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Uncompensated losses and damaged livelihoods: Restorative and distributional injustices in Brazilian hydropower

Adam Mayer[a,*], Maria Claudia Lopez[b], Emilio F. Moran[c]

[a] Michigan State University, Center for Global Change and Earth Observations, 218 Manly Miles, East Lansing, MI, 48824, USA
[b] Michigan State University, Department of Community Sustainability, 480 Wilson Road, Room 326, East Lansing, MI, 48824, USA
[c] Michigan State University, Center for Global Change and Earth Observations, Department of Geography, Environment, and Spatial Sciences, East Lansing, MI, 48824, USA

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ABSTRACT

The construction of hydroelectric dams is associated with a range of social-ecological impacts, including significant changes in the economies of rural places where large dams are built. Dam builders and governments promoting hydropower have implemented compensation programs to redress the damages done by hydropower projects but there are critiques of whether they achieve those objectives. In the current analysis, we apply an energy justice framework to consider the impacts of the Jirau and Santo Antonio dams in the Madeira River basin of the Brazilian Amazon. Considering both distributional and restorative aspects of energy justice, we evaluate how these dams have changed economic livelihoods and household income and whether households received compensation that addressed the damages suffered. We find that displacement, resettlement or otherwise moving locations because of the dams is an important contributor to economic losses (e.g. changing jobs, lost income) and those who experienced economic losses were not more likely to be compensated than others. These losses occur in spite of the promises of dam proponents that this infrastructure will increase job opportunities, incomes and bring about economic development.

1. Introduction

Hydropower has a complex history, with dams being steadily dismantled in the global North, yet hundreds of dams are planned or under construction in the global South (Fearnside, 2006; Moran et al., 2018; Siciliano et al., 2018a; Zarfl et al., 2015). Developing nations build hydropower to provide affordable and ostensibly “clean” energy. Although hydropower may contribute to national economic development targets of nations like Brazil, China and Vietnam (among many others), it is also associated with numerous social and environmental impacts (Cernea, 2004; Gracey and Verones, 2016; Hecht et al., 2019; Lees et al., 2016; Wild et al., 2019; Doria et al., 2021)

Hydropower’s history is characterized by forced, often violent, displacement of large numbers of people and little input from populations impacted by the projects (Asiama et al., 2017; Jusi, 2006; Morvaridi, 2004; Ty et al., 2013; Virtanen, 2006). So much so that a World Commission on Dams was created to evaluate and recommend what should be done to mitigate these negative impacts. A set of recommendations (WCD 2000) was the result, but these were not implemented by the countries building the most dams (China, Brazil, India) on the grounds that abiding by these guidelines would slow their economic development. Since the publication of the World Commission on Dams (WCD 2000) guidelines, some dam builders and governments have begun to provide compensation to displaced populations (Cernea, 2004; World Commission of Dams, 2000; Scudder, 2001). However, most compensation programs are insufficient since they fall short of redressing the losses experienced by displaced populations. These compensations fail to take into consideration the loss of cultural and social resources (Cernea, 2008; Vanclay, 2017; Mayer et al., 2021a). Further, many people living near dams are not included in compensation programs even when their livelihoods are disrupted by the construction of the dam (Doria et al., 2021; Castro-Diaz et al., 2018; Manyari and de Carvalho, 2007; Adams, 1985)

Subsistence livelihoods, especially fishing, become much more challenging after a dam is completed (Arantes et al., 2022; Castro-Diaz et al., 2018; da Costa Doria et al., 2018; Doria et al., 2021). Yet we do not understand the full extent to which hydropower causes other changes in livelihoods and the consequences of those changes for household

* Corresponding author.
E-mail addresses: mayerada@msu.edu (A. Mayer), mlopez@msu.edu (M.C. Lopez), moranef@msu.edu (E.F. Moran).

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income. Further, it is unclear if compensation programs effectively redress damage to livelihoods, with many scholars critiquing compensation practices (Cernea, 2008; Mayer et al., 2021b; Vanclay, 2017), while others find that compensation may improve the lives of some displaced persons (Randell, 2016, 2017). To comprehend compensations better, some authors are calling for a multidimensional assessment both of the impacts people suffer and the compensation mechanisms people should receive (Wang et al., 2012)

The purpose of this paper is three-fold. First, we examine how livelihoods, specifically occupations, changed in the Madeira River Basin due to the constructions of the Santo Antonio and Jirau dams. Secondly, we consider how changing occupations may have impacted household income. Lastly, we ask how those who changed occupations or lost income due to the dams were compensated for their losses or not.

