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Governing the transition to renewable energy: A review of impacts and policy issues in the small hydropower boom

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ABSTRACT

The transition to renewable energy technologies raises new and important governance questions. With small hydropower (SHP) expanding as part of renewable energy and climate mitigation strategies, this review assesses its impacts and identifies escalating policy issues. To provide a comprehensive literature review of small hydropower, we evaluated over 3600 articles and policy documents. This review identified four major concerns: (1) confusion in small hydropower definitions is convoluting scholarship and policy-making; (2) there is a lack of knowledge and acknowledgement of small hydropower's social, environmental, and cumulative impacts; (3) small hydropower's promotion as a climate mitigation strategy can negatively affect local communities, posing contradictions for climate change policy; and (4) institutional analysis is needed to facilitate renewable energy integration with existing environmental laws to ensure sustainable energy development. For readers interested in small hydropower, we clarify areas of confusion in definition and explain the corresponding impacts for distinct system designs. For a broader readership, we situate small hydropower implementation within international trends of renewable energy development – the contradictory impacts of climate change policy, emerging dynamics in energy finance, and reliance on market mechanisms. Our paper provides a timely contribution to scholarship on small hydropower and the transition to renewable energy.

1. Introduction

The worldwide transition to renewable energy technologies raises new and important governance questions. Each technology proposed within global climate change mitigation policy produces varying costs and benefits from local to international levels. Development of small hydroelectric power (hereafter referred to as SHP) is frequently mentioned and actively promoted within climate change mitigation policies and many national-level climate and renewable energy policy frameworks. Sector reviews, academic literature, and financing trends in renewable energy indicate that SHP has gained significant traction over the last ten years, and continues to gain momentum. The World Small Hydropower Report (Small Hydropower World (SHW), 2013), published under the auspices of the UN, [2] states that there is 75 GW of installed capacity of SHP globally, with an additional 173 GW of potential remaining to be developed.

Although SHP contributes less than approximately 2% of total electricity generation, these projects are established in more than 150 countries and are often concentrated in mountain regions. While SHP may support the transition from fossil fuels to more sustainable electricity systems, the prevalent assumption that SHP is an inherently low impact technology (Bakiş, 2007; Boustani, 2009; Dudhani et al., 2006; Dursun, and Gokcol, 2011; Kaldellis, 2007; Khan, 2015; Khurana and Kumar, 2011; Nautiyal et al., 2011; Ohunakin et al., 2011; SHW, 2013; Yuksel and Dorum, 2011) is informed by little systematic analysis or debate. There is, in fact, growing evidence from case studies around the world that the current explosive growth in SHP is associated with a range of negative impacts and increasing social conflict.

For example, in British Columbia, Canada, hundreds of new SHP projects are planned with little government oversight or planning, leading to "willy-nilly industrialization of the landscape" (Shaw, 2011: 753), eroding public trust in energy governance (Shaw et al., 2015), and creating major challenges for public participation and consideration of local environmental impacts (Jaccard et al., 2011). In Turkey, plans for development of SHP have provoked conflict over private appropriation of land, water and forests, as well as environmental impacts (Başkaya et al., 2011; Islar, 2012; Konak and Sungu-Eryilmaz, 2015; Kucukali, 2014). In Norway, researchers find that the social impacts on activities such as hunting and recreation, as well as the

Abbreviations: SHP, Small Hydropower; SHW, Small Hydropower World; LHP, Large Hydropower; EIA, Environmental Impact Assessment; MW, Megawatt; ROR, Run-of-river; LCOE, Levelized Cost of Electricity; IRENA, International Renewable Energy Agency; CDM, Clean Development Mechanism

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cumulative environmental impacts which harm wilderness areas, endangered species, and landscape aesthetics, are more substantial per megawatt (MW) produced by SHP than for large hydropower (LHP) (Bakken et al., 2012, 2014). In Chile, SHP projects face local opposition from municipalities, the tourism sector, and indigenous communities (Susskind et al., 2014). In India, Kumar and Katoch (2015a) document struggles of affected communities for more robust employment, community development, and compensation for negative impacts. As these examples illustrate, conflicts involving SHP go beyond water use, touching on multiple resources, and involving a variety of actors and interests at different scales.

To better understand the scope and nature of conflicts, in this paper we address the lack of systematic analysis of SHP by providing a comprehensive literature review of trends in both academic and policy literature. Our approach to the review was informed by three general questions: (1) How is SHP defined in policy and academic contexts?; (2) What are the main impacts identified in the literature?; and, (3) How is SHP addressed within climate change and energy policy, and what are the governance implications? The review focuses on key themes that are useful in understanding the balance of costs and benefits associated with this set of technologies, and their relation to governance. A full analysis of the governance of SHP requires attention to both energy aspects – including electricity markets and arrangements of public and private actors in decision-making – as well as examining interactions with institutions that govern water and land use. Approaching SHP as a question of environmental governance includes considering the work of government and third party actors to coordinate resource use, assign rights to resources and resolve conflicts, as well as shape policy and regulation.[1] As such, we highlight what is being overlooked in current debates over SHP development and suggest ways that policies could more effectively address ongoing challenges.

Following introductory sections, the paper is structured around four key problems within the existing debate on SHP. The first two problems, apparent in academic literature, are addressed in Section 4. First, SHP is defined in a variety of conflicting and often misleading ways. As a category, SHP is often defined according to generating capacity with widely varying upper limits, and a broad range of system designs are grouped together under this label. We propose that system design is a more useful criterion for understanding SHP impacts and governance implications than generating capacity. In the literature on small hydropower, the type of system design is often overlooked, presenting an obstacle for comparative study and policy-making. The second problem is further complicated by the first. The impacts of SHP are underestimated and poorly understood in the climate mitigation and renewable energy policy literatures, in particular because they are so site-specific (IPCC, 2011). To address this gap, we outline the different system designs and their influence on impacts (Sections 4.1–4.2), and the sets of impacts drawn from case studies (Sections 4.3–4.7). The interconnection of the two problems creates some overlap in the section contents.

