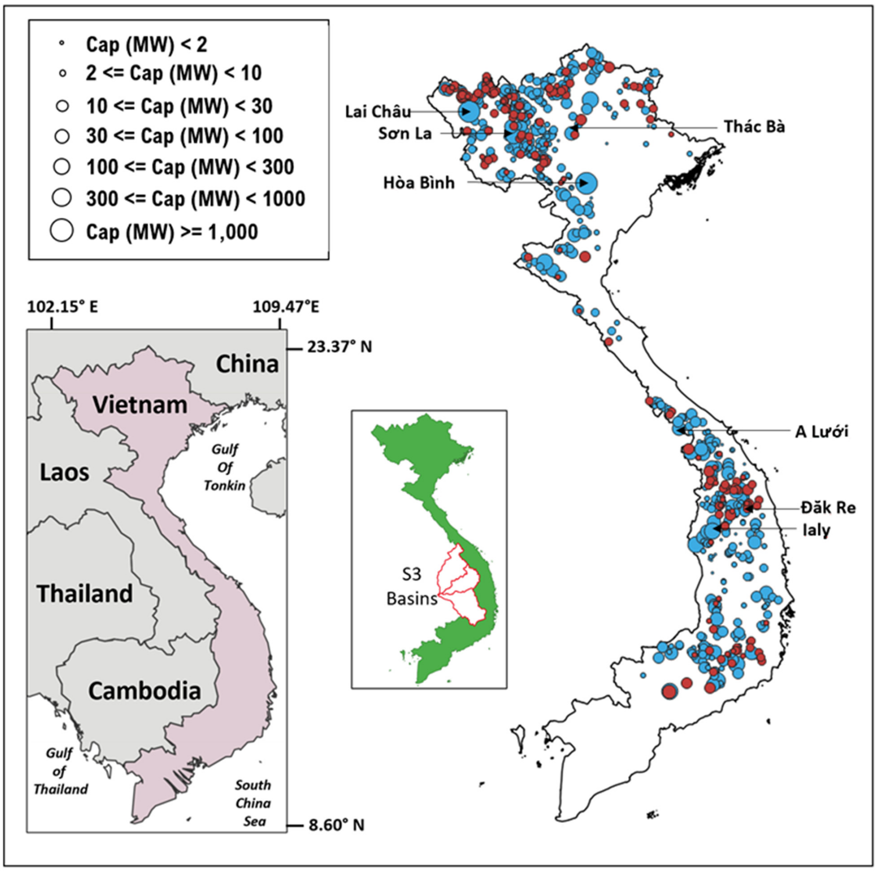

Figure 1. Spatial distribution of hydropower facilities in Vietnam. The main figure on the right shows the location of 532 operational hydropower facilities in Vietnam (blue) and 172 HPFs that are in some stage of construction (red). The names associated with arrows refer to large or important HPFs that are discussed in the paper. The general location of the S3 rivers discussed in the paper are shown in the inset. The circles in the legend are not fully to scale but are representative.

Small HPFs with less than 30 MW of installed capacity make up the bulk of existing HPFs (~77%), but only 19 percent of the installed capacity (4237 MW). Of these 412 small HPFs, 219 range in installed capacity from 8–29 MW; 193 have installed capacities < 8 MW. In agreement, all but 18 of the 172 HPFs that are in various phases of construction are small. Collectively, the total of 601 small HPFs in operation (412), in some phase of construction (172), or not located (17; assumed to be small) is higher than that listed in a 2020 report from the MOIT's Department of Electricity and Energy, which referred to 342 operational small HPFs and a further 158 under construction (500 total) [14].

With respect to reliability, the most recent draft National Power Development Plan 8 (PDP8) from September 2021 lists installed hydropower capacity in Vietnam as 20,771 MW, which is slightly lower than our estimate of 22,383 MW (Table 1). The difference of 1612 MW is within 7 percent error. Again, some discrepancy is expected because the draft plan doesn't include many independent HPFs. The database in this analysis may also include some HPFs that were decommissioned without wide-spread knowledge, or conversely, it may not have included all small HPFs without sufficient documentation. Further the estimated range of hydroelectricity generated (74 to 112 TWh/y for 2022; Table 1) is higher than the IEA's reported range of 63 to 86 TWh for 2017 to 2020 [15]. Discrepancy in the output estimates largely stems from the fact that complete data sets on electricity production for many HPFs are not readily available. Some annual outputs had to be estimated from the relationship shown in Figure 2B.

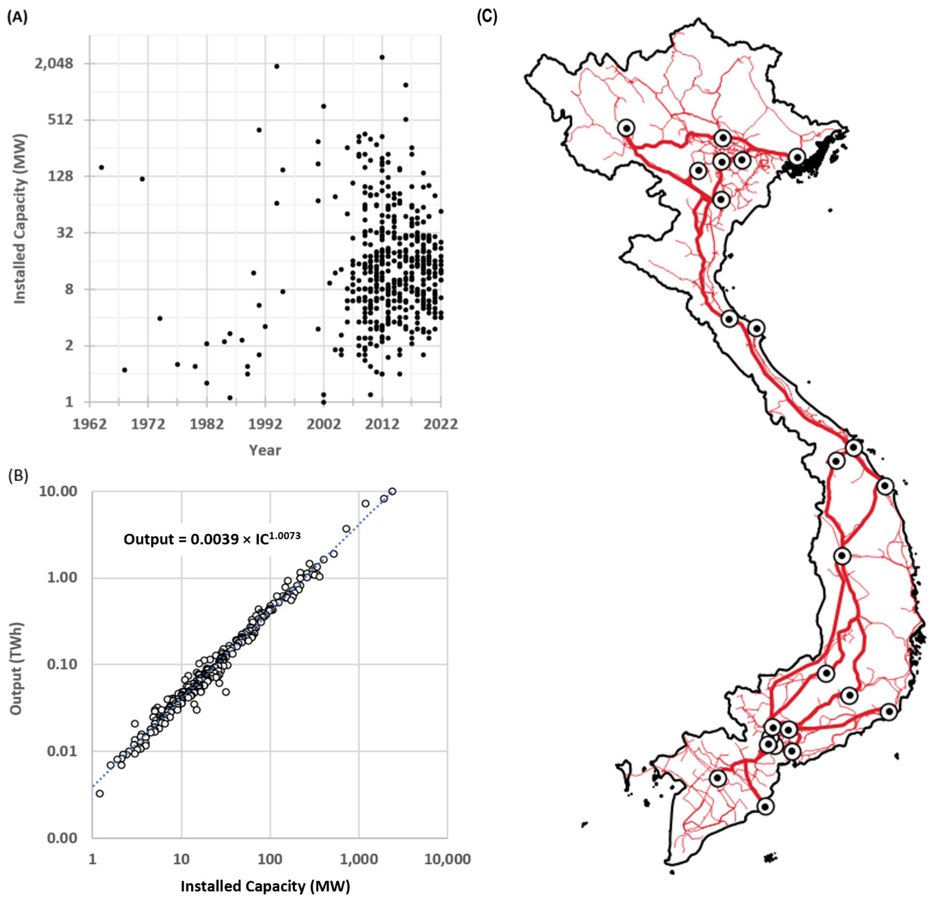

Figure 2. Evolution of installed hydropower capacity over time in Vietnam. (**A**) Timing of installed capacity of hydropower facilities in Vietnam coming online. A drastic increase in the building of hydropower facilities began after the turn of the century. (**B**) Relationship between installed capacity (IPC) and annual power output (APO) of 339 HPFs in Vietnam reporting data. (**C**) The electrical power grid network in Vietnam (ca 2020).

Based on the confidence that the new HPF database provides a realistic portrayal of Vietnam's hydropower capacity, Vietnam's web of 721 HPFs in operation or under construction equates to one per 459 km^2 of land or one per every 135,000 persons. This level of intensity relates largely to the presence of many small HPFs (again, 77% of the total). The density of the network is portrayed across space at the national and local scales in Figures 1 and 3, respectively. While both figures underscore how intensively Vietnam's hydropower resources have been exploited, the development in the S3 (Sekong, Sê San, and Srêpôk) river system (Figure 3) shows the willingness of the Vietnamese government to transform both the nation's riverscape and that of the headwaters of its downstream neighbors, drawing much concern for the lack of consideration for affected populations and ecosystems [16–19].

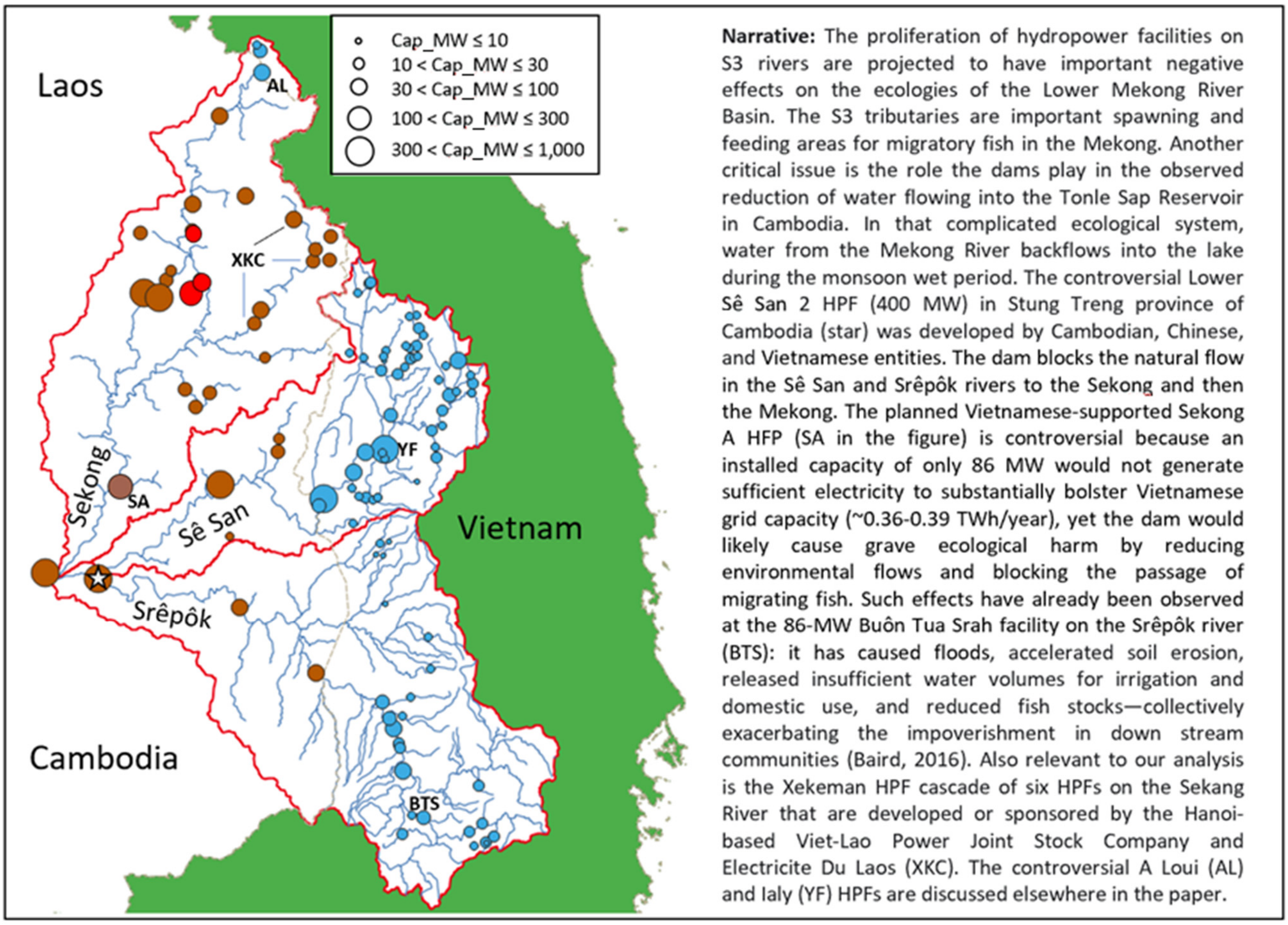

Figure 3. Hydropower facilities built and planned on S3 rivers and their tributaries. Existing facilities in Vietnam are indicated by blue circles. Planned facilities in Laos and Cambodia appear in brown; the red circles indicate HPFs under construction. The boundaries of the Sekong, Sê San, and Srêpôk river catchments appear in red. The dotted grey line is the Vietnam border. These three international rivers join near the confluence with the Mekong River in Cambodia. The star shows the location of the Sê San 2 HPF. Not all small tributary streams are shown. Other symbols and labels are described in the narrative, including the names of specific HPFs shown. The S3 catchment location is shown in Figure 1. Also see [18].

The 720-MW Ialy (Yali Falls) HPF, the second major post-1975 hydroelectric project, represents the core of the exploitation of the international S3 rivers. Built on the Sê San River about 80 km upstream of Cambodia between 1993 and 2002, it paved the way for dozens more HPFs to follow, within Vietnam as well as Lao PDR and Cambodia [19]. Collectively, 81 hydropower facilities are built on the tributaries or main branch of the Sê

San (n = 51), Srêpôk (26), and Sekong (4) rivers in Vietnam, with a total installed capacity of 3658 MW. Dozens more are planned for Cambodia and Laos (Figure 3).

2.3. Can We Eat More?

Perspectives on the future of hydropower development in Vietnam are diverse. In 2014, the IHA estimated that 19 to 21 GW of the full hydropower potential of 35 MW was economically feasible (based on levelized cost of electricity production (LCOE)). According to their figures at that time, installed capacity was just over 17 GW, implying that limited additional hydropower development was economically viable [7,20]. Given that the analysis in this paper shows current installed capacity is nearly 22,400 GW, with another 3550 MW potentially coming online in the near future, it would appear that this early vision has already have been reached. This conclusion aligns with a 2017 paper in which the director of the Hanoi University of Science and Technology's New Energy Research Center concluded that most if not all of the economically viable hydropower resources in Vietnam have already been exploited [21]. By contrast, Vietnam's national electricity corporation estimates the nation's exploitable hydropower resources ranges from 30 to 38 GW, implying that an increase in current installed potential of 15–45% is plausible at some cost [22].

Somewhere in the middle is the estimate from a recent study by Xu et al. [23]. Using conservative criteria to estimate the feasible, economical, and sustainable (FES) hydropower potential, they estimate that Vietnam has 16 TWh per year of exploitable hydropower potential remaining. This total corresponds to almost 3.9 GW of additional capacity which would bring the total installed capacity to roughly 26 GW (Figure 1). Nearly all of this remaining potential is roughly equivalent to the combined capacities of the 189 HPFs (3690 MW) identified above as being in some stage of development or cannot be located (Footnote in Table 1). The remainder could be achieved by building a few of the small plants that are currently awaiting approval.