2. Dam impacts and changing livelihoods

In the global South, developing and middle-income nations seek to reduce their reliance on energy imports, diminished their fossil fuels usage and power their growing economies (Siciliano et al., 2018a; Winemiller et al., 2016; Zarfl et al., 2015) with the development of hydropower. In Brazil, dams have been framed by government and the media as necessary for the country (Atkins, 2017, 2019; Mayer et al., 2021a), and local populations impacted by dams are influenced by that message (Mayer et al., 2021a). Although proponents of hydropower tout it as "green" or "clean", its severe ecological impacts render these claims dubious (Doria et al., 2018; (Fearnside, 2003; Fearnside and Pueyo, 2012).

Environmental impacts include deforestation (Lim et al., 2017; Lohani et al., 2020; Pandit and Grumbine, 2012), changes in riverine ecosystems that lead to declining aquatic populations (Benchimol and Peres, 2015; Ziv et al., 2012). These changes create challenges for groups that depend upon rivers for fishing and transportation (Castro-Diaz et al., 2018; Ezcurra et al., 2019; Stevenson and Buffavand, 2018; Wiejaczka et al., 2018). The sudden in-flux of workers, most of whom are young and male, places significant stress on housing, sewage, water, and other systems in locations that are ill-equipped to handle a population increase (Cernea, 2004; Gauthier and Moran, 2018). Communities also experience negative health impacts and increased crime during dam-construction booms (Mayer et al., 2021b; GRISOTTI, 2016; Marin and da Costa Oliveira, 2016).

Displacement is another impact, with some 80 million people displaced globally in the last 100 years (Scudder, 2012). This mass movement has obvious implications for economic livelihoods—many can no longer engage in the same economic activities. Randell (2017) considered a population resettled due to Brazil's Belo Monte Dam and found that the compensated households she studied were able to transition and reproduce their desirable livelihoods and continue cattle or cocoa production on their new land. However, Calvi et al. (2020) report that the construction of the Belo Monte dam led to agricultural labor shortages and specialization in high-value commodities. Yet, Bui and Schreinemachers (2011) found remarkably different results for a compensation program in Vietnam. They note that resettled farmers had temporarily increased income due to payments, but most of this funding went toward consumption, rather than investment in productive activities. Their study implies that poorly implemented compensation programs may provide some short-term benefits but not translate into improved livelihoods in the long-term. This is true for most cases from the literature (Cernea, 2008; Scudder, 2012). Next, we relate the literature on energy justice to hydropower and compensation.

3. Energy and environmental justice

Environmental justice scholarship emerged from the community-engaged efforts of scholars working in the southern U.S. with African American populations (Bullard, 1994; Taylor, 2000). Environmental justice diversified into multiple theoretical and empirical approaches. A core observation of early environmental justice research—and much subsequent scholarship—is that social groups that are marginalized across various dimensions (e.g. low levels of formal education, low income, racial, ethnic and religious minorities) often disproportionately suffer from the damages caused by industrial activities (Crowder and Downey, 2010; Downey and Hawkins, 2008; Mohai and Saha, 2015). These unequal burdens are called *distributional* injustices.

Borrowing from the environmental justice literature, but also informed by an eclectic blend of insights, a new generation of scholars has developed an "energy justice" literature. Jenkins et al. (2016) explain that energy justice applies justice principles to energy consumption and production, regulatory structures, and related concerns. The authors explain that the energy justice framework describe where injustices emerge and processes for remediation; the framework initially included three dimensions—distributional, procedural and recognition. Then, McCauley and Heffron (2018) added restorative energy justice. Here, we focus on distributional and restorative justice. The former refers to the distribution of both positive and negative outcomes (Sovacool and Dworkin, 2014). For example, many of the benefits of hydroelectric dams (e.g. reliable and affordable energy) do not accrue to populations near the dams—instead, dams typically power far-off metropolitan areas and industrial sectors (Moran et al., 2018). This represents a distributional injustice given the enormous impacts felt by communities that are near to, hydroelectric dams which serve as an "energy sacrifice zone" for metropolitan areas (e.g. (Hernández, 2015). Restorative energy justice highlights the need to redress injustices caused by energy activities.[1] In the case of dams, researchers have noted that Environmental Impact Assessments (EIAs) and Social Impact Assessments (SIAs) should be able to stop a dam in case it will harm people or the environment (Siciliano et al., 2018b). They rarely if ever do even when the impact assessments clearly show the harms to local people.