Two caveats are important in the analysis of Xu et al. [23]: (1) Their calculation of remaining power was based on a low estimate of existing power generation in Vietnam; and (2) if they were to include stricter criteria to prevent building in biodiversity hotspots, the remaining FES potential would only be about 2 TWh (pers. comm), corresponding to only about 420–590 MW of installed capacity, which is a fraction of what will soon come on line. However, if little regard is given to costs, both economically and with respect to humanity and the environment, Vietnam's feasible potential is an additional 64 TWh/y, an increase in 70% or ~18 GW (Supplemental data in [23])—surpassing the maximums of 35 to 38 MW mentioned above.

As the preceding paragraphs should make clear, methodologies for evaluating hydropower potential are varied and contested owing to differing objectives and interests. Nevertheless, despite the lack of consensus, the view of this paper is that Vietnam's hydropower resources are currently exploited at levels that approach, if not exceed their practical sustainable maximum. The remainder of the paper explores how this situation evolved historically, the social and ecological implications, and the role hydropower might play in reducing Vietnam's dependence on fossil fuels.

3. Histories of Hydropower

3.1. Early Water Control

The simple existence of hydropower potential isn't enough to explain the transformation of Vietnam's riverscape after 1945. Rather, that outcome reflects Vietnam's unique history, culture, and politics. A crucial long-term factor is the historical connection of the ability to control water with economic prosperity, social stability, and political legitimacy. The building and maintenance of dikes and canals for flood control and irrigation was a preoccupation of imperial regimes, often requiring the large-scale mobilization of both human and financial capital. The earliest mention of dikes in the Red River Delta is from the 2nd century CE: a map prepared by imperial authorities in 1803 shows 124 km of river and sea dikes in the region [24]. In the South, large state-led canal-building projects opened up parts of the Mekong Delta to settlement and development in the 1800s [25].

The colonial period saw the connection between political power and hydraulic engineering deepen as pre-colonial projects of flood control, irrigation, and transportation were taken up and transformed by the application of new technologies like steam dredges, advances in construction engineering methods, and refined understandings of hydrological processes [26]. Nowhere was the impact of hydraulic engineering felt more than in the Mekong Delta, where the dredging of canals opened vast new areas to cultivation, helping to make Vietnam the world's third largest exporter of rice by the 1920s. As French policymakers began pursuing more developmentalist, modernizing policies in the 1920s, attention turned to hydroelectricity. The nation's first hydroelectric facilities, Tà Sa and Nà Ngần in Cao Bing province, were completed in 1928 [27]. In the Central Highlands, the 600-kW Ankroet generating station, suppling power to the nearby provincial capital of Dalat, was completed in 1945 (over time it was upgraded and expanded, reaching 4.4 MW by 2004). Preliminary studies were undertaken for much larger HPFs on the Đà river in the North and the Đa Nhim river in the Central Highlands, but never progressed past the planning stages [28].

After the effective partition of the country in 1954, both of Vietnam's post-colonial polities—the Republic of Vietnam (RVN) in the South and the Democratic Republic of Vietnam (DRV) in the North—began to plan and build hydroelectric installations. In the South, the Đa Nhim hydropower project was built with financial and technical aid from Japan between 1961 and 1964. However, the 160-MW HPF and its power lines were a target of the Communist-led insurgency and electricity from the dam never reached its intended consumers in Saigon, 315 km distant. The Mekong River Commission undertook preliminary studies of the hydropower potential of tributaries of the Mekong originating in Vietnam's central highlands, most notably the Sê San and Srêpôk (Figure 3; blue symbols). But no work was undertaken and hydropower was never prioritized by the governments of the RVN in the same way it would be in the North.

3.2. The Origins of a Hydro-Developmentalist Ideology

In the North, an ideological commitment to social and economic transformation through modern technology combined with mountainous terrain and high rainfall to produce an ideology of hydro-developmentalism that owed much to Soviet models. In 1920, Lenin had proclaimed "Communism is Soviet power plus the electrification of the whole country," and promulgated the fifteen-year State Plan for the Electrification of Russia (GOELRO). Under Stalin, that preoccupation with electricity provided the justification for enormous hydroelectric projects like the ones at Dnieprostroi and Rybinsk. Built at tremendous human cost, these projects not only provided electricity for factories and towns, but also were powerful symbols of Soviet engineering prowess and ability to remake nature, society, and the individual [29]. Later in Vietnam, Party officials duly quoted Lenin at the opening of each new hydropower facility, while propaganda posters proclaimed "The fatherland needs electricity like the body needs blood" ("Tổ quốc cần điện như cờ thể cần máu," 1966) and exalted the role of new hydropower dams in building socialism ("Sông Đà—Trị An—Để có nhiều điện cho chủ nghĩa xã hội", 1982).

Already by 1957, teams of Vietnamese, Soviet, and Chinese experts were making surveys and drawing up plans for the transformation of the nation through hydropower at every scale, from small dams generating power for pumped irrigation systems to large projects like the Thác Bà reservoir and dam. For planners, these facilities not only utilized a "free", renewable resource, but also allowed them to bring electricity to communities, mines, and factories in the nation's upland regions. The first HPFs to be built in the postcolonial period, like Bàn Thạch in Thanh Hoá province, date to this period [30]. Even today, when the vast majority of communities are connected to the national electrical grid, local grids powered by micro-HPFs play an important role in providing electricity to remote communities [31].

3.3. The Turn to Megaprojects

While small hydropower would remain part of the state's overall energy strategy, after 1960 state attention shifted to the DRV's first hydropower mega-project. Begun in 1962, construction of the Thác Bà reservoir and hydropower plant was halted by American bombing in 1966. Construction resumed in 1969 and it was finally completed in spring 1972. The resources devoted to the huge project during wartime, not to mention the decision to flood more than 230 km^2 of prime farmland and relocate some 35,000 people confirms the symbolic importance the state attached to the dam. Even when American laser-guided bombs knocked out the dam's power station just months after the final generator had come into operation, officials determined to return the plant to operation no matter the cost [30]. The commitment to flagship hydropower megaprojects only intensified after the end of the war. The first of them, the Hòa Bình dam, would begin construction in 1978. But drawing a lesson from Thác Bà, the government decided to build energy security into the dam itself. Despite the cost and technical complexity, the generating facilities of the Hòa Bình dam and a series of later dams like Ialy, Hàm Thuận, and Đa Mi would be installed underground, protected from even the largest conventional bombs.

3.4. Hydropower and Energy Security

Hydropower also addressed an even more fundamental aspect of energy security: the need for energy independence. Policy makers were acutely aware of the role energy had played in the war and postwar years. The skyrocketing cost of oil after 1973 had hamstrung the highly mechanized RVN army and undermined its ability to resist communist forces in 1975. And just a few years later, the Communist government would also experience energy insecurity when a slowdown in oil imports from the USSR stalled generators and compelled officials to reduce already-low household electricity quotas. Thus, postwar planning was intended to ensure energy independence through the exploitation of three domestic resources: hydropower from the nation's Center and North; coal from the North; and gas from fields off the southern coast. In the immediate postwar years, hydropower was the cornerstone of energy independence, with the output of dams such as Hòa Bình (1920 MW) and Ialy (720 MW) dwarfing that of the new coal powered plants like the 440 MW Phả Lại facility, completed in 1988. Meanwhile, gas-fired plants would only start to come online in the late 1990s. Thus, well into the 2000s, hydropower helped Vietnam remain largely self-sufficient in energy use.

3.5. The Evolution of a Hydro-Industrial Complex

Planning and building HPFs and their associated infrastructure drove the development of important elements of a Vietnamese "hydro-industrial complex". The first DRV cabinet, formed in 1945, saw Trần Đăng Khoa, a French-trained civil engineer, appointed as Minister of Transportation and Public Works; ten years later following the end of the first Indochina War, he assumed leadership of a reorganized Ministry of Irrigation and Construction. Along with the Committee for Planning and other key Ministries like Industry and Defense, the Ministry and its successors would share responsibility for setting overall energy policy and planning major hydropower projects. Together with Soviet advisors, in 1960 Vietnamese planners drew up the nation's first "Power Development Plan" (Quy hoạch Phát triển Điện lực) modeled on similar plans dating to the first GOELRO plan of 1920 for the electrification of the USSR. The PDP plans, published every ten years, still set out the main features of the nation's future energy landscape.

Over time, the institutions tasked with planning and overseeing the construction and operation of hydropower projects evolved into semi-autonomous state companies. These include what are today some of Vietnam's largest corporations, like the Vietnamese Power Engineering Consulting Joint Stock Company 1 (PECC1), the Song Da Corporation, Công ty lắp máy Việt Nam (LILAMA), and Underground Works Construction Joint Stock Company (VINAVICO), which was the first Vietnamese company to list on the NASDAQ capital market. Even before the era of market reforms that began in the mid-1980s, these companies operated with a great deal of autonomy, and, within the confines of the centrally planned economy, sought to prosper, grow, diversify, and profit. The end of central planning, the devolution of many planning and approval functions to provincial governments, and the equitization of state-owned companies only reinforced these tendencies. The result was the creation of powerful, independent companies with easy access to provincial and local governments, all with an interest in large construction projects.

The year 1995 marked a major shift in Vietnam's hydropower institutions as the Ministry of Energy was absorbed into the Ministry of Industry and many of the responsibilities for overseeing hydropower development gradually transferred to a new state enterprise, Electricity Vietnam (EVN). The origins of EVN date to the 1992 decision to build a North-South high-voltage transmission line that would deliver surplus electricity from the Hòa Bình dam to factories and urban areas in the country's South. When the line was completed in 1994, the government created a centralized enterprise to oversee the new national electricity grid (Tổng Công ty Điện lực Việt Nam, after 2010 the Tập đoàn Điện lực Việt Nam). Today, the corporation not only manages the national power grid, but through subsidiaries it operates hydropower and coal-fired power plants which together account for more than half of the nation's total installed capacity. As such, the central government's role is limited mainly to setting targets and broad policy priorities through decadal PDPs. By contrast, EVN has the ability to determine the profitability of every HPF in Vietnam as well as the final mix of power sources—renewables or fossil fuels, local or imported—of the electricity used by Vietnamese consumers.

Powerful institutions like VINAVICO and EVN were shaped by both national and international contexts. Early Vietnamese dam projects were designed, financed, and supervised with Soviet (later Russian) or Chinese assistance. Over time, Vietnam's former socialist allies were joined by countries including Sweden, Norway, and Japan, along with representatives from international bodies like the World Bank and Asian Development Bank [32,33]. For many Western companies, the interest in developing markets such as that in Vietnam was driven by growing opposition to dam-building in their own home markets. Yet while Western companies made some inroads with larger projects, the small dams that have represented the bulk of hydropower development since 2000 were built largely with Chinese technology [21]. Thus, even as Vietnamese engineering and construction expertise grew and Vietnamese companies in turn exported expertise to countries like Laos and Cambodia, they were imbricated in international networks of consulting, engineering, finance, and construction, all with vested interests in dam construction.

3.6. The Wages of Hydropower

Vietnamese engineering, construction, and consulting enterprises are also implicated in the particular nature of large public works projects. Graft is a common feature of construction almost anywhere, but it was endemic to the command economy where private profit was theoretically impossible, resources were few, and the ability of a state enterprise to meet quotas or deadlines dependent on access to off-plan resources. Mega-projects like Thác Bà required the mobilization of enormous amounts of labor, material, and funds, opening up unprecedented opportunities for the diversion of resources to other ends. The dam was a case in point: within less than five years of completion, problems resulting from substandard construction were enough to prompt a major investigation by the central authorities. The design, construction, and management team from Thác Bà would go on to lead the far larger Hòa Bình project, bringing not just their expertise but also their practices, both good and bad [30].

Besides the dams themselves, hydropower projects required infrastructure that provided additional opportunities for profit by construction companies and officials. This included roads and powerlines, housing for workers and experts, and homes and services for relocated populations. The building of the North-South high-voltage transmission line, for example, saw a sitting Minister of Energy sentenced to three years in prison for graft in 1992 [34]. As the scale and scope of hydropower development grew in the 1990s and

2000s, so too did opportunities for private profit. When these structural incentives met the vested interests of national and international institutions and access to international finance capital, the result was a flurry of dam construction after 2000 [35].

3.7. Sustainable Hydropower?

Over time, Vietnamese began to take steps to ensure dam building was carried out more responsibly, at least in theory. In 1993, the government began requiring environmental assessment impact studies for all new hydropower projects, and the following years saw a series of policies that brought Vietnamese practices into alignment with World Bank and other development agencies standards regarding social impact, relocation, and compensation from the various impacts of dam construction [36]. At the same time, increasing public awareness of the ecological and social impacts of dam-building coalesced in the "Vietnam Rivers Network" (Mạng lưới Sông ngòi Việt Nam), which brought together Vietnamese NGOs, state-employed scientists, and other concerned individuals. The group lobbied to prevent the construction of the Đồng Nai 6/6A dams and is also credited with shifting state policy against the construction of dams on the mainstream of the Mekong [37,38].

Arguably, however, the new requirements for dam projects served less to limit ecological and social impact than to facilitate the participation of international partners. And aside from isolated cases like the two Đồng Nai dams, the influence of the Vietnam Rivers Network has been limited: for example, while the Vietnamese government may now officially oppose new dams on the Mekong mainstream, it has still approved building dozens of dams on its tributaries (Figure 3), with devastating downstream consequences [39–42].

Recent years may have seen the pace of hydropower development decline (Figure 2A). In 2016, Vietnam's Ministry of Industry and Trade (MOIT) announced the removal of 471 small and cascade hydropower facilities with a total installed capacity of 2059 MW from its PDP 7 and rejected another 213 potential projects of combined capacity of 2059 MW [43]. While growing awareness of the ecological and social consequences of dam building and growing domestic opposition to further construction may have played a role, other factors probably determined the policy shift. First, by 2016, the potential for hydropower development had become increasingly limited, with most or all economically feasible locations for large and medium HPF already exploited. Second, the development of many HPFs was slowed by financial issues and long construction phases. Third, other energy options, whether coal-fired plants or renewables like solar, were cheaper and faster to build than HPFs, and, at least in the latter case, implied fewer environmental concerns.

Finally, the slowdown in dam construction in Vietnam reflected a shift to new markets, as Vietnamese construction and electricity companies turned their attention to the rivers of Laos with large projects like the Xekaman (290 MW), Xekaman 3 (250 MW), Xekaman-Sanxay (32 MW) on the Sekong River, as well as the planned 86-MW Sekong A dam (See narrative in Figure 3). Thus, 2016 may represent less the end of the development of Vietnamese hydropower than a shift in focus to new sites that transfer the negative social and ecological impacts of medium-to-large HPFs beyond the nation's borders, while retaining all of the energy and much of the economic benefit for Vietnam and its hydro-industrial complex. [17,33,44].

3.8. Powering a Nation

In terms of electricity provision, Vietnam today is considered a remarkable success. In 1975, less than three percent of rural Vietnamese households had access to electricity. In contrast, by 2010, at least 95% of households in Vietnam had sufficient electricity for lighting; and today that number approaches 100 percent [45,46]. With hydroelectricity providing more than 60 percent of total electricity consumption between 1990 and the early 2000s, and still providing more than 30 percent today, much of that success can be attributed to hydropower at every scale from mega-projects like Sơn La to the unheralded micro-hydro grids that bring electricity to isolated communities. Whether as a driver of social development, increased production and exports, or rising domestic consumption, hydroelectricity has been a fundamental part of Vietnam's remarkable performance in conventional measures of social and economic development since 1990.

On the level of policy, the state's overall energy strategy can also be considered a success. Brownouts and the occasional blackout aside, electrical supply in Vietnam since the mid-1990s has, broadly speaking, been able to meet demand. While specific policies have changed over time, from the days of central planning in the 1980s through the decentralization of planning and the liberalization of the electricity market in the 2000s, per person electricity generation has grown at approximately 10 percent per year (Figure 4 inset)—or approximately 30 percent faster than the 6.9 percent rate of GDP growth over the same time [47] (Figure 4; red line). Thus, per person electricity generation has doubled four times, roughly every 6–8 years, from 130 kWh in 1990 to 2511 kWh in 2021. Population grew roughly from 68 to 97 million during the same period. Historically, hydroelectricity has been central to this rapid expansion of supply, as can be seen in the main panel of Figure 4. The key consideration here is that hydropower could accommodate the growing demand for electricity when demand was still at relatively low levels and rivers with high hydropower potential remained to be exploited. Neither of these conditions pertain today.

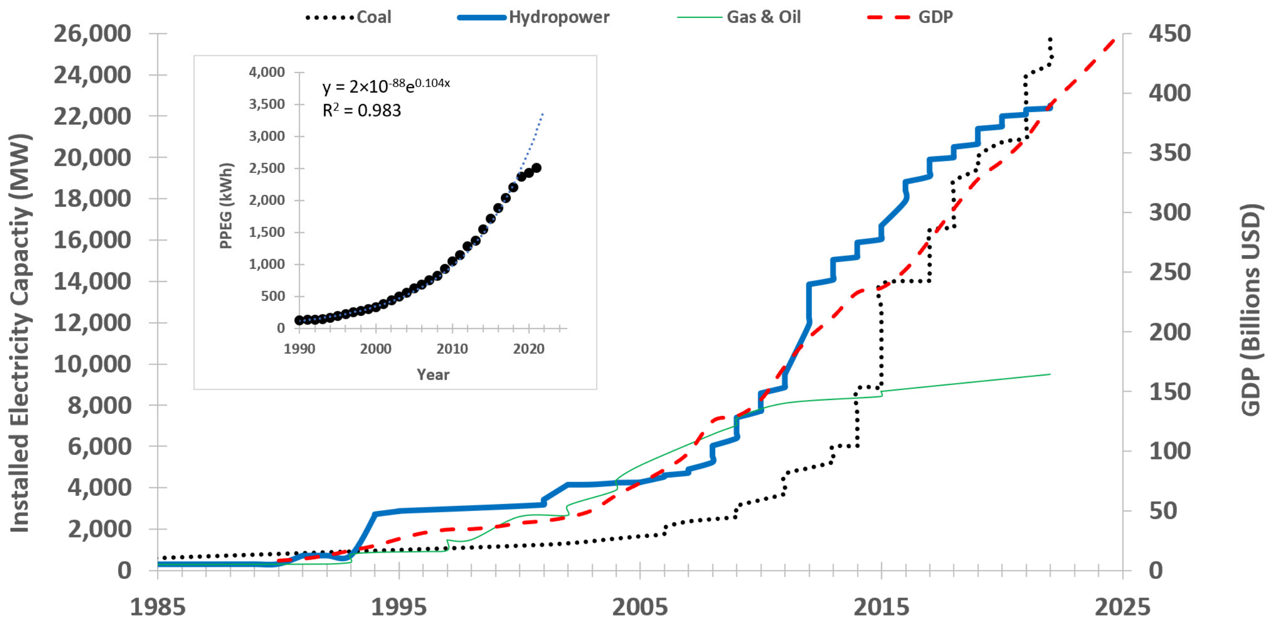

Figure 4. Installed Capacity in Vietnam over time. The main panel shows the growth in cumulative installed peak electrical generation capacities of coal, gas & oil, and hydropower. The change in gross domestic product (GDP) is shown in the main figure in red. Prior to about 2010, hydropower was the backbone of Vietnam's electricity production. The inset shows the change in per person energy generation (PPEG) in Vietnam over time. GDP, PPEG, and installed coal capacity grow exponentially. After about 2017, the growth in installed hydropower capacity appears to have reached a limit and is currently plateauing (sigmoidal shape). In the inset, the deviation from exponential growth in PPEG for 2020–2022 aligns with the COVID-19 Pandemic.

The reliance on hydropower is seen most obviously in the state's Power Development Plans. From the very first plan in 1960 through the revised PDP 7 (2016) for the period between 2011 and 2015 and toward 2030, hydropower development has been prioritized. Only after 2016 did coal begin to replace hydroelectricity and gas as the primary source of electricity: this shift is observable in Figure 4. The transition away from hydroelectricity was in recognition that the potential to develop more large-scale HPFs was waning. For example, the revised PDP 7 (2016) projected hydropower capacity to reach 24,611 MW in 2025, then only increase another 3260 MW by 2030 to 27,871 MW. These figures largely align with our estimate that 26 GW of installed capacity will soon be reached.

The April 2022 PDP8 draft plan caps hydropower capacity (excluding the potential for pumped storage to boost hydroelectricity production) in 2030 at just below 26,000 MW, representing a further reduction in future portfolios (Table 2). Currently, the largest gains in capacity until 2030 are expected to come from other renewables (wind and solar) and liquid natural gas (LNG) and related gas technologies (Table 2; "LNG (mixed technologies)"). While the proportion of coal in the entire energy portfolio reduces, the capacity of coal-fired thermal power must grow from about 20 GW in 2020 to 37 GW (85%) by 2030, doubling by 2033 to match projections (Table 2; Figure 5; Discussed in more detail in Section 5).

Table 2. Vietnam's projected energy portfolio (2025–2045), as outlined in the PDP8 draft plan.

Source/Year	2020 *	2025	2030	2035	2040
Total (MW; all sources)	69,258	102,193	137,663	190,391	233,816
Coal-fired thermal power	29%	29%	27%	23%	21%
a. Domestic	0.70	0.57	0.45	0.40	0.34
b. Import	0.30	0.43	0.55	0.60	0.66
Gas, Oil, Diesel	13%	14%	21%	24%	24%
a. LNG (mixed technologies)	0.79	0.94	1.00	1.00	1.00
b. Thermal + diesel	0.21	0.06	0.00	0.00	0.00
Hydropower	30%	25%	19%	16%	13%
a. Hydro-large	0.83	0.80	0.76	0.67	0.63
b. Hydro-small	0.17	0.20	0.19	0.18	0.18
c. Hydro-pumped	0.00	0.00	0.05	0.15	0.19
Wind	1%	11%	13%	17%	20%
Solar	24%	17%	14%	16%	18%
Biomass and other	1%	2%	2%	2%	2%
Power import (China, Laos)	2%	3%	4%	3%	2%

* Percentages reflect contributions to the total installed capacity; fractions refer to the contributions of subtypes (letter listed) to a major energy source. Reference: Data are from the base-load demand summary by Burke and Nguyen [48].

If the last three decades have seen state planners meet broad goals of matching supply to demand and expanding the electrical grid to include all Vietnamese citizens, the means they used to achieve this have changed over time. This approach has had important implications for other aspects of energy policy, most notably security. As a renewable domestic resource, hydropower seemed to guarantee energy security for Vietnamese policymakers in the 1970s and 80s. Thus, from an early date, the Hòa Bình-Sơn La-Lai Châu cascade on the Đà River was planned as the backbone of the nation's energy supply. Today, this trinity makes up one quarter of the nation's installed hydropower capacity, generating approximately 22 to 27 TWh per year.

The fundamental obstacle in achieving energy security for Vietnamese planners has been the exponential rate of growth in electricity use (Figure 4 inset). Despite exploiting new sources of energy like the Sơn La dam or the PM 3 gas fields off the coast of Cà Mau, growth in demand has exceeded growth in available domestic energy resources since the early 2000s. To address electricity deficits during the last two decades, Vietnam turned to its neighbors for imported energy: China starting in 2004; then Laos in 2013 [49]. During the period of 2013–2019 an estimated 20 TWh were imported from these two neighboring countries, with the bulk coming from China.

The PDP8 draft anticipates electricity imports rising from 1272 MW in 2020 to around 3.5 GW by 2025 then 5.7 GW by 2030, from imports from Laos and China (Table 2; Figure 5). However, this is likely to change: the *Saigon Times* reported that Vietnam may import as much as 14 GW of electricity from Laos, 3.8 GW from China, and 4 GW from Cambodia from about 2021 until 2030 [50]. Thus, even as dam construction reached its peak in the 2010s, the relative importance of hydropower in Vietnam's energy budget steadily decreased, and the energy security once promised by this seemingly unlimited renewable domestic resource has proven ephemeral as the nation has turned to energy imports and new coal-fired plants to address rising demands. Yet, small-scale hydropower expansion is still being pursued, despite known negative impacts (Table 3).

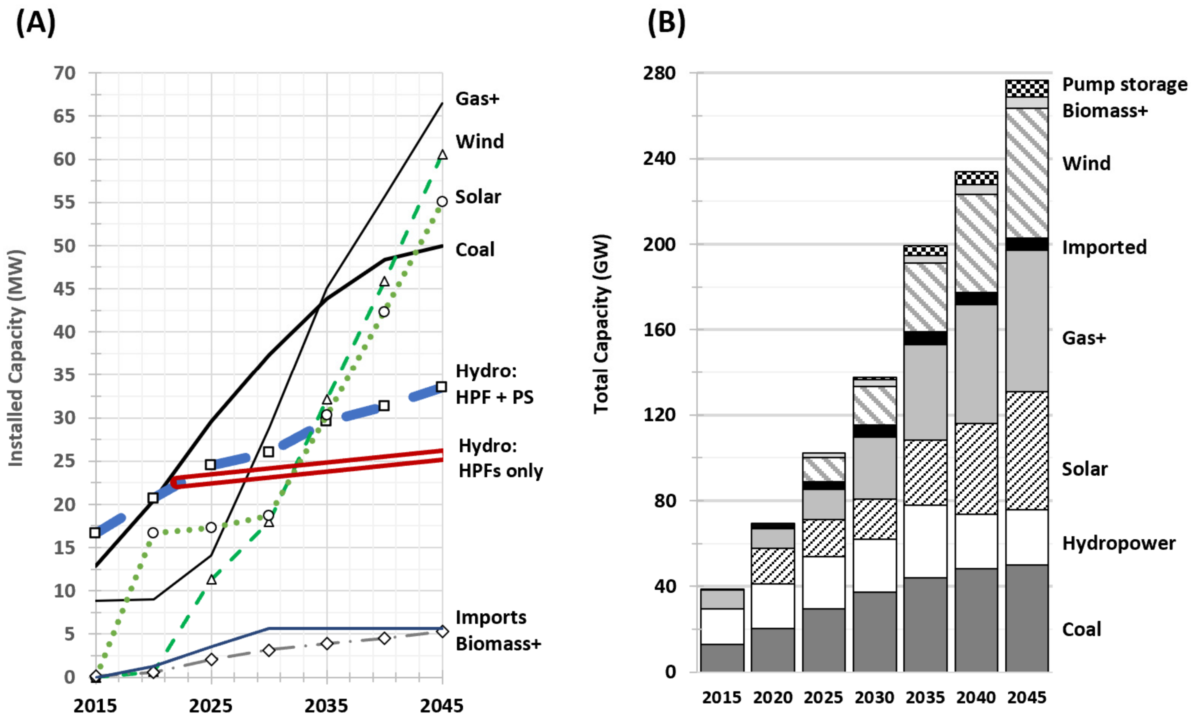

Figure 5. Projected installed electrical generation capacity until 2045. (**A**) Observed (2015–2020) and Projected (2025–2045) contributions of various energy sources to electricity generation in Vietnam, based on PDP 8 draft plan 2021. The red double line indicates the diminutive contribution of HPFs to the total hydropower contribution that would be provided beginning 2025, unless pumped storage (PS) was developed (dashed blue line; HFP + PS). Meeting Vietnam's growing electricity demand will require immense increases in the capacity of wind (onshore + offshore) and solar capacities, as well as non-renewable coal and gas (namely combined cycle gas turbines utilizing new LNG) capacities. Imported electricity is anticipated to level before 2030. (**B**) Proportions of observed (2015–2020) and Projected (2025–2045) contributions of various energy sources to electricity generation in Vietnam, based on PDP 8 draft plan 2021. Note that these values differ slightly from the PDP 8 plan that was approved in May 2023, after this paper was in final stages of publishing.

Table 3. Some positive and negative aspects of HPF development on Vietnam's riverscape.

Positive	Negative
Drought resilience	Reduced electricity generation in dry periods Man-made hydrological droughts
Flood control (especially small events)	Floods during: Unanticipated water release Breaches on poorly designed/managed dams Increased surface runoff on degraded lands
Support irrigation farming	Loss of croplands & reduction of irrigation water
Increased water supply for domestic/municipal use	Reduced river flow for use downstream, affecting: Hydropower generation Navigation & general use Saltwater intrusion

Table 3. *Cont.*

Positive	Negative
Reduction in river turbidity/sediment	Sediment issues including: Accumulation behind dam (reduce lifetime) Insufficient sediment to maintain deltas High sediment/turbidity during construction Sand mining issues (construction)
Renewable energy production from: Hydropower Pumped Storage Floating solar	Loss of natural river functioning including: Seasonal base flows and flood waves Sediment, nutrient, organic material transport Hyporheic exchange, recharge Fluctuations related to hydropeaking
Offsetting the impacts of traditional fossil fuel HPFs: Less GHG emissions Less air pollution (SO_2, NO_x, PM2.5) Less noise pollution and water loss Reservoirs store carbon in sediments	Associated impacts of reservoirs: GHG footprint of HPF Noise and air pollution during construction Sand mining (construction) Anoxia potential
Creation of new jobs in construction phases Post-building operations and development	Illegal activities & vice (drugs, prostitution) Livelihood losses to fisheries and farming
New uses including: Recreation, aesthetics & photography Fishing & hunting	Loss of traditional uses/functions such as: Recreation & landmarks (e.g., waterfalls) Fishing & Farming
Infrastructure improvements: e.g., Roads, bridges, schools, etc. Power grid improvements	Land degradation Forest loss/damage Road-related erosion & landslides Roads increase accessibility to exploit forest
Create new reservoir habitats	Aquatic habitat degradation/alteration affecting: Streambed, floodplains, wetlands Disease ecology implications Invasive species potential; algal blooms Obstruction to migrating fish
Local & national benefits: e.g., Renewable energy Nation building Investment opportunities	Geopolitical implications Limited lifetime of reservoirs Exacerbation of hazard impacts Human displacement

3.9. Overview

The undeniable benefits of the electricity generated by Vietnam's dams must be placed alongside the considerable associated environmental and social costs [5,12,51–53] (Table 3). While water is a renewable energy source, dams are not as green nor as clean as often portrayed [54–56]. Nor are they necessarily socially just: the human consequences are often lost in the "shadow of development" [57], particularly when many of the immediate costs are borne by marginalized groups such as ethnic minorities [57,58]. Plainly speaking, dam and reservoir construction have considerable documented negative impacts (Table 3). However, unlike metrics such as annual electricity generation or GDP growth rates, many of these outcomes defy easy measurement and sufficient articulation.