Hydropower impacts have occasionally been framed as a justice issue, and a careful reading of the voluminous literature on hydropower reveals manifest injustices, even if scholars do not invoke a justice framework. Many authoritarian nations—or nations transitioning from authoritarianism—have implemented large-scale hydroelectric projects with little to no consultation of impacted populations, even resorting to violence to make way for development (Baldwin and Twyford, 2007; Hay et al., 2019; Scudder, 2001; Siciliano and Urban, 2017; Garcia et al., 2021). Efforts of various activist groups and NGOs have reduced some of these procedural injustices (Baldwin and Twyford, 2007; Hay et al., 2019; Scudder, 2001; Siciliano and Urban, 2017) yet hydropower projects rarely involve meaningful participation from groups that are negatively affected. Brazil is not an exception in this (Gugliano and Luiz, 2019). Communities and NGOs mobilized against the Belo Monte dam along the Xingu river for decades until, in 2011, construction began by presidential fiat (Fearnside, 2012; Hall and Branford, 2012) that ignored the cumulative evidence from the harms that would occur if it were constructed. In fact, Belo Monte was supposed to abide by Article 169 of the International Labor Organization (ILO) requiring dam builders to have consultation with traditional and indigenous populations, but in the end the consultation did not follow the requirements of the ILO article (Boanada Fuchs, 2015).

Following the WCD Report (World Commission of Dams, 2000), compensation programs became more common but still came short of what WCD recommended. The type of compensation varies, ranging

[1] Notably (Sovacool and Dworkin, 2015), locate "access to legal means to achieve redress" as a sub-component of procedural justice, rather than a standalone domain like the restorative energy justice of Heffron and McCauley (2017). Thus, there are some divergences between leading scholars on the definition of key terms. For our purposes, we lean on Heffron and McCauley's (2017), whose conceptual framework situates restorative justice as a unique facet of energy justice, rather than a variant of procedural justice.

from a combination of housing, cash payments, community infrastructure, and land. Cernea (1997) suggests that compensation should cover lost assets, lost income, and assistance with relocation and resettling. However, the majority of compensations schemes fail to redress damages. Cernea (2008) argues that "in real life … compensation reveals itself to be both impotent and misleading: it is unable to perform the restorative miracles with which it is officially and rhetorically credited" (p. 90). Cernea (2008) explains that compensation programs are often inadequate due to poor planning in the initial phases of a project. Compensation programs rarely capture losses that are difficult to monetize, such as the reduction of social capital or cultural resources (Tilt and Gerkey, 2016; Vanclay, 2017; Mayer et al., 2021a).

Millions of people are affected by dams and never compensated. This is particularly the case of communities living downstream from dams who are largely ignored on the grounds that they are not affected (Adams, 1985; Richter et al., 2010). For others, farm production will decline as agricultural workers leave farms, seeking employment at the dam (Bro et al., 2018). Host communities see changes in their well-being and they are not compensated for the decline in their quality of life (Mayer et al., 2021b). Thus, compensation programs as they currently exist generally fall short not only because they do not take into consideration all the population that is affected by dams, but also because compensation is insufficient to restore livelihoods, and well-being of the compensated population, and often do not teach people new skills needed in their new settlements. In addition of this, it is important to note that hydropower projects are often built with several explicit and implied promises to populations near the dam, such as the promise that hydropower will bring sorely needed economic development, increase income and wealth, improve infrastructure (hospitals, roads, schools, electricity access), and provide employment opportunities (Amazon Watch n.d.).

In the current analysis, we apply concepts of distributional and restorative justice to the case of the Jirau and Santo Antonio dams in the Madeira Basin in Brazil. In the next section, we describe the study region. Then, we detail the data that we use to evaluate the relationship between hydroelectric dams, changing livelihoods, loss of income, and compensation.

4. Study region

Since the 1950s, over 500 large dams have been constructed in Brazil, resulting in the flooding of at least 3.4 million hectares of land, and the displacement of over 1 million people (Zhouri and Oliveira, 2007). Brazil is perhaps the most hydropower dependent nation on earth, with some 67% of the nations' electricity provided by hydropower (da Silva et al., 2016).