While feasibility studies are typically conducted prior to building a hydropower facility, the main consideration in Vietnam has tended to be profitability, but often with lack of transparency resulting in many of the nuanced costs associated with dam building being ignored [59]. Luu and von Melding [60] claim that for small-to-medium-scale HPFs, in general, environmental impact assessments often fail to address thoroughly issues such as forest loss/degradation, damage to aquatic ecosystems, exacerbation of environmental hazards, and social impacts including displacement and disruption of livelihood activities such as fisheries, aquaculture, and near-river agriculture (cf. [34,45,49,50,61,62]). To frame our questioning the sustainability of hydropower in Vietnam, we review some of these issues with reference to local contexts in the following subsections.

4. Consequences of Hydropower Development

4.1. Carbon Footprint

A paradox of building hydroelectric plants to offset GHG emissions from traditional fossil fuel power plants is that HPFs themselves have a carbon footprint associated with construction and long-term biogenic GHG emissions [56]. Artificial reservoirs created by damming rivers and flooding large vegetated areas are sources of GHGs released to the atmosphere, particularly in tropical climates [63,64]. A recent analysis of 480 hydropower impoundments worldwide determined the median GHG emissions from hydroelectric reservoirs was small: 23 gCO_2-eq/kWh [65]. The estimated net GHG emissions from the 260-MW Trung Sơn HPF (1.019 TWh/year) is only about 4.5 gCO_2-eq/kWh, based on the methodology of the World Bank [66]. However, when construction impacts are considered, the net GHG footprint increases to 8.4 gCO_2-eq/kWh (cf. World Bank [66]). This elevated rate demonstrates that a large part of the carbon footprint is potentially contributed by forest destruction and degradation.

In practice, it is difficult to determine accurate emission rates from reservoirs, as well as the net carbon storage dynamics [67]. Despite uncertainties, emission rates from hydropower reservoirs are usually much lower than those from gas and coal-fired plants (medians = 490 and 820 gCO_2-eq/kWh, respectively [68]. However, in some cases emissions may not be trivial, as suggested for the tropical Mekong region by Rasanen et al. [56], who estimated that the fluxes from reservoirs in the Mekong with the highest emissions range from 320–1990 gCO_2-eq/kWh. To date, a solid estimate of the footprint of Vietnam's large HPF network is uncertain.

4.2. Forest Loss and Degradation

The Ministry of Agriculture and Rural Development (MARD, 2015) reports that the total forest loss from hydropower development is 22,340 ha in 30 provinces [69]. Dang suggests a much higher figure of 50,000 ha, which includes logging during the construction of the various components of the HPF and also flooding by the reservoirs [70]. The estimated forest losses from the reservoirs at Hòa Bình and Sơn La alone combine to about 7800 ha. Forest loss due to the reservoir construction in the Đồng Nai Catchment above the Trị An HPF is estimated at 4900 ha [71]. The ten hydropower reservoirs (1600 MW) that Pham and Tran investigated in the highlands of central Vietnam caused 2271 ha of forest loss and another 3667 ha of plantation loss [69].

Even small hydropower plants, which are purported to cause less forest loss than conventional dam-reservoir systems, may require several kilometers of excavation to build the tunnels or canals that deliver water from the upstream intake to the downstream power generating unit [53]. The small (5 MW) Bạch Đằng HPF project in Cao Bằng province, for example, was predicted to cause forest loss of 47 ha [14]. Pham and Tran describe three more cases of substantial forest loss: Hà Nang (11 MW) caused 36.15 ha of natural forest loss; Đắk Ru (15 MW) destroyed more than 100 ha of natural forest; and for Đăk Pô Kô (15 MW), 117.2 ha of natural forested land was cleared [69].

The construction of roads to build HPF support infrastructure often contributes greatly to forest loss and/or degradation [53]. Forest destruction for example at the site of the 60-MW Đăk Re HPF in Kon Tum district of Quảng Ngãi province was widespread (Figure 6). While road-building has the societal benefit in linking rural communities with larger cities and regional markets [72], research worldwide has shown that greater road access into previously undeveloped forest areas tends to lead to additional forest loss over time [73]. Further, land development may also encroach on forests below dams and surrounding reservoirs after construction: e.g., for the 1200 MW Lai Châu HPF (Figure 6).

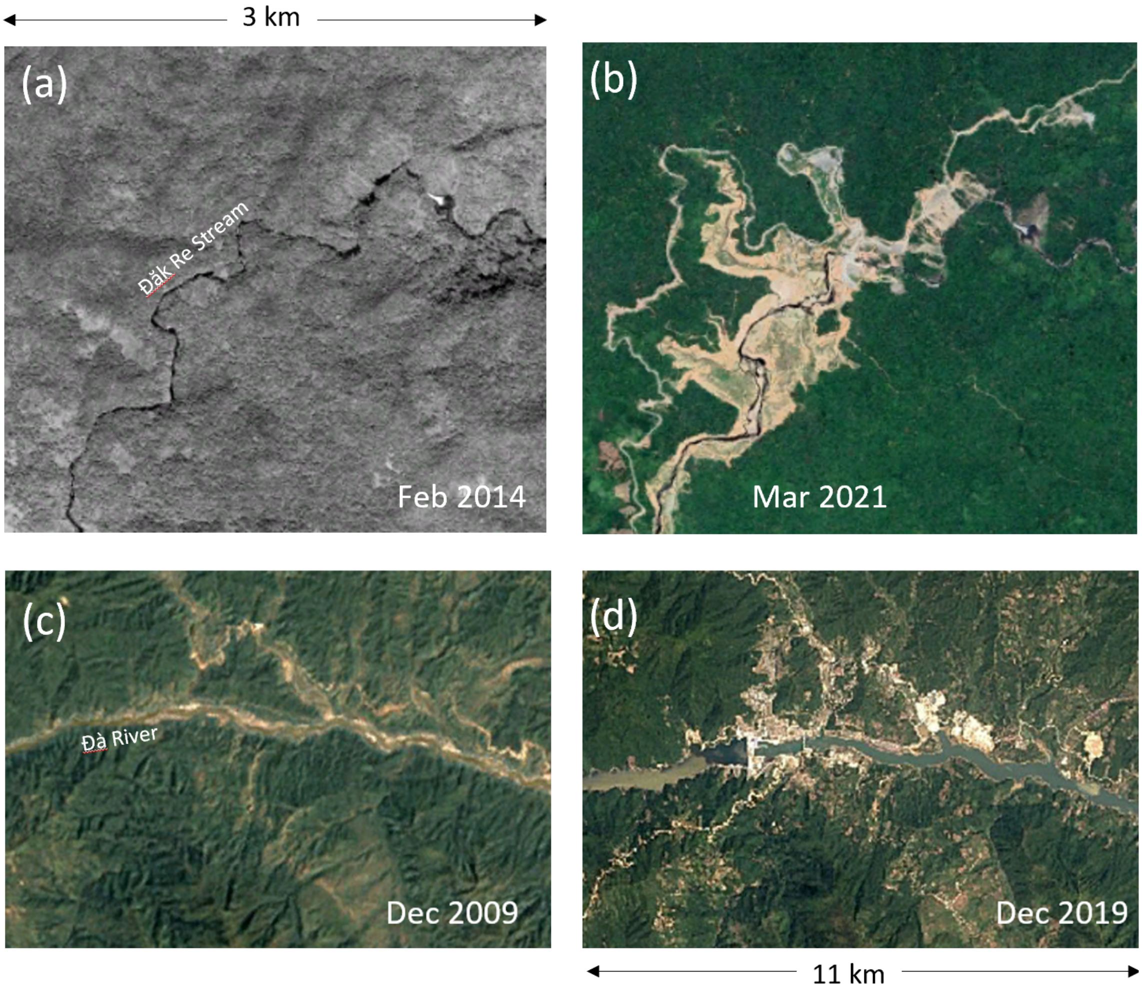

Figure 6. Environmental impacts of HPF construction in Vietnam. (**a**,**b**) Extreme loss of about 50 ha of high-value forest at the location of the 60-MW HPF on the Đắk Re stream in Quang Ngai province (location indicated in Figure 1). Images before and after disturbance are for years 2014 (**a**) and 2021 (**b**). Forest trees, including many of the critically endangered *Erythrophleum fordii* trees, were cleared along the stream channel, outside of the projected reservoir bed area. Substantial forest was lost or degraded along the road network, which is now susceptible to surface erosion and mass wasting. Additionally, the reservoir sits about 1 km above the Hùng Ngàn Waterfall. Thus, water will bypass the waterfall as it is channeled to the electrical generating unit about 6 km downstream in a different river system to augment flow into the nearby unfinished 10-MW Đắk Re 2 HPF (not shown in figure). (**c**,**d**) The area surrounding the 1200-MW Lai Châu hydropower reservoir before (**c**) and after (**d**) the dam was constructed on the Đắ River. The facility became operational in 2016. Noticeable is the extent of forest disruption following the construction of the dam. Images: Google Earth.

Unfortunately, national park or nature reserve status has not always deterred hydropower development in sensitive environments: e.g., for the Sêrêpôk 3, Sêrêpôk 4, Krông Kmar, and Buôn Kuốp HPFs [74]. Even today there is a reluctance to prevent forest loss or to enforce reforestation by all investors after the completion of a HPF [74]. Pham and Tran write that the funds to support mandatory forest replacement are often collected; however, effective replantation is difficult to achieve because of "ineffective implementation, poor management of budget, poor forest quality after replantation, and limited benefits for local people due to lack of participation," as well as the inability of the central government agencies to create develop viable policies [69].

Hydropower development—and the companies that carry it out—have been inextricably linked to a wave of deforestation that began in Vietnam in the 1980s and later expanded to Laos and Cambodia [75]. The construction of roads and the various components of HPFs in remote forested areas provide convenient cover for illegal logging [70]. Newspaper reports from the 1990s detail how the roads built for hydroelectric projects facilitated large-scale illegal logging that clearly required the collusion of construction companies and provincial officials [76]. The practice continues to this day, creating yet another paradox of hydropower development: the proper functioning of a HPF relies, in part, on the integrity and stability of the natural environment above its location, yet forest loss/degradation from HPF construction potentially changes the partitioning of rainfall into streamflow that powers the generation of electricity [77]. It also contributes to erosion and mass wasting processes that both reduce reservoir lifetime and the efficiency of electrical generation throughout the year.

4.3. Disruption of Environmental Flows and Ecological Habitat

Fundamentally, a dam obstructs the natural movement of water in a river or stream, impeding "environmental flows" involving water, sediments, nutrients, minerals, and organisms including plankton [78–82]. The retention of water by HPF structures changes the natural stream hydrograph, altering the nature of base, peak, and storm flows that influence catchment water balances and critical river variables such as temperature, water chemistry, and material fluxes at various temporal scales [83–85]. Reservoir-based HPFs cause unnatural (sub)daily fluctuations in stream flow, called hydropeaking, which is caused by matching hydroelectricity production with fluctuating demands [86,87]. With respect to seasonality, the Sơn La dam caused flows in the rainy period to decrease by 5 to 43 percent; and dry season flows increased on average by 72 percent following installation [84].

Prior work determined that the Hòa Bình dam reduces the annual delivery of suspended particulate material in the Đà River by half or more, implying that transported particulate material is being stored unnaturally behind the dam, rather than within natural locations in the catchment, or being exported to the coastal zone [73]. Other environmental impacts associated with insufficient flows affecting coastal zones include saltwater intrusion, insufficient sediment delivery to maintain deltas and contribute to beach stability, and lack of nutrients exported to the continental shelf to support coastal fish and plant ecosystems—although these issues are complicated by sea level rise and/or other activities such as sand mining, dyke construction, and groundwater extraction [87–92].

In the case of aquatic organisms, the flow disruption is potentially bidirectional, hindering the migration/dispersal of a variety of keystone and ecosystem-supportive species [93,94]. The analysis of Ziv et al. [93] concluded that the construction of cascades of dams on the main stem and tributaries of the Mekong River would have a catastrophic impact on fish productivity and diversity (cf. [95]). On the Đồng Nai River, Pham determined that planktonic diatom assemblages were affected by the Trị An dam, which altered turbidity and dissolved nutrient ions below the reservoir [83]. Despite the mentioning of the need to preserve ecological systems in environmental impact assessments, studies are rarely ever conducted in systems other than the Mekong River basin regarding this issue—judging by the paucity of findings reported in the literature.

Some believe that the basin-scale fragmentation caused by small dams in the larger river catchments are potentially more detrimental to environmental services than large dams, at least by some metrics [96]. A recent analysis of four planned small-scale hydropower cascades in Vietnam (Nậm Chiến, Nậm Tha, Ngòi Xan, and Sập) by ASTAE determined that the most profound cumulative impacts would relate to habitat fragmentation, loss of connectivity, and the subsequent impacts on the terrestrial and riverine valued ecosystem components [53]. That same study stressed the need to view cascades as a singular system, rather than focusing on the impacts of individual HPFs, as the "effects on an important ecosystem component such as aquatic fauna are synergistic" because "development of the cascade exacerbates the impacts on migration and mobility of riverine and terrestrial animals" (cf. [54]).

A crucial challenge in dam/reservoir management is releasing enough stored water at the correct time to maintain connectivity and support ecosystem processes [97–100]. Some types of HPF design may affect low flows, exacerbating hydrological drought as water is diverted around stream sections or into different river systems altogether, an issue that is particularly sensitive on international rivers [101]. Locally, for example, hydro-electricity generation at the Đăk Mi 4 HPF (A & B) requires inter-basin water transfer from the Vu Gia to the Thu Bồn subbasin, drastically reducing the flow volume in the former [102]. Hydrological droughts, associated in part with water abstractions for irrigation and hydropower generation, are some of the most devastating disasters in terms of economic loss in Central Vietnam [102]. The problem is not limited to the nation's Central region: in March of 2021, improper operation of the Thác Giềng 1 HPF (Bắc Kạn) in Northern Vietnam caused the Cầu River to dry up [103].

One of the most amazing examples of water diversion is associated with the A Lưới HPF (location shown in Figures 1 and 3). The dam of A Lưới HPF is located on the A Sáp River about 2 km from the border with Laos. Water in the reservoir backs up 12 km to the east where it enters an intake at ~570 m elevation that delivers it through an 11-km tunnel to the hydropower generating unit (~200 m elevation) on the other side of the Annamese Mountains. The water is released in the Bồ River Catchment, where it flows to the Pacific Ocean near Huế after joining the Hương River, rather than flowing into Lao PDR, then Cambodia, and eventually Vietnam on the Mekong Delta. While the 170-MW dam is technically impressive, it also fundamentally remakes ecologies in river catchments in three countries—collectively, three river systems in Vietnam.

Related to the issue of stream desiccation, the government recently issued minimum flow requirements for more than 600 projects nationwide of a variety of sizes [13]. Critical is that many small HPFs in Vietnam that are purported to be "run-of-the-river"(ROTH) facilities have dams that store a large volume of water or other structures that divert most water around lengthy stream sections, failing to maintain sufficient flows. The spirit of ROTH is not simply small size—in fact many such systems are large (Ian Baird, pers comm.)—but the avoidance of long-term storage and maintenance of constant environmental flows (including the passage of organisms) that support both aquatic and human systems [104]. Babel et al. found that while there are tradeoffs between hydropower production and maintaining environmental flows, general operation policies can be modified to both improve power production and maintain ecological conditions, as in the case of the La Ngà river and several large dams [105]. It is unclear the extent that this balance can be achieved for many small HPFs built in cascades on streams with great seasonality in streamflow, especially baseflow.

4.4. Natural and Anthropogenic Hazards

Flood protection is often a reasonable justification for multi-use dam construction in Vietnam [106]. From a management perspective, multi-use represents sound stewardship of water resources [107]. Large reservoirs tend to remove the peaks from extreme high flows reducing the occurrence and/or magnitude of floods. According to EVN, the Hòa Bình dam has "controlled" more than 100 large floods since being built, including in 1996, as the reservoir was receiving flows from upstream in excess of 13,000 m^3/s meanwhile discharging at a rate of 9000 m^3/s, preventing water levels in Hanoi downstream from becoming dangerous [108]. This type of flood protection comes with a sacrifice to electricity production however. In a study of the 40 largest HPFs in 12 basins in Vietnam, Nguyen-Tien et al. [106] estimated that, on average, HPFs lost 18% of their productivity (795.5 MWh per day) during flood periods, sacrificing 1 MWh to mitigate 1 m^3/s of flow increase.

Yet while floods can bring enormous negative social and economic costs, they are also an inherent natural hydro-geomorphological process that shapes the land surface and supports ecological systems [109,110]. Non-catastrophic floods, including annual pulses in tropical systems, facilitate fish productivity, influence biotic composition and dispersal, create/maintain wildlife habitat (e.g., deep pools, feeding areas), recharge wetlands, rejuvenate soil fertility through nutrient and soil redistribution, construct flood plains, and contribute to groundwater recharge [111–114]. Thus, the technical flood protection service provided by dams has associated ecological and environmental costs that are rarely articulated.

From a hazard perspective, poorly designed or poorly managed dams can exacerbate flood impacts; and dam failures can be catastrophic [115,116]. According to a 2018 report by the Vietnamese General Department of Natural Disaster Prevention and Control, 260 flash floods and landslides occurred between 2010 and 2017, resulting in 910 killed or missing [117]. Officials blamed deforestation, much of which could be linked to hydropower development. However, the dam-hazard issue is contentious. Proponents of dams argue that associated disasters are caused by poor design, operation, and maintenance rather than the dams per se [118].

Owing to Vietnam's geographical location in SE Asia, tropical storms are particularly challenging for safe operation of HPFs given the potential for extreme rainfall to generate high-volume floods. A recent example is from October 2020, when tropical storm Linfa caused landslides at the Rào Trăng HPF, leaving 17 people dead or missing [119]. Other examples demonstrate the elevated risk of managing HPFs during flood events in Vietnam due to the challenges in predicting storm tracking across the South China Sea, and therefore, forecasting rainfall. In 2020, high discharges into the reservoir at the Đăk Mi 4 HPF in Quảng Nam province during Typhoon Molave forced the operator to rapidly release water, flooding downstream communities that were simultaneously inundated by the same storm [120]. In 2021, the Ba Hạ hydropower facility in Phú Yên released 4000 to 9000 m^3 of water through its floodgates to prevent breaching after two other facilities upstream had opened their floodgates because of heavy rains [121]. Finally, in April of 2022, water was released through the dam of the A Lưới HPF, flooding downstream areas in Laos without consideration of safety [122]. These events demonstrate how a recurrent lack of communication between dam operators and downstream communities potentially turns environmental hazards into human disasters.

Two additional points in the debate on the relationship between dams and flood hazards are relevant. Firstly, many dams in Vietnam have very likely been designed without sufficient hydrological data sets to engineer them to withstand flows with tremendous energy that are associated with large storms and steep environments. Secondly, in catchments with high sediment loads, reservoir lifetimes can be short-lived, on the order of 20 to 50 years. As sediment is stored behind the dam, the reservoir loses its ability to store flood waters. However, this issue may not be critical in Vietnam. Wild and Loucks estimated that sediment retention capabilities of dam/reservoir systems planned on the S3 river systems would not be exhausted in less than 100 years, despite trapping 40–80% of the annual sediment loads [123]. More work is needed to understand this issue clearly in the headwaters of Vietnam, including the estimation of the trapping bedload, which is a very difficult variable to measure accurately [124].

From a different perspective, droughts are highly problematic to HPF operations. Maintaining critical water depths and velocities in the annual dry period has proven challenging in Vietnam where insufficient runoff from tributary streams may limit hydropower production in drier periods [125,126]. Coordinated releases of dam water are a potential strategy for alleviating downstream hydrological drought [127,128], but not all types of HPFs support this capability. This issue has been particularly contentious for the Lower Mekong region as water released from the multiple dams in the Upper Mekong Basin was deemed by many as too little to maintain viable flows during the drought conditions of 2019–2020 [129]. Ironically, one proposed solution to the problem of drought is to build even more dams in the Lower Mekong Basin to maintain water access during dry spells [130].

A final hazard with increasing attention in Vietnam relates to the potential for large reservoirs to induce seismic activities through the interaction of changing water levels and natural seismic processes in the area. Although not conclusive, some research suggests that small earthquakes occurring in the vicinity of some HPFs may have been triggered by periodic loading-unloading of reservoir water, for example at the Sông Tranh 2 and Sơn La HPFs [131,132].

4.5. Societal Impacts

Hydropower dams have had great societal benefit, yet many have had negative impacts on people in the vicinity of reservoirs and other dam infrastructure [72,133,134]. As demand for electricity has grown, the "economics" of executing quick installation has tended to take precedence over concerns the communities affected by dam construction [16]. Arguably the most critical issue is the displacement of communities as part of building the reservoirs of large HPFs such as Thác Bà (35,000 pax resettled/displaced), Hòa Bình (58,000), and Sơn La (91,000). Resettlement often puts pressure on community members and exacerbates social problems such as poverty, domestic violence, splintered families, broken community structures, and engagement in illegal or dangerous activities [135]. The issue is further complicated by ethnic politics. Writing in 2014, Pham estimated that ethnic minorities made up 90 percent of the approximately 200,000 people who had been displaced/relocated because of hydropower construction in Vietnam [12].

In the case of Hòa Bình, the flooding of the reservoir (including 11,000 ha of farmland) required the displacement of 58,000 people to new areas where they encroached upon the livelihoods of others while competing for forest, water, and land resources [136,137]. Inadequate compensation was also a problem. Households displaced for the construction of the Hòa Bình dam/reservoir, for example, were compensated for about 0.3 ha of land, a fraction of the 6–8 ha they previously utilized [138]. Further, as the new lands were not as fertile as their former fields or were inappropriate for their farming methods, many displaced people became impoverished. In an example from Bắc Giang, the ethnic Mường community of Lương Phong were faced with the challenge of farming the dry steep slopes surrounding the reservoir, after being forced from their fertile rice lands in close proximity to forest resources with a reliable water supply [137]. With villagers having little experience in upland techniques, the lands quickly became degraded, losing fertility. Declining yields forced them to move to other lands, a repetitive process that led both to extensive land degradation and poverty [138].

While displacement may be much less of a problem today, the livelihoods of people are still often affected by the many issues mentioned above: inter alia reduction of flows supporting agriculture and fishing, alteration of hazard risks, stream ecology degradation, loss of farmlands, and forest resource degradation. Further, failure to provide timely and adequate compensation for these losses remains a problem today [139].

5. The Theater of Decarbonization

Today, the push to decarbonize energy production is driving renewed interest in hydropower development worldwide [139]. One result of this agenda in Vietnam is the plan to increase the capacity of several existing dams, including the first three large dams built after 1975. In 2021 the French Development Agency announced that it would provide financial support for adding two turbines of 240 MW each to the Hòa Bình dam, bringing its total capacity to 2400 MW. Meanwhile, both Ialy and Trị An are slated to increase capacity by 360 and 200 MW, bringing their totals to 1080 and 600 MW, respectively. This 1040 MW of new capacity will generate an estimated 3 to 5 TWh of electricity per year. In this sense, the increased capacity could represent an important environmental offset by avoiding new construction on rivers and streams in the forested uplands. Nevertheless, plans to add capacity are not typically framed in terms of avoiding impacts from additional dam construction, but rather in terms of offsetting GHG emissions associated with power plants using fossil fuels [140].

Thus, while the central government may have withdrawn approval for hundreds of dam projects since 2016, HPF construction has continued and is now promoted as a means to decarbonize energy production. According to a report by the Ministry of Industry and Trade's Department of Electricity and Renewable Energy, as of 2020 there were 158 hydroelectric projects under construction (again, 172 were found in the analysis herein; footnote of Table 1) and a further 369 either under investigation or awaiting study [14]. Yet whether adding new turbines to existing dams or building new small HPFs, much of this development appears part of a "theater of decarbonization" that serves to dissimulate the construction of new thermal electricity plants both in Vietnam and Laos [141] and the increasing role of coal and gas technologies in the nation's future energy budget (Figure 5; Table 2).

The Draft PDP8 indicates a steady increase in "imported" coal-fired thermal power capacity of about 6 to 8 GW per half decade in the foreseeable future (Table 2; [48]), increasing from a baseline of 6.15 MW in 2020 to 12.68 GW (2025) then 20.36 GW (2030). It eventually reaches a target of 35.19 GW in 2045 when domestic coal-fired capacity has reduced to about the same as in 2020 (14.73 GW). The projections suggest a "not-in-my-backyard" approach to decarbonization that will do little to address the fundamental problem of reducing dependence on energy generated from coal. At the same time, the installed capacity of LNG and other gas technologies are projected to double from 14 to 28 GW in only five years (2025 to 2030), then double again to about 56 GW by 2040 (Figure 6; Table 2). With reference to the sustainability theme of this paper, compared to the massive projected increases in coal and gas capacity, the construction of hundreds of new small dams will play a negligible role in addressing the long-term growth in the demand for electricity (shown by the dotted blue line in Figure 5).

While the construction of earlier dams was driven by development goals, after 2023 the addition of hydropower capacity—along with the projected development of wind and solar resources—will serve mainly to maintain the perception of an acceptable balance of renewables in Vietnam's energy portfolio. But maintaining this perception will come at a heavy cost for Vietnam's rivers, including in some extremely sensitive environments. This theater of decarbonization is driven fundamentally by the continued rise in electricity consumption (Figure 4 inset), an issue facing most countries worldwide. Demand for electricity in Vietnam is forecasted to grow by at least five percent annually until the middle of the 21st century [142]. As this growth is compounding, electricity demand would double approximately every ten years. Leaving aside the issue of pumped storage, for which the technology and implementation is still nascent, even if all of Vietnam's remaining theoretical hydropower potential is exploited through the construction of dense cascades of HPFs on all the nation's rivers—regardless of costs of production and impacts to society and the environment—the result will make little contribution to meeting the increased demand in electricity nationwide (Figure 5).

The GHG-emission-offsetting potential of HPFs of two or more orders of magnitude versus fossil fuel plants has been a key playing card for investors when lobbying for authorization to build HPFs in sensitive environments: i.e., the good of renewable energy is argued to outweigh any associated negative impacts. The argument, however, is less clear than it appears. First, unless a very large HPF on the order of Ialy (720 MW; ~3.7 TWh) can be built, more than 100 small and less-efficient HPFs (median ~8 MW; Table 1) are needed to offset the emissions of a 600-MW coal-fired plant such as Thái Bình 1 (~3.6 TWh). This rough estimate does not consider the carbon footprint of the individual HPFs. Second, as mentioned above, additional coal-fired capacity, as well as LNG, must be added to meet projected electricity demands irrespective of an increasing role of hydropower (Table 2). Third, projected electricity output from the arsenal of Vietnam's HPFs is uncertain owing to potential changes in rainfall patterns/magnitude as the climate changes and as reservoir siltation eventually affects the generation capacity of many facilities [86,143]. A final issue is that projected economic benefits of new hydropower development are often overestimated to attract investors and gain government approval [144].

For the present, facing the issue of sustainability is made difficult by institutions and structures that promote hydropower development [145]. As the review of the history of hydropower development above has shown, one outcome of Vietnam's early and deep embrace of hydro-developmentalism has been the creation of a "hydro-industrial complex" composed of thousands of enterprises, including some of Vietnam's largest, for whom hydropower projects and their associated infrastructure are important sources of profit and growth. These in turn are supported by manufacturing and engineering companies in China, Russia, and the West, as well as public and private financing organizations worldwide. In Vietnam today, the new imperative to decarbonize energy production has combined with inertia and a pre-existing combination of interests to push almost inevitably towards the construction of yet more HPFs no matter the social and ecological costs. Absent a decision by the state to reorient Vietnamese enterprises and institutions towards energy sources where they have little experience, more ecologies and the communities that depend on them will likely be sacrificed to create the illusion of decarbonization. In fact, given the projected growth in energy demand, this reorientation will have to be made sooner or later. The only question is how many more rivers will be eaten before it finally happens.