Our study region, the Madeira River Basin, is home to two large dams whose construction began in 2008—Santo Antonio and Jirau— and where the construction commenced before the environmental impact assessment had been completed (Fearnside, 2014). These "run-of--the-river" dams require a smaller reservoir than conventional dams, each having an installed capacity of 3000 MW. Compared to dams constructed previously, steps were taken to ostensibly reduce environmental impacts. These include removing tree biomass before flooding the reservoir area and relocating some species (Burrier, 2016). The dams also employ fish ladders that allegedly allow for fish to maintain their migratory patterns, although their effectiveness has been challenged (Agostinho et al., 2012; Almeida et al., 2020). Some 120 km separates the two dams, with Santo Antonio located roughly 7 km from Porto Velho, the capital city of the state of Rondonia with a population of 400, 000. The small town of Mutum-Parana was completely flooded to make way for the dam, with residents resettled mostly in the communities of Nova Mutum and Vila Jirau. Fig. 1 provides a map of the location of the communities.

The dam consortia hired a consulting firm to hold meetings with communities in the region, although these efforts did not lead to meaningful engagement or input (Burrier, 2016; Gugliano and Luiz, 2019; Rodrigues Rezende, 2009). Fonseca et al. (2013) suggest that only four meetings were held in the region, and Gugliano and Luiz (2019) suggest that these meetings did not engage communities and were monitored and controlled by the dam builders—at least one meeting had armed guards present which clearly discourage those attending from expressing themselves openly. From the lens of the energy justice framework, many procedural inequalities occurred since decisions were made by authorities far removed from the host region and communities

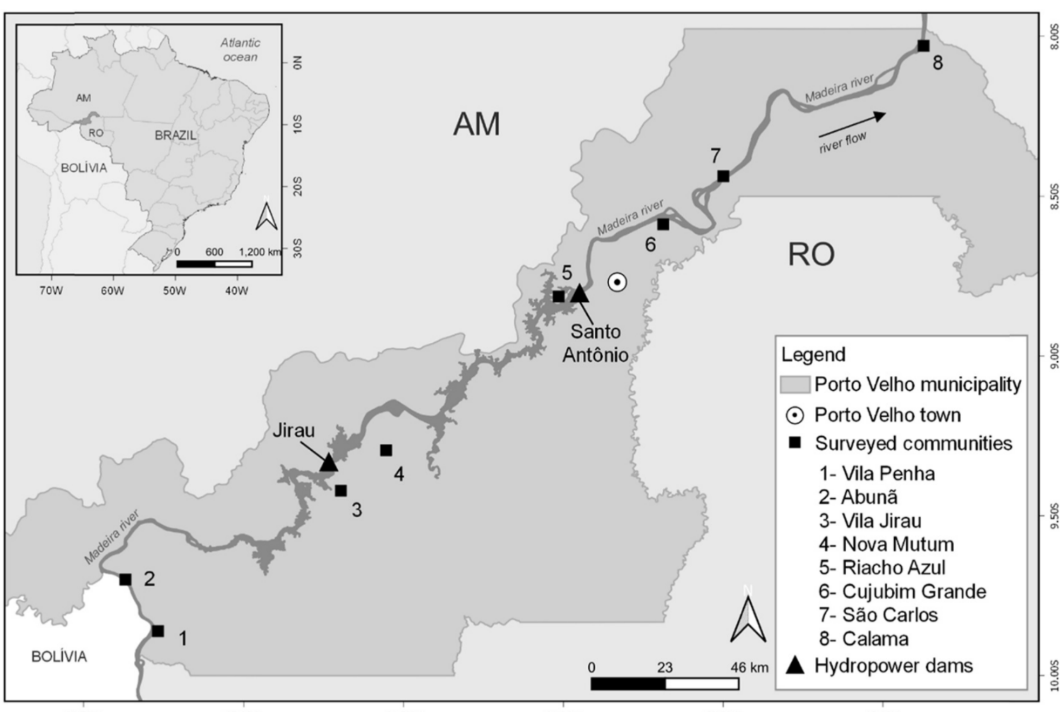

Fig. 1. Map of the study area in the state of Rondonia, Brazil. Map courtesy of Igor Johansen Cavallini.

did not have much say.