6. Conclusions

With one of the most intensively exploited riverscapes in Asia, Vietnam has in an important sense "eaten" its rivers. And yet all signs indicate that it will eat more. History and politics are crucial for understanding why. Today's reengineered riverscape has been thousands of years in the making. Historically, Vietnamese regimes have prioritized water control for irrigation, transportation, and flood control. After the revolution, officials of the DRV and later SRV adopted from their Soviet allies a hydro-developmentalist ideology, seizing upon hydropower as a means to transform nature for the good of society. Even as the country pursued a war of reunification, the state devoted enormous resources to the construction of the Thác Bà dam between 1962 and 1973. After 1975, the lessons learned from that iconic facility would be applied in a series of mega-projects like Hòa Bình, Sơn La and Lai Châu. These costly projects vastly increased Vietnamese energy supply and for many years constituted the backbone of the nation's electricity supply.

While these projects were symbolically and practically important to national development, they were also carried out by institutions and within particular structural constraints. Collectively, they form an effective "hydro-industrial complex" with vested interests in hydropower development. As the Vietnamese government liberalized markets and devolved planning responsibilities after 2000 and local actors were able to tap into global financial markets, the result was a remarkable wave of dam building that saw hundreds of small hydropower installations built on the nation's rivers (Figures 2A and 4). The result has been the creation of a complex techno-natural riverscape on a national scale. While dam-building slowed somewhat after 2016 due to the increasingly marginal returns, the new imperative to "transition" from fossil fuels and the resulting "theater of decarbonization" will strengthen the hand of dam-building lobbies and almost certainly result in more facilities being built on an already highly-exploited riverscape.

Yet history and politics only tell part of the story. For decades, hydropower has been the cornerstone of Vietnam's energy production, playing a crucial role in the transformation of Vietnamese economy and society. It has played a similarly crucial role in remaking the nation's river systems, forests, farmlands, and villages. As our discussion of the ecologies of hydropower makes clear, along with the services like flood control and irrigation that reservoirs provide, and the undeniable benefits electricity brings to the economy and society, HPF construction has been accompanied by many negative impacts to the environment and a subset of the society in Vietnam.

At this point, it's worth returning to the analogy of "eating the rivers" that frames this paper. Applying technologies to "eat" resources is a very human activity. Swidden agriculturalists were "engineers" of the forest no less than the civil engineers, financiers, and policy-makers who have remade Vietnam's contemporary riverscape. The question is whether they do it sustainably or not. Many traditional swiddening practices were both efficient and sustainable given the communities and consumption patterns they supported, the expansive forests they inhabited, and the technologies they employed. Underpinning this sustainability was an epistemology that brought the technological, the social, and the natural together in a single frame. In this way they allowed forests to recover to support the needs of natural ecosystems and the survival of future generations [1,146–148].

In contrast, hydropower development operates very differently. Consumption patterns are crucial: forest farmers did not need exponentially more crops each year. Nations consuming electricity however do. Scale also matters: whereas forest farmers were intimately aware of the costs and benefits of their manipulation practices in the forests where they lived, hydropower development effectively distances the two, labeling anthropogenic hazards as "natural" and hiding many of the costs far away from urban centers of power (and power consumption), both locally and internationally [149]. While forest farmers had an inherently "ecological" understanding of techno-social-natural processes, competing epistemologies of today make it difficult to apprehend the complex systems at play, as metrics like GDP growth, LCOE, and gCO_2-eq/kWh contest with—and usually win over—measures of species diversity, ecosystem fragmentation, livelihood resilience, and environmental flows. But the fundamental difference is that swidden agricultural practices depend on eating new forest lands lightly, while those borrowed in the past are allowed to rest and to recover. As we have argued, Vietnam has run out of rivers to eat, and there is no indication that those already consumed will find some sort of respite.

To conclude, since 2000 the powerful "hydropower myth" has played out to the detriment of environmental and social ecologies across the entire space of Vietnam in a manner that is largely without precedent [145]. There is no question that hydroelectricity has played a vital role in the nation's impressive economic growth since the 1980s. However, the window has closed on traditional hydropower (leaving aside pumped storage) as a major contributor to the future growth of Vietnam's energy supply. One must therefore question the utility of building additional small hydropower facilities, as planned, whether to address increasing demand for electricity or to reduce the reliance on fossil fuels as part of mitigating climate change. A more sustainable approach would do two things. First, address key structural issues that have thus far prevented other forms of renewable energy from contributing to the electricity generation portfolio. Second, engage meaningfully with the need to sustain social and economic development without an exponential growth in energy consumption. Doing so could provide a useful point of comparison and potential model for countries around the world attempting to find a path to a more equitable and sustainable future. Whether in Vietnam or elsewhere, this paper argues, the key is to combine a holistic, ecologically sensitive, historically grounded, and politically informed approach with a rigorous evaluation of the costs and benefits of available energy technologies.

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References

1. Condominas, G. *Nous Avons Mangé La Forêt*; Mercure de France: Paris, France, 1957.
2. Bakker, K. The Politics of Hydropower: Developing the Mekong. *Political Geogr.* **1999**, *18*, 209–232. [CrossRef]
3. Hirsch, P. The Changing Political Dynamics of Dam Building on the Mekong. *Water Altern.* **2010**, *3*, 312–323.
4. Hecht, J.S.; Lacombe, G.; Arias, M.E.; Dang, T.D.; Piman, T. Hydropower Dams of the Mekong River Basin: A Review of Their Hydrological Impacts. *J. Hydrol.* **2019**, *568*, 285–300. [CrossRef]
5. Soukhaphon, A.; Baird, I.G.; Hogan, Z.S. The Impacts of Hydropower Dams in the Mekong River Basin: A Review. *Water* **2021**, *13*, 265. [CrossRef]
6. Middleton, C.; Allouche, J. Watershed or Powershed? *Critical Hydropolitics, China and the 'Lancang-Mekong Cooperation Framework.' Int. Spect.* **2016**, *51*, 100–117. [CrossRef]
7. IHA. *Hydropower Status Report*; International Hydropower Association: Paris, France, 2022.
8. White, R. *The Organic Machine: The Remaking of the Columbia River*; A Critical Issue; 6. Printing; Hill and Wang: New York, NY, USA, 2001; ISBN 978-0-8090-1583-2.
9. Pritchard, S.B. *Confluence: The Nature of Technology and the Remaking of the Rhône*; Harvard Historical Studies; Harvard University Press: Cambridge, MA, USA, 2011; ISBN 978-0-674-04965-9.
10. Carew-Reid, J.; Kempinski, J.; Clausen, A. *Biodiversity and Development of the Hydropower Sector: Lessons from the Vietnamese Experience—Volume I: Review of the Effects of Hydropower Development on Biodiversity in Vietnam*; International Centre for Environmental Management: Hanoi, Vietnam, 2010.
11. Dao, N. Damming Rivers in Vietnam: A Lesson Learned in the Tây Bắc Region. *J. Vietnam. Stud.* **2011**, *6*, 106–140. [CrossRef]
12. Pham, H.T. Dilemmas of Hydropower Development in Vietnam: Between Dam-Induced Displacement and Sustainable Development. Ph.D. Dissertation, Utrecht University, Utrecht, The Netherlands, 2014.
13. Ministry of Natural Resources and Environment. *Danh Mục Giá Trị Dòng Chảy Tối Thiểu ở Hạ Du Các Hồ Chứa, Đập Dâng Ban Hành Kèm Theo Quyết Định Số 1609/QĐ-BTNMT (List of Maximum and Miminum Flow Standards of Reservoirs and Barrages)*; Appendix to Decree Number 1609/QĐ-BTNMT of the Ministry of Natural Resources and the Environment; Ministry of Natural Resources and the Environment: Hanoi, Vietnam, 2022.
14. RFA Bộ Công Thương Nói Loại Bỏ Hàng Trăm Thủy Điện Nhỏ Khỏi Quy Hoạch: Chạy Tội Phá Rừng? (Ministry of Industry and Trade Said to Remove Hundreds of Small Hydroelectricity from Planning: Will It Effect the Crime of Deforestation?). Radio Free Asia 2020. Available online: https://www.rfa.org/vietnamese/in_depth/eliminate-many-small-hydroelectricity-but-who-is-responsible-for-deforestation-10202020132758.html (accessed on 20 October 2022).
15. IEA. *Hydropower Data Explore*; International Energy Agency: Paris, France, 2022.
16. Nguyen, V.D.S. *The Political Economy of Hydropower Dam Construction in Vietnam*; Stimson Center: Washington, DC, USA, 2008.
17. Middleton, C.; Grundy-Warr, C.; Yong, M. Neoliberalizing Hydropower in the Mekong Basin: The Political Economy of Partial Enclosure. *Soc. Sci. J.* **2013**, *43*, 299–334.
18. Baird, I.G. Non-Government Organizations, Villagers, Political Culture and the Lower Sesan 2 Dam in Northeastern Cambodia. *Crit. Asian Stud.* **2016**, *48*, 257–277. [CrossRef]
19. Wyatt, A.B.; Baird, I.G. Transboundary Impact Assessment in the Sesan River Basin: The Case of the Yali Falls Dam. *Int. J. Water Resour. Dev.* **2007**, *23*, 427–442. [CrossRef]
20. IHA. *Vietnam Profile*; International Hydropower Association: Paris, France, 2014.
21. Dang, D.T. Phát Triển Thủy Điện ở Việt Nam: Tiềm Năng và Thách Thức (Hydropower Development in Vietnam: Potential and Challenges). Năng lượng Việt Nam 2017. Available online: https://nangluongvietnam.vn/phat-trien-thuy-dien-o-viet-nam-tiem-nang-va-thach-thuc-19934.html (accessed on 20 October 2022).
22. EVN. *Overview of Hydropower in Vietnam*; Electricity Vietnam: Hanoi, Vietnam, 2019.
23. Xu, R.; Zeng, Z.; Pan, M.; Ziegler, A.D.; Holden, J. A Global-Scale Framework for Hydropower Development Incorporating Strict Environmental Constraints. *Nat. Water* **2023**, *1*, 113–122. [CrossRef]
24. Tana, L. The Sea Becomes Mulberry Fields and Mulberry Fields Become the Sea': Dikes in the Eastern Red River Delta, c.200 BCE to the Twenty-First Century CE. In *Natural Hazards and Peoples in the Indian Ocean World*; Bankoff, G., Christensen, J., Eds.; Palgrave Series in Indian Ocean World Studies; Palgrave Macmillan US: New York, NY, USA, 2016; pp. 55–78. ISBN 978-1-349-94856-7.
25. Biggs, D. Problematic Progress: Reading Environmental and Social Change in the Mekong Delta. *J. Southeast Asian Stud.* **2003**, *34*, 77–96. [CrossRef]
26. Biggs, D.A. *Quagmire: Nation-Building and Nature in the Mekong Delta*; Weyerhaeuser Environmental Books; First Paperback Edition; University of Washington Press: Seattle, WA, USA; London, UK, 2012; ISBN 978-0-295-99199-3.
27. EVN Khi Nhân Vật Lịch Sử... Chép Sử Ngành Điện (When Historical Figures... Record the History of the Electricity Industry). Văn hoá EVN 2019. Available online: https://www.evn.com.vn/d6/news/Khi-nhan-vat-lich-su-chep-su-nganh-Dien-6-12-24805.aspx (accessed on 20 October 2022).

28. Phạm, V.T. Bài Học Lớn Địa Chất Công Trình Từ Thuỷ Điện Hoà Bình. In *Tiếng vọng Sông Đà*; Nguyễn, T.Á.N., Ed.; Nhà xuất bản Phụ nữ Việt Nam: Hanoi, Vietnam, 2022; pp. 179–184. ISBN 978-604-3-48072-6.
29. Josephson, P.R. *Industrialized Nature: Brute Force Technology and the Transformation of the Natural World*; Island Press/Shearwater Books: Washington, DC, USA, 2002; ISBN 978-1-55963-777-0.
30. Sasges, G. Construire le Socialisme Hydraulique en Combattant: L'hydroélectricité, le Barrage de Thac Ba et la Construction du Vietnam 1957–1973. In In Proceedings of the IrAsia Seminar Series, Aix-Marseille University, Marseille, France, 2 December 2022.
31. ADB. *Energy for All: Viet Nam's Success in Increasing Access to Energy through Rural Electrification*; Asian Development Bank: Manila, Philiphines, 2011; pp. 1–9.
32. Thin, V.D.; Skofteland, E.; Lifwenborg, G. National Hydropower Plan NHP Study in Vietnam. In *Hydropower in the New Millenium*; Balkerma, A.A., Ed.; Swets & Zeitlinger Publishers: Bergen, Norway, 2001.
33. Middleton, C.; Garcia, J.; Foran, T. Old and New Hydropower Players in the Mekong Region: Agendas and Strategies. In *Contested Waterscapes in the Mekong Region: "Hydropower, Livelihoods and Governance"*; Molle, F., Ed.; Taylor and Francis: Hoboken, NJ, USA, 2012; pp. 23–54. ISBN 978-1-84977-086-6.
34. Malesky, E. Researching Vietnamese Politics. *J. Vietnam. Stud.* **2018**, *13*, 127–162. [CrossRef]
35. WB. *Enabling Private Capital to Unlock Vietnam's Small Hydropower Potential*; World Bank: Washington, DC, USA, 2021.
36. Le, A.T.; Dao, T.V.N. *Phát Triển Thuỷ Điện ở Việt Nam: Thách Thức và Giải Pháp*; NXB Khoa học và Kỹ thuật: Hanoi, Vietnam, 2016.
37. Wells-Dang, A. Civil Society Networks in Cambodia and Vietnam. In *Southeast Asia and the Civil Society Gaze: Scoping a Contested Concept in Cambodia and Vietnam*; Waibel, G., Ehlert, J., Feuer, H., Eds.; Routledge studies on civil society in Asia; Routledge: London, UK; Taylor & Francis Group: New York, NY, USA, 2014; pp. 61–76. ISBN 978-0-415-70966-8.
38. Wells-Dang, A. Civil Society and Advocacy Networks in Vietnam. In *Routledge Handbook of Contemporary Vietnam*; London, J.D., Ed.; Routledge: Oxford, UK.; New York, NY, USA, 2022; pp. 73–87. ISBN 978-1-138-79225-8.
39. Kummu, M.; Sarkkula, J. Impact of the Mekong River Flow Alteration on the Tonle Sap Flood Pulse. *AMBIO A J. Hum. Environ.* **2008**, *37*, 185–192. [CrossRef]
40. Arias, M.E.; Piman, T.; Lauri, H.; Cochrane, T.A.; Kummu, M. Dams on Mekong Tributaries as Significant Contributors of Hydrological Alterations to the Tonle Sap Floodplain in Cambodia. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 5303–5315. [CrossRef]
41. Campbell, I.; Barlow, C. Hydropower Development and the Loss of Fisheries in the Mekong River Basin. *Front. Environ. Sci.* **2020**, *8*, 566509. [CrossRef]
42. Binh, D.V.; Kantoush, S.A.; Saber, M.; Mai, N.P.; Maskey, S.; Phong, D.T.; Sumi, T. Long-Term Alterations of Flow Regimes of the Mekong River and Adaptation Strategies for the Vietnamese Mekong Delta. *J. Hydrol. Reg. Stud.* **2020**, *32*, 100742. [CrossRef]
43. Poindexter, G. Vietnam Reduces Number of Hydropower Plants in Its Power Development Plan 7. Available online: https://www.hydroreview.com/business-finance/vietnam-reduces-number-of-hydropower-plants-in-its-power-development-plan-7/#gref (accessed on 20 October 2022).
44. Middleton, C.; Matthews, N. Whose Risky Business? Public–Private Partnerships, Build-Operate-Transfer and Large Hydropower Dams in the Mekong Region. In *Hydropower development in the Mekong Region: Political, Socio-Economic, and Environmental Perspectives*; Matthews, N., Geheb, K., Eds.; Earthscan studies in water resource management; Routledge: London, UK; Taylor & Francis Group: New York, NY, USA, 2015; p. 26, ISBN 978-0-415-71913-1.
45. Ha-Duong, M.; Nguyen, H.-S. Subjective Satisfaction and Objective Electricity Poverty Reduction in Vietnam, 2008–2018. *FREP* **2021**, *1*, 43–60. [CrossRef]
46. Roome, J. *Hydropower in Vietnam: The Right Way to Do It.*; World Bank: Washington, DC, USA, 2016.
47. OWID. Vietnam: How Much Electricity Does the Country Consume Each Year? Our World in Data: Oxford, UK, 2022.
48. Burke, F.; Nguyen, T.H. *Vietnam: Key Highlights of New Draft of National Power Development Plan (Draft PDP8)*; Baker McKenzie: Chicago, IL, USA, 2021.
49. *EVN Import of Electricity: Solution to Ensure National Energy Security*; Electricity Vietnam: Hanoi, Vietnam, 2020.
50. Lan, N. Vietnam to Increase Electricity Imports from Laos, Cambodia, China. Saigon Times 2020. Available online: https://english.thesaigontimes.vn/vietnam-to-increase-electricity-imports-from-laos-cambodia-china/ (accessed on 20 October 2022).
51. Von Sperling, E. Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects. *Energy Procedia* **2012**, *18*, 110–118. [CrossRef]
52. Okuku, E.O.; Bouillon, S.; Ochiewo, J.O.; Munyi, F.; Kiteresi, L.I.; Tole, M. The Impacts of Hydropower Development on Rural Livelihood Sustenance. *Int. J. Water Resour. Dev.* **2016**, *32*, 267–285. [CrossRef]
53. ASTAE. *Cumulative Impacts and Joint Operation of Small-Scale Hydropower Cascades: Case Studies for Selected River Basins in Northwest Vietnam*; Asia Sustainable and Alternative Energy Program: Washington, DC, USA, 2014.
54. McCully, P. *Silenced Rivers: The Ecology and Politics of Large Dams*; Zed Books: London, UK; New York, NY, USA, 2001; ISBN 978-1-85649-901-9.
55. Ahlers, R.; Budds, J.; Joshi, D.; Merme, V.; Zwarteveen, M. Framing Hydropower as Green Energy: Assessing Drivers, Risks and Tensions in the Eastern Himalayas. *Earth Syst. Dynam.* **2015**, *6*, 195–204. [CrossRef]
56. Räsänen, T.A.; Varis, O.; Scherer, L.; Kummu, M. Greenhouse Gas Emissions of Hydropower in the Mekong River Basin. *Environ. Res. Lett.* **2018**, *13*, 034030. [CrossRef]
57. Richter, B.D.; Postel, S.; Revenga, C.; Scudder, T.; Lehner, B.; Churchill, A.; Chow, M. Lost in Development's Shadow: The Downstream Human Consequences of Dams. *Water Altern.* **2010**, *3*, 14–42.

58. Siciliano, G.; Del Bene, D.; Scheidel, A.; Liu, J.; Urban, F. Environmental Justice and Chinese Dam-Building in the Global South. *Curr. Opin. Environ. Sustain.* **2019**, *37*, 20–27. [CrossRef]
59. Lang, C. The National Hydropower Plan Study: Planning and Damming in Vietnam. *Watershed* **2000**, *5*, 48.
60. Luu, C.; Von Meding, J. Hydropower Development and Environmental Impact Assessments in Vietnam: Current Practice and Shortcomings. In Proceedings of the Sustainable Water and Sanitation Services for All in a Fast Changing World, Hanoi, Vietnam, 15–19 September 2014.
61. Jackson, S.; Sleigh, A. Resettlement for China's Three Gorges Dam: Socio-Economic Impact and Institutional Tensions. *Communist Post-Communist Stud.* **2000**, *33*, 223–241. [CrossRef]
62. Cross, W.F.; Baxter, C.V.; Donner, K.C.; Rosi-Marshall, E.J.; Kennedy, T.A.; Hall, R.O.; Kelly, H.A.W.; Rogers, R.S. Ecosystem Ecology Meets Adaptive Management: Food Web Response to a Controlled Flood on the Colorado River, Glen Canyon. *Ecol. Appl.* **2011**, *21*, 2016–2033. [CrossRef]
63. Giles, J. Methane Quashes Green Credentials of Hydropower. *Nature* **2006**, *444*, 524. [CrossRef]
64. Yan, X.; Thieu, V.; Garnier, J. Long-Term Evolution of Greenhouse Gas Emissions From Global Reservoirs. *Front. Environ. Sci.* **2021**, *9*, 705477. [CrossRef]
65. Ubierna, M.; Santos, C.D.; Mercier-Blais, S. Water Security and Climate Change: Hydropower Reservoir Greenhouse Gas Emissions. In *Water Security Under Climate Change*; Biswas, A.K., Tortajada, C., Eds.; Water Resources Development and Management; Springer Singapore: Singapore, 2022; pp. 69–94. ISBN 9789811654923.
66. WB. *Greenhouse Gases from Reservoirs Caused by Biogeochemical Processes*; World Bank: Washington, DC, USA, 2017.
67. Jager, H.I.; Griffiths, N.A.; Hansen, C.H.; King, A.W.; Matson, P.G.; Singh, D.; Pilla, R.M. Getting Lost Tracking the Carbon Footprint of Hydropower. *Renew. Sustain. Energy Rev.* **2022**, *162*, 112408. [CrossRef]
68. Schloemer, S.; Bruckner, T.; Fulton, L.; Hertwich, E. Annex III: Technology-Specific Cost and Performance Parameters. In *Climate Change 2014: Mitigation of Climate Change: Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Ed.; Cambridge University Press: New York, NY, USA, 2014; ISBN 978-1-107-05821-7.
69. Pham, H.T.; Tran, H.N. *Hydropower Plant Development and Forest Recompensing Plantation in Viet Nam*; Tropenbos International: Hue, Vietnam, 2017.
70. Dang, T.K.P. The Discourse of Forest Cover in Vietnam and Its Policy Implications. *Sustainability* **2022**, *14*, 10976. [CrossRef]
71. Truong, N.; Nguyen, H.; Kondoh, A. Land Use and Land Cover Changes and Their Effect on the Flow Regime in the Upstream Dong Nai River Basin, Vietnam. *Water* **2018**, *10*, 1206. [CrossRef]
72. Nguyen, H.; Pham, T.; Lobry de Bruyn, L. Impact of Hydroelectric Dam Development and Resettlement on the Natural and Social Capital of Rural Livelihoods in Bo Hon Village in Central Vietnam. *Sustainability* **2017**, *9*, 1422. [CrossRef]
73. Trædal, L.T.; Angelsen, A. Policies Drive Sub-National Forest Transitions in Vietnam. *Forests* **2020**, *11*, 1038. [CrossRef]
74. Nguyen, T.; Nguyen, N. Confessions of a Hydropower Calamity in Vietnam. Available online: https://e.vnexpress.net/projects/confessions-of-a-hydropower-calamity-in-vietnam-3655314/index.html (accessed on 20 October 2022).
75. Butler, R. Hydro Projects a Front for Logging in Vietnam. Available online: https://news.mongabay.com/2013/09/hydro-projects-a-front-for-logging-in-vietnam/ (accessed on 20 October 2022).
76. Trieu, X. Thêm 5 Tỷ Đồng Cho Công Trình Thuỷ Điện Hàm Thuận (An Additional 5 Billion Đồng for the Hàm Thuận Hydroelectric Project). *Quân đội Nhân dân* **1991**, *4*.
77. Stickler, C.M.; Coe, M.T.; Costa, M.H.; Nepstad, D.C.; McGrath, D.G.; Dias, L.C.P.; Rodrigues, H.O.; Soares-Filho, B.S. Dependence of Hydropower Energy Generation on Forests in the Amazon Basin at Local and Regional Scales. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 9601–9606. [CrossRef] [PubMed]
78. Magilligan, F.J.; Nislow, K.H. Changes in Hydrologic Regime by Dams. *Geomorphology* **2005**, *71*, 61–78. [CrossRef]
79. Poff, N.L.; Zimmerman, J.K.H. Ecological Responses to Altered Flow Regimes: A Literature Review to Inform the Science and Management of Environmental Flows: Review of Altered Flow Regimes. *Freshw. Biol.* **2010**, *55*, 194–205. [CrossRef]
80. Acreman, M.; Arthington, A.H.; Colloff, M.J.; Couch, C.; Crossman, N.D.; Dyer, F.; Overton, I.; Pollino, C.A.; Stewardson, M.J.; Young, W. Environmental Flows for Natural, Hybrid, and Novel Riverine Ecosystems in a Changing World. *Front. Ecol. Environ.* **2014**, *12*, 466–473. [CrossRef]
81. Latrubesse, E.M.; Arima, E.Y.; Dunne, T.; Park, E.; Baker, V.R.; d'Horta, F.M.; Wight, C.; Wittmann, F.; Zuanon, J.; Baker, P.A.; et al. Damming the Rivers of the Amazon Basin. *Nature* **2017**, *546*, 363–369. [CrossRef]
82. Ely, P.; Fantin-Cruz, I.; Tritico, H.M.; Girard, P.; Kaplan, D. Dam-Induced Hydrologic Alterations in the Rivers Feeding the Pantanal. *Front. Environ. Sci.* **2020**, *8*, 579031. [CrossRef]
83. Pham, L. Comparison between Water Quality Index (WQI) and Biological Indices, Based on Planktonic Diatom for Water Quality Assessment in the Dong Nai River, Vietnam. *Pollution* **2017**, *3*, 311–323.
84. Yen, C.; Picco, L.; Bao, T. Hydopower Dam and Hydrological Alternation on the Da River in Son La, Vietnam. *J. For. Sci. Technol.* **2019**, *7*, 124–132.
85. Chantha, O.; Ty, S. Assessing Changes in Flow and Water Quality Emerging from Hydropower Development and Operation in the Sesan River Basin of the Lower Mekong Region. *Sustain. Water Resour. Manag.* **2020**, *6*, 27. [CrossRef]
86. Wasti, A.; Ray, P.; Wi, S.; Folch, C.; Ubierna, M.; Karki, P. Climate Change and the Hydropower Sector: A Global Review. *WIREs Clim. Chang.* **2022**, *13*, e757. [CrossRef]