Hydroelectric dams are often promoted with many promises to provide jobs, economic development, infrastructure, and other opportunities to local communities. President Lula touted the job-creating benefits of the Jirau and Santo Antonio dams (Presidência da República/Secretaria de Imprensa, 2009) and the federal government stated that 40,000 jobs would be created in the region (Rondonia ao vivo, 2008). However, poor working conditions led the workers to strike on four different occassions. In 2011, fire destroyed workers' housing, leaving 10,000 temporarily homeless. Workers were typically confined to temporary housing, with strict schedules. Forty-one workers died during construction (Rondônia ao vivo, 2015). Thus, the direct employment opportunities provided by the dams where not nearly as attractive as promised. The dam consortia also promised to improve some infrastructure in Porto Velho such as new schools and healthcare facilities since the city was receiving new people (Prefeitura do Município de Porto Velho, 2009)

5. Data collection

The research team collected survey responses from 673 households from 8 communities (Fig. 1) near the dams using in-person interviews between August 2019 and March 2020. Interviewers were trained on the use of tablets and on standard ethical practices in survey research. The interviewers were supervised by two post-doctoral researchers who accompanied the team each day. Four two-person teams typically administered the survey in a community. One interviewer would implement the survey, while the second took notes and assisted with reducing distractions. Interviewers were provided tablets with the Qualtrics platform and all surveys were automatically geocoded. Data collected was uploaded each day at the end of the day or as soon as the team had internet access.

To develop our sampling frame, we used Google Earth satellite data and GIS software to view buildings with visible roofs. Each of the potential homes was assigned a number and we drew a random sample from these numbers, with sampling proportional to size in each community. We also randomly selected alternates if structures were not homes. Enumerators visited homes up to five times to focus on the chosen sample.

The full survey instrument had some 500 potential questions, but, due to skip patterns and nested questions, most respondents answered about 180 questions. The average completion time was 1.5 h, and 3–5% of households per community refused to complete the survey. We asked questions about socio-economics, engagement and negotiations with dam builders, and how the dams had impacted the respondent and their families. Fifty-two percent of the respondents were female head of household, averaged 48 years of age, and the most frequent level of education was primary school. In the next section, we describe the variables used in our analysis.

6. Variables

6.1. Outcomes

We use four outcome variables to capture the economic impacts of the dams. First, respondents reported whether they had to change their jobs due to the dams, with 64% of downstream respondents and 46% of upstream residents stated that the dam caused them to change jobs (see Fig. 2). Our variable for lost income was recoded to a binary variable from a variable with response categories of "unsure", "stayed the same", "decreased" or "increased". Eight percent of downstream respondents and 11.3% of upstream respondents stated that the dam had caused them to lose income. The third indicator is related to challenges that the dams had created to fishing, wherein respondents could state that the dams had increased, decreased, or had no effect on fishing-related problems (only 7 respondents indicated that no one in their households fished). Fish are the main source of protein in the region and therefore it is a common activity that dwellers in the region do, even if it is not their main economic activity. A large majority (78%) indicated that the dams had created problems for fishing. Our final indicator is whether the respondent's household received compensation, with 1.5% of downstream and 28.9% of upstream households indicating that they had received some type of compensation.[2]

6.2. Predictors

We use a binary indicator for whether the respondent indicated that their household needed to move due to the construction of the dams (0 = moved, 1 = did not move), with nearly 22% indicating that they had moved. This variable is uniquely important from the energy justice perspective—populations that were resettled, displaced, or otherwise forced out due to the dams may have experienced more severe distributional impacts (e.g. job losses) and need to be compensated to achieve restorative justice.

Our models include several variables to capture socio-economic status to understand distributional inequalities. These are a four-category measure of education (ranging from no formal education to a technical or university degree), age in years, and whether the household was headed by a female. We also captured whether the respondents' household owned land or owned a home. Education and asset ownership allow us to understand the distribution impacts of the dams—that is, was the impact of the dams based upon the socio-economic status of respondents or their households? Finally, we also use a binary indicator for the location of the respondents' community—upstream or downstream of the dams since communities living downstream from the dams tend to be overlooked by dam builders, are not compensated, but suffer a lot of negative impacts from the dam that are not usually recognized by dam builders (Adams, 1985; Richter et al., 2010). Table 1 provides descriptive statistics for these variables.

7. Models

We rely on binary logistic regression models because all our outcomes are binary. Table 2 reports odds-ratios and standard errors for these models.[3] Model 1 uses the binary indicator of economic activity change as the outcome. Our socio-economic variables—that is, female head of household, education, and land or home ownership—do not reach statistical significance. Indeed, only residence in a community upstream of the dams is statistically significant (OR = 0.496, $p = 0.000$).

Model 2 considers a loss of income and adds job loss (the outcome from the first model) as a predictor. In this model, we again find that our indicators of socio-economic status (ownership of land, housing, and female headed household) do not approach statistical significance. Yet persons who were forced to move due to the dam report a loss of income (OR = 2.144, $p < 0.05$). Model 3 uses fishing-related problems as the dependent variable. Here, we find that resettled individuals were more likely to state that they were experiencing problems with fishing (OR = 2.169*, $p < 0.05$), in addition not surprisingly, people who reported a loss of income also were more likely to report problems with fishing.