87. Trung, L.D.; Duc, N.A.; Nguyen, L.T.; Thai, T.H.; Khan, A.; Rautenstrauch, K.; Schmidt, C. Assessing Cumulative Impacts of the Proposed Lower Mekong Basin Hydropower Cascade on the Mekong River Floodplains and Delta–Overview of Integrated Modeling Methods and Results. *J. Hydrol.* **2020**, *581*, 122511. [CrossRef]
88. Brunier, G.; Anthony, E.J.; Goichot, M.; Provansal, M.; Dussouillez, P. Recent Morphological Changes in the Mekong and Bassac River Channels, Mekong Delta: The Marked Impact of River-Bed Mining and Implications for Delta Destabilisation. *Geomorphology* **2014**, *224*, 177–191. [CrossRef]
89. Anthony, E.J.; Brunier, G.; Besset, M.; Goichot, M.; Dussouillez, P.; Nguyen, V.L. Linking Rapid Erosion of the Mekong River Delta to Human Activities. *Sci. Rep.* **2015**, *5*, 14745. [CrossRef]
90. Loc, H.H.; Van Binh, D.; Park, E.; Shrestha, S.; Dung, T.D.; Son, V.H.; Truc, N.H.T.; Mai, N.P.; Seijger, C. Intensifying Saline Water Intrusion and Drought in the Mekong Delta: From Physical Evidence to Policy Outlooks. *Sci. Total Environ.* **2021**, *757*, 143919. [CrossRef]
91. Le Huy, B.; Le, H.; Xuan, H.N. The Harmful Effect of the Hydro-Electric Dams Upstream of the Mekong River: Effect on the Ecosystems and Livelihoods of People in Mekong Delta, Vietnam. *Water Conserv. Sci. Eng.* **2022**, *7*, 1–20. [CrossRef]
92. Piman, T.; Manish, S. *Case Study on Sediment in the Mekong River Basin: Current State and Future Trends*; Stockholm Environment Institute: Stockholm, Sweden, 2017.
93. Ziv, G.; Baran, E.; Nam, S.; Rodríguez-Iturbe, I.; Levin, S.A. Trading-off Fish Biodiversity, Food Security, and Hydropower in the Mekong River Basin. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 5609–5614. [CrossRef]
94. Barbarossa, V.; Schmitt, R.J.P.; Huijbregts, M.A.J.; Zarfl, C.; King, H.; Schipper, A.M. Impacts of Current and Future Large Dams on the Geographic Range Connectivity of Freshwater Fish Worldwide. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 3648–3655. [CrossRef]
95. Dugan, P.J.; Barlow, C.; Agostinho, A.A.; Baran, E.; Cada, G.F.; Chen, D.; Cowx, I.G.; Ferguson, J.W.; Jutagate, T.; Mallen-Cooper, M.; et al. Fish Migration, Dams, and Loss of Ecosystem Services in the Mekong Basin. *AMBIO* **2010**, *39*, 344–348. [CrossRef]
96. Baumgartner, L.J.; Marsden, T.; Duffy, D.; Horta, A.; Ning, N. Optimizing Efforts to Restore Aquatic Ecosystem Connectivity Requires Thinking beyond Large Dams. *Environ. Res. Lett.* **2022**, *17*, 014008. [CrossRef]
97. Ward, J.V.; Stanford, J.A. Ecological Connectivity in Alluvial River Ecosystems and Its Disruption by Flow Regulation. *Regul. Rivers: Res. Manag.* **1995**, *11*, 105–119. [CrossRef]
98. Richter, B.D.; Thomas, G.A. Restoring Environmental Flows by Modifying Dam Operations. *Ecol. Soc.* **2007**, *12*, 12. [CrossRef]
99. Bradford, M.J.; Heinonen, J.S. Low Flows, Instream Flow Needs and Fish Ecology in Small Streams. *Can. Water Resour. J.* **2008**, *33*, 165–180. [CrossRef]
100. Wang, Y.; Liu, P.; Dou, M.; Li, H.; Ming, B.; Gong, Y.; Yang, Z. Reservoir Ecological Operation Considering Outflow Variations across Different Time Scales. *Ecol. Indic.* **2021**, *125*, 107582. [CrossRef]
101. López-Moreno, J.I.; Vicente-Serrano, S.M.; Beguería, S.; García-Ruiz, J.M.; Portela, M.M.; Almeida, A.B. Dam Effects on Droughts Magnitude and Duration in a Transboundary Basin: The Lower River Tagus, Spain and Portugal: Droughts magnitude and duration. *Water Resour. Res.* **2009**, *45*, W02405. [CrossRef]
102. Firoz, A.B.M.; Nauditt, A.; Fink, M.; Ribbe, L. Quantifying Human Impacts on Hydrological Drought Using a Combined Modelling Approach in a Tropical River Basin in Central Vietnam. *Hydrol. Earth Syst. Sci.* **2018**, *22*, 547–565. [CrossRef]
103. Tuấn, S. Yêu Cầu Thủy Điện Thác Giềng 1 Vận Hành Đúng Quy Trình (Requesting Thác Giềng 1 Hydroelectric Facility Operate According to Procedures). Available online: https://nhandan.vn/yeu-cau-thuy-dien-thac-gieng-1-van-hanh-dung-quy-trinh-post637302.html (accessed on 20 October 2022).
104. Opperman, J. Crocodiles Are Not Geckos: The Realities Of Run-Of-River Hydropower. Forbes. June 6 2019. Available online: https://www.forbes.com/sites/jeffopperman/2019/06/06/crocodiles-are-not-geckos-the-realities-of-run-of-river-hydropower/?sh=54b749a86371 (accessed on 20 October 2022).
105. Babel, M.S.; Nguyen Dinh, C.; Mullick, M.R.A.; Nanduri, U.V. Operation of a Hydropower System Considering Environmental Flow Requirements: A Case Study in La Nga River Basin, Vietnam. *J. Hydro-Environ. Res.* **2012**, *6*, 63–73. [CrossRef]
106. Nguyen-Tien, V.; Elliott, R.J.R.; Strobl, E.A. Hydropower Generation, Flood Control and Dam Cascades: A National Assessment for Vietnam. *J. Hydrol.* **2018**, *560*, 109–126. [CrossRef]
107. Branche, E. The Multipurpose Water Uses of Hydropower Reservoir: The SHARE Concept. *Comptes Rendus Phys.* **2017**, *18*, 469–478. [CrossRef]
108. EVN. Hòa Bình Hydropower Plant Controls More Than 100 Floods with Peak of 5000 M3/s. 2016. Available online: https://en.evn.com.vn/d6/news/Hoa-Binh-Hydropower-Plant-Controls-more-than-100-Floods-with-Peak-of-5000-m3s{-}{-}66-163-468.aspx (accessed on 20 October 2022).
109. Poff, N.L.; Allan, J.D.; Bain, M.B.; Karr, J.R.; Prestegaard, K.L.; Richter, B.D.; Sparks, R.E.; Stromberg, J.C. The Natural Flow Regime. A Paradigm for River Conservation and Restoration. *BioScience* **1997**, *47*, 769–784. [CrossRef]
110. Jackson, M.B.; Ishizawa, K.; Ito, O. Evolution and Mechanisms of Plant Tolerance to Flooding Stress. *Ann. Bot.* **2009**, *103*, 137–142. [CrossRef]
111. Junk, W.J.; Bayley, P.B.; Spark, R.E. The Flood Pulse Concept in River-Floodplain Systems. *Can. Spec. Publ. Fish Aquat. Sci.* **1989**, *106*, 110–112.
112. Poff, N.L. Ecological Response to and Management of Increased Flooding Caused by Climate Change. *Philos. Trans. R. Soc. London. Ser. A Math. Phys. Eng. Sci.* **2002**, *360*, 1497–1510. [CrossRef] [PubMed]

113. Young, P.S.; Cech, J.J.; Thompson, L.C. Hydropower-Related Pulsed-Flow Impacts on Stream Fishes: A Brief Review, Conceptual Model, Knowledge Gaps, and Research Needs. *Rev. Fish Biol. Fish.* **2011**, *21*, 713–731. [CrossRef]
114. Talbot, C.J.; Bennett, E.M.; Cassell, K.; Hanes, D.M.; Minor, E.C.; Paerl, H.; Raymond, P.A.; Vargas, R.; Vidon, P.G.; Wollheim, W.; et al. The Impact of Flooding on Aquatic Ecosystem Services. *Biogeochemistry* **2018**, *141*, 439–461. [CrossRef]
115. Dam, T.T.; Pisaniello, J.D.; Burritt, R.L. Small Dam Safety Problems in Vietnam and Associated Responsibility and Accountability: Evidence from a Rural Commune. *J. Asia-Pac. Cent. Environ. Account.* **2011**, *3*, 154–181.
116. Lempérière, F. Dams and Floods. *Engineering* **2017**, *3*, 144–149. [CrossRef]
117. Thang, T. Tăng Cường Ứng Dụng Công Nghệ Trong Phòng Chống Lũ Quét, Sạt Lở Đất (Increasing the Application of Technology Flood and Landslide Prevention). Hà Nội mới 2018. Available online: https://hanoimoi.com.vn/ban-in/Xa-hoi/906984/tang-cuong-ung-dung-cong-nghe-trong-phong-chong-lu-quet-sat-lo-dat (accessed on 20 October 2022).
118. Tran, T.A. Small Hydropower Plants Should Not Be Blamed for Floods: Industry Minister. Vietnam News 2020. Available online: https://vietnamnews.vn/society/804276/small-hydropower-plants-should-not-be-blamed-for-floods-industry-minister.html (accessed on 20 October 2022).
119. Nhat, L. Trở Lại Nơi Thảm Họa Rào Trăng (Returning to the Site of the Rào Trăng Disaster). Tuổi Trẻ Online 2021. Available online: https://tuoitre.vn/tro-lai-noi-tham-hoa-rao-trang-20211012095148412.htm (accessed on 20 October 2022).
120. Nguyen, D.; Dac, T. Recompense for Flood Losses Caused by Dam Discharge, Hydropower Plant Told. VNExpress International 2020. Available online: https://e.vnexpress.net/news/news/recompense-for-flood-losses-caused-by-dam-discharge-hydropower-plant-told-4187613.html (accessed on 20 October 2022).
121. Xuan, N. Hydropower Plants Worsen Central Vietnam Flooding. VNExpress 2021. Available online: https://e.vnexpress.net/news/news/hydropower-plants-worsen-central-vietnam-flooding-4397690.html (accessed on 20 October 2022).
122. RFA Water Release from Vietnamese Dam Floods Villages in Southern Laos. Radio Free Asia 2022. Available online: https://www.rfa.org/english/news/laos/vietnam-04042022194110.html (accessed on 20 October 2022).
123. Wild, T.B.; Loucks, D.P. Managing Flow, Sediment, and Hydropower Regimes in the Sre Pok, Se San, and Se Kong Rivers of the Mekong Basin. *Water Resour. Res.* **2014**, *50*, 5141–5157. [CrossRef]
124. Ziegler, A.D.; Sidle, R.C.; Phang, V.X.H.; Wood, S.H.; Tantasirin, C. Bedload Transport in SE Asian Streams—Uncertainties and Implications for Reservoir Management. *Geomorphology* **2014**, *227*, 31–48. [CrossRef]
125. Warfe, D.M.; Pettit, N.E.; Davies, P.M.; Pusey, B.J.; Hamilton, S.K.; Kennard, M.J.; Townsend, S.A.; Bayliss, P.; Ward, D.P.; Douglas, M.M.; et al. The 'Wet-Dry' in the Wet-Dry Tropics Drives River Ecosystem Structure and Processes in Northern Australia: Flow Drivers of Tropical Australian Rivers. *Freshw. Biol.* **2011**, *56*, 2169–2195. [CrossRef]
126. Keller, K.; Allsop, Q.; Brim Box, J.; Buckle, D.; Crook, D.A.; Douglas, M.M.; Jackson, S.; Kennard, M.J.; Luiz, O.J.; Pusey, B.J.; et al. Dry Season Habitat Use of Fishes in an Australian Tropical River. *Sci. Rep.* **2019**, *9*, 5677. [CrossRef] [PubMed]
127. Rangecroft, S.; Van Loon, A.F.; Maureira, H.; Verbist, K.; Hannah, D.M. Multi-Method Assessment of Reservoir Effects on Hydrological Droughts in an Arid Region. Dynamics of the Earth system: Interactions. 2016. Available online: https://esd.copernicus.org/preprints/esd-2016-57/ (accessed on 20 October 2022).
128. Wu, J.; Yuan, X.; Yao, H.; Chen, X.; Wang, G. Reservoirs Regulate the Relationship between Hydrological Drought Recovery Water and Drought Characteristics. *J. Hydrol.* **2021**, *603*, 127127. [CrossRef]
129. Daniel, R. *Dams and Droughts, Data and Diplomacy in the Mekong*; Stockholm Environmental Institute: Bangkok, Thailand, 2021.
130. Tatarski, M. Vietnam Struggles to Find Solutions for Extreme Dry Seasons in Mekong. Available online: https://www.thethirdpole.net/en/livelihoods/vietnam-solutions-dry-seasons-mekong-delta/ (accessed on 20 October 2022).
131. Dinh, T.C.; Dinh, T.C.; Anh, T.T.; Quoc, V.D.; Le Van, D.; Thanh, H.D.; Xuan, B.M.; Nam, H.P.; Huu, T.N. Overview of the Characteristics of Reservoir-Triggered Seismic Activity at Some Hydropower Reservoirs in Vietnam. *J Geol Soc India* **2021**, *97*, 1574–1582. [CrossRef]
132. Telesca, L.; Thai, A.T.; Cao, D.T.; Ha, T.G. Spectral Evidence for Reservoir-Triggered Seismicity at Song Tranh 2 Reservoir (Vietnam). *Pure Appl. Geophys.* **2021**, *178*, 3817–3828. [CrossRef]
133. Moran, E.F.; Lopez, M.C.; Moore, N.; Müller, N.; Hyndman, D.W. Sustainable Hydropower in the 21st Century. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 11891–11898. [CrossRef]
134. Nguyen, N.Q.; Lenihan, M.; Saint-Pierre, C.; Nguyen, T.M.P.; Phan, H.D. *Managing Social Risks and Impacts from Hydropower Development: Sharing Experience from a Medium-Sized Dam Project in Vietnam*; World Bank: Washington, DC, USA, 2020.
135. Huang, Y.; Lin, W.; Li, S.; Ning, Y. Social Impacts of Dam-Induced Displacement and Resettlement: A Comparative Case Study in China. *Sustainability* **2018**, *10*, 4018. [CrossRef]
136. Wallace, C.P. Is Asia Robbing Rural Poor to Power the Rich? Vietnam's Hoa Binh Dam Displaced 50,000 and Wrecked Forests. Critics Ask Whether Hydroelectric Energy Is Worth It. Los Angeles Times 1992. Available online: https://www.latimes.com/archives/la-xpm-1992-02-18-wr-2322-story.html (accessed on 20 October 2022).
137. Hirsch, P.; Sinh, B.T. *Social and Environmental Implications of Resource Development in Vietnam: The Case of Hoa Binh Reservoir*; RIAP Occasional Paper; University of Sydney, Research Institute for Asia and the Pacific: Sydney, Australia, 1992.
138. Dao, N. Dam Development in Vietnam: The Evolution of Dam-Induced Resettlement Policy. *Water Altern.* **2010**, *3*, 324–340.
139. Dimanchev, E.G.; Hodge, J.L.; Parsons, J.E. The Role of Hydropower Reservoirs in Deep Decarbonization Policy. *Energy Policy* **2021**, *155*, 112369. [CrossRef]

140. AFD. *Green Energy In Vietnam: Expanded Hòa Bình Hydropower Plant Will Reduce Co2 Emissions*; Agence Française de Développement: Paris, France, 2021.
141. Petchkaew, K. Unraveling the Mystery of Laos' U-Turn from Renewables to Coal to Power the Battery of Southeast Asia. Available online: https://earthjournalism.net/stories/unraveling-the-mystery-of-laos-u-turn-from-renewables-to-coal-to-power-the-battery-of (accessed on 20 October 2022).
142. Luong, B. Conditions for Vietnam to Become High-Income Country by 2045. VNExpress International 2022. Available online: https://vietnamnet.vn/en/conditions-for-vietnam-to-become-high-income-country-by-2045-2060733.html (accessed on 20 October 2022).
143. Fitzgerald, M. Vietnam's Declining Hydropower Gen Has EVN Sourcing Alt Power. Available online: https://www.enlit-asia.com/generation/vietnams-declining-hydropower-gen-has-evn-sourcing-alt-power/ (accessed on 20 November 2022).
144. OXFAM. *Economic Evaluation of Hydropower Projects in the Lower Mekong Basin*; Mae Fah Luang University: Chiang Rai, Thailand, 2017.
145. Williams, J.M. The Hydropower Myth. *Env. Sci Pollut Res* **2020**, *27*, 12882–12888. [CrossRef]
146. Ziegler, A.D.; Fox, J.M.; Webb, E.L.; Padoch, C.; Leisz, S.J.; Cramb, R.A.; Mertz, O.; Bruun, T.B.; Vien, T.D. Recognizing Contemporary Roles of Swidden Agriculture in Transforming Landscapes of Southeast Asia: Swidden Agriculture in Southeast Asia. *Conserv. Biol.* **2011**, *25*, 846–848. [CrossRef] [PubMed]
147. Van Vliet, N.; Mertz, O.; Heinimann, A.; Langanke, T.; Pascual, U.; Schmook, B.; Adams, C.; Schmidt-Vogt, D.; Messerli, P.; Leisz, S.; et al. Trends, Drivers and Impacts of Changes in Swidden Cultivation in Tropical Forest-Agriculture Frontiers: A Global Assessment. *Glob. Environ. Chang.* **2012**, *22*, 418–429. [CrossRef]
148. Ziegler, A.D.; Borstein, D.; Yuen JiaQi, Y.J. The Viability of Swidden Agriculture and Its Uncertain Role in REDD+. In *Shifting Cultivation Policies: Balancing Environmental and Social Sustainability*; Cairns, M., Ed.; CABI: Wallingford, UK, 2017; pp. 194–206, ISBN 978-1-78639-179-7.
149. Middleton, C. The Political Ecology of Large Hydropower Dams in the Mekong Basin: A Comprehensive Review. *Water Altern.* **2022**, *15*, 251–289.