The final model (Model 4) is a binary logistic regression model for whether the household received any form of compensation. Those who

[2] Households could receive several different forms of compensations and combinations of different types of compensation. Some who were resettled were compensated with housing. Some seventy-four percent reported receiving cash, while others negotiated for boats, fishing equipment, agricultural inputs, and other types of compensation. More details about the compensation process and associated negotiations are available from the authors.

[3] We checked our models for multicollinearity using variance inflation factors, none of which exceeded 2.5, indicating that multicollinearity was not a problem in our models.

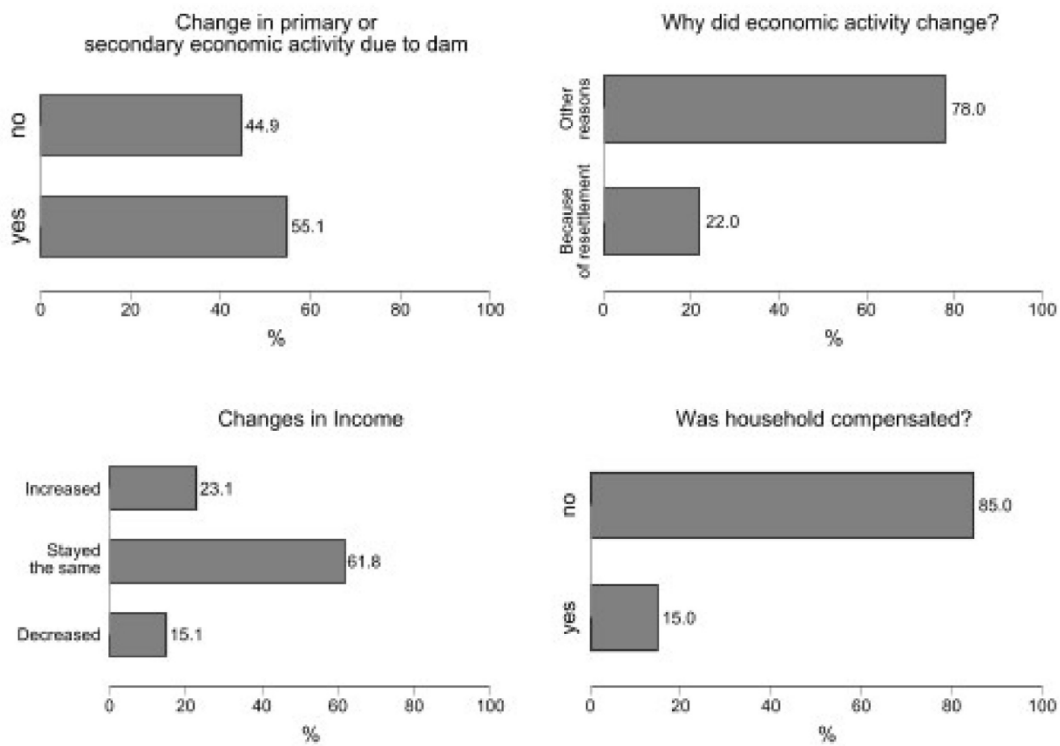

Fig. 2. Outcome Variables. Source: Survey conducted in the Madeira River Basin in 2019/2020.

Table 1
Descriptive statistics for predictor variables.

	Description	Mean	Std. Dev.
Female Head of Household	0 = male head of household, 1 = female head of household	0.293	0.455
Education			
No formal education/illiterate	0 = all others, 1 = no education or illiterate	0.119	0.324
Primary Education	0 = all others, 1 = Primary Education	0.535	0.499
Secondary Education	0 = all others, 1 = Secondary Education	0.267	0.443
Technical Degree	0 = all others, 1 = Technical Degree	0.019	0.138
University Degree	0 = all others, 1 = University Degree	0.059	0.237
Age	Respondents age in years	48.121	15.181
Upstream	0 = downstream community, 1 = upstream community	0.496	0.500
Own Land	0 = does not own land, 1 = owns land	0.141	0.348
Own Home	0 = does not own home, 1 = owns home	0.833	0.374

lived upstream of the dams were more likely to state that they had received compensation (OR = 13.015, $p < 0.001$). Resettlement was also positively associated with compensation (OR = 9.806, $p < 0.001$). However, the null effects of job changes, a loss of income, or problems with fishing suggest that many damages went uncompensated.

Logistic regression models have well-known challenges of interpretation, with many methodologists recommending the use of average marginal effects (AMEs) or predicted probabilities to make logistic regression results more intuitive. For our binary outcome variables, the AMEs can be interpreted as the change in probability of success (that is, the higher category of the binary variable).

Table 3 provides AMEs of our "moved due to dam" variable for each model in Table 2. Households that moved were not more likely to state they changed jobs (AME = 0.000), while those who moved were 6% more likely to report lost income (AME = 0.064), 12% more likely to indicate that they experienced problems with fishing (AME = 0.121) and the AME for the compensation model is 0.18—that is, those who

Table 2
Logistic regression results for job change, income loss, and compensation.

	Model 1 (Job Change)	Model 2 (Income Loss)	Model 3 (Fishing Problems)	Model 4 (Compensation)
	or(se)	or(se)	or(se)	or(se)
Female Head of House	1.272	0.915	0.759	0.862
	(0.23)	(0.29)	(0.19)	(0.3)
Education (ref. no education or illiterate)				
Primary	1.404	0.895	1.761	1.836
	(0.39)	(0.49)	(0.62)	(1.04)
Secondary	1.723	1.585	1.173	0.853
	(0.56)	(0.94)	(0.48)	(0.57)
Technical/ University	1.578	2.528	1.123	1.908
	(0.62)	(1.63)	(0.56)	(1.6)
Age	1.01	0.984	0.986	1.021
	(0.01)	(0.01)	(0.01)	(0.01)
Own Land	1.377	0.691	1.246	1.568
	(0.33)	(0.32)	(0.44)	(0.62)
Own Home	1.512	0.594	1.045	1.53
	(0.34)	(0.2)	(0.33)	(0.68)
Resettled	0.995	2.144*	2.169*	9.806***
	(0.21)	(0.72)	(0.71)	(3.32)
Upstream	0.496***	1.091	1.044	13.015***
	(0.09)	(0.36)	(0.26)	(7.28)
Job Change		0.781	0.966	0.727
		(0.22)	(0.22)	(0.23)
Income Loss			0.312***	2.534
			−0.1	(1.24)
Fishing Problems				1.396
				(0.63)

Note: *** for $p < 0.001$, ** for $p < 0.01$, * for $p < 0.05$.

Table 3
Average Marginal effects of resettlement.

Model 1(Changed job)	0.00
Model 2 (Lost Income)	0.06
Model 3 (Fishing Problems)	0.12
Model 4 (Compensation)	0.18

Note: Estimates Derived from the regression models reported in Table 2.

resettled were 17% more likely to receive compensation. We direct the reader to Appendix A for further robustness checks.

8. Discussion

Hydropower development is fraught with gross injustices across distributional, recognition, procedural and restorative justice dimensions, with many dam builders and governments implementing poorly conceived participation, distributional, and compensation schemes to address some of these injustices. In this paper, we asked how hydropower projects change livelihoods in the form of economic activities (e.g. occupations), household income, and how both are associated with receiving compensation. In this section, we discuss our findings and their implications for restorative and distributive energy justice and debates around compensation for the damages engendered by large hydropower projects.

Several of the findings displayed in Table 2, while not statistically significant, are of theoretical significance given the energy justice motivation of this analysis. We used a range of predictors to capture the socio-economic status of our respondents, very few of which are statistically significant across models. The outcomes we measure here do not seem to be determined by socio-economic status but seem to be the result of households being forced to move, displaced, or resettled in some way. There are a few possible explanations for these null findings. The households in the 8 communities we studied are generally poor and the region has a compressed income distribution with little difference in socio-economic status between households. Put another way, we do not observe a situation wherein households with higher socio-economic status are able to shield themselves from economics impacts because such higher status households are simply not present, note for example that almost 80% of the households mentioned that fishing was impacted by the dams. Distributional injustices likely occur on a regional scale, not just among groups that are directly compensated. The energy from dams goes to distant metropolitan areas and the industrial sector, with rural communities near dams accrue few benefits—this situation is a clear distributional injustice across large geographic expanses. However, within proximate communities the impacts of hydropower may be felt across the socio-economic spectrum, particularly if there is only modest variation in income, education, and asset ownership. It seems that forced migration—i.e. being, resettled, displaced or otherwise forced to move—is the primary driver of economic decline for households and this is something that occurs because of the dams construction. We also note that some residents may not lose their livelihoods, but those livelihoods may become more difficult, as is often the case with fishers who face declining yields with the larger fish declining first (Arantes et al., 2022). These fishers often go uncompensated.

Compensation programs *could* effectively redress the damages induced by energy projects. Yet restoration has rarely been achieved (Cernea, 2008; Ty et al., 2013). Only about 15% of the sample indicated that their household or community had received any compensation, despite the reality that impacts reverberated across the region. Those who had lost income were not more likely to receive compensation, and many resettled respondents were not compensated. These findings imply a lack of restorative justice in the Madeira river basin communities—severe negative consequences that do not appear to have been effectively redressed even 9 years after completion of the dams. For instance, those who reported a job loss or lost income were not more likely to be compensated. These economic losses should be the type of damages that can be more readily calculable and addressed, unlike social and cultural losses (e.g. Vanclay, 2017; Tilt and Gerkey, 2016; Mayer et al., 2021a). Many displaced families are still litigating with the dam builders, implying that restorative injustice continues.

It is well-documented that the deleterious impacts of dams are widespread, and our results corroborate this finding, as both upstream and downstream residents reported that they had lost economic livelihoods or experienced a loss of income (i.e. Fig. 2). This finding underscores the frequent observation that compensation programs are often insufficient and arbitrary as to who should be compensated (Vanclay, 2017; Castro-Diaz et al., 2018). In some instances, residents of communities near dams may retain their primary livelihood but find that it is much more difficult to sustain. This pattern has been observed with fisherfolk, who rarely quit fishing but find that fishing has become less productive, more time consuming, and generally more difficult (e.g. Castro-Diaz et al., 2018). In our data, some 79% of respondents reported that fishing had become more difficult, although fishing was only a primary livelihood for about 22% of the sample. Fish is the main source of protein in the region. Therefore, it is likely that this negative impact in fishing may have repercussions in the food security of households. In other words, the communities likely experienced economic impacts not related to their direct employment that are not fully captured here and warrant attention in further research.

The energy justice framework that motivates this paper is useful to highlight the complexity of hydropower's diffuse and long-term impacts. Conventionally, energy justice researchers, informed by the foundation of environmental justice scholarship, have linked socio-economic and demographic variables to distributional impacts. We find little evidence of this type of socio-economic distributional injustice within the communities we study because the dams have affected everyone in the region, and all the communities we worked with were poor to start with. That is, negative impacts seem to be quite broad across the study region and not necessarily concentrated among a specific group. Yet we do observe a deficit of restorative justice, where those who have experienced severe deleterious impacts from the dams are not fully compensated. and the distributional injustices likely occur on a broader geographic scale than we studied.

9. Conclusion and policy implications

Our research suggests that compensation programs are grossly insufficient, and incomes and livelihoods are rarely restored after a dam is constructed. This indicates a lack of restorative justice. Indeed, dam proponents often make substantial promises about jobs and other resources that communities will gain. To create restorative justice, we suggest that dam consortia consult with local populations and provide generous compensation, not only monetary but also in kind like training to ensure that their lives and livelihoods can be restored, and even improved. One step in that direction is to ensure that social impact assessments are carried out by independent firms, and not those beholden to the construction companies as is now the case. Another step is to ensure that both upstream and downstream communities are viewed as impacted, as we have shown they are. In addition, compensation schemes need to take into consideration the multidimensional aspects of people's lives that are affected by dams, and to provide compensation beyond housing for the resettled. Consultation is one of the weakest links in the chain of impacts, and this needs to be fortified to ensure the voices of the people affected makes a real difference in how their livelihoods are restored.

CRediT authorship contribution statement

Adam Mayer: Conceptualization, Methodology, Software, Writing – original draft. **Maria Claudia Lopez:** Conceptualization, Writing –

review & editing, Funding acquisition. **Emilio F. Moran:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. Robustness Check

In the final step of our analysis, we use the *konfound* method to understand how robust the effect of resettlement is to measurement error (Xu et al., 2019; Frank et al., 2013). Konfound estimates a percentage of cases that would have to be measured with error (i.e. misclassified) to render a statistically significant effect non-significant, and vice versa. Table 3 displays the results of this analysis. Nearly all the cases of resettlement (98%) would have to be measured with error to invalidate the null effects measured in model 1, while slightly more than half would have to misclassified to render the effect of resettlement in model 2 statistically non-significant. The konfound analysis suggests that our key results are relatively robust to measurement error.

Results of Konfound analysis	
Model 1	98.81%
Model 2	52.32%
Model 3	41.48%
Model 4	84.30%

Note: Table describes the percentage of cases for the resettlement variable that would have to be measured with error to invalidate the inference.

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