The next two problems, addressed in Section 5, received less direct attention in the academic literature, and are more apparent in international policy debates. First, SHP project implementation demonstrates the potential for conflict between climate change adaptation and mitigation. This presents paradoxical challenges for confronting climate change, from the local to international level. Second, international support of market mechanisms as the means to encourage renewable energy development and the role of public and private actors in the governance of energy finance (Newell, 2011) is resulting in institutional confusion and incoherence. Not only may reliance on market mechanisms overlook citizen participation in decision-making, but case studies also suggest that new policies are interacting with existing environmental laws in unintended ways. For example, renewable energy goals and financial drivers can stress national environmental laws and policies.

After examining each problem, in the concluding section we focus on critical factors shaping the balance of costs and benefits, in the hopes of advancing scholarship and informing more comprehensive policy-making for small hydropower. We use the term costs to discuss social and environmental burdens, however we note that applying an economic (price) based metrics to measure impacts can oversimplify cumulative and cultural impacts.

2. Background

In industrialized countries of Europe and the U.S., as well as other countries such as South Africa, industry engineers promote a future focus of SHP development on refurbishing previously developed dam sites and retrofitting irrigation canals and urban water supply systems (Bartle, 2002; Butera and Balestra, 2015; European Small Hydropower Association, 2004; Kosnik, 2008; Kucukali, 2010; Loots et al., 2015; Paish, 2002b). In contrast, case studies and articles focused on identifying small hydropower potential suggest that in much of the developing world, growth is oriented to new ‘high head’ sites, located in mountainous regions (Al-Juboori and Guven, 2016; Boustani, 2009; Dudhani et al., 2006; Durson and Gokcol, 2011; Khurana and Kumar, 2011; Kusre et al., 2010; Larentis et al., 2010; Purohit, 2008; Rawat et al., 2013; Rojanamon et al., 2009; Sharma et al., 2013; Zarfl et al., 2015; SHW, 2013; Yi et al., 2010).[2] High head sites are those that have steep elevation gradients, or relief, and typically occur in mountainous terrain (Anderson et al., 2015; IPCC, 2011; Paish, 2002b). Without overgeneralizing these regions, we can say that the development of SHP in mountainous areas that are sensitive to climate change and rich in biodiversity and cultural importance raises a common set of issues globally.

In mountainous landscapes with less infrastructural development, the impacts of hydropower construction, particularly through habitat fragmentation, are more significant than in river basins with existing infrastructure such as dams and roads (Anderson et al., 2008; Bakken et al., 2012). These changes can provoke profound social impacts (Abbasi and Abbasi, 2011; Bakken et al., 2014; Kumar and Katoch, 2014b, 2015b; Lazzaro et al., 2013; Pinho et al., 2007; Premalatha et al., 2014). Rivers and surrounding landscapes are culturally significant in many societies, in particular for indigenous people (Durning, 1993; Toledo, 2001). Since mountainous regions are currently experiencing faster than average rising temperatures and increasing hydroclimatic variability (IPCC, 2007), promoting infrastructural development may place additional pressure (costs) on vulnerable ecosystems and the people who rely on them for their livelihoods. On the other hand, depending on how SHP is developed, it may provide benefits (low cost electricity, access roads, development programs) that support local communities and their ability to adapt to changing circumstances.

In many nation states, SHP is often misconstrued as benign, which is used to justify minimal regulation and oversight (Premalatha et al., 2014). We suggest this stems from policymakers’ lack of knowledge and acknowledgement of the impacts associated with individual projects as well as the cumulative effects of developing multiple projects in a river basin. Failure to consider the site-specific impacts of SHP projects illustrates the importance of governance arrangements, i.e. policy, regulation, and decision-making, in determining how the costs and benefits of SHP are distributed. These arrangements largely dictate how projects are planned and sited, and the role of local communities in these processes.

[1] We follow similar definitions by Bauer (2015) and Lemos and Agrawal (2006).

[2] See the Small Hydropower World (2013) for additional information on SHP potential by nation state and region.

Many studies of the economics of SHP are concerned with calculating the characteristics of plant design that will maximize return on investment (Aggidis et al., 2010; Bøckman et al., 2008; Forouzbakhsh et al., 2007; Hosseini et al., 2005; Karlis and Papadopoulos, 2000; Voros et al., 2000). The basic problem that these authors seek to address is that increasing the capacity of a plant requires a greater capital investment, which beyond a certain threshold reduces the value of a project. Therefore, these studies seek to determine the ideal characteristics of system design – including head, volume of water, and turbine type – that will minimize costs and maximize profits. As Bøckman et al. (2008) note, one source of uncertainty that these calculations face is the future price of electricity. If prices are low in the future, investing in increased capacity may not pay off. The role of hydropower in regional electricity markets can also play a role in determining future prices. They cite the example of Nordic countries where hydropower contributes over 50% to the grid – when generation is high during spring runoff, electricity prices drop. These considerations are relevant for other regions where many SHP projects are planned.

Other studies are concerned less with the details of system design and more with identifying the costs of SHP relative to other energy sources. IRENA (2012) estimates that the Levelized Cost of Electricity (LCOE) for SHP ranges between 2 and 10 US cents/Kw. Other studies summarized by IPCC (2011) show LCOE for SHP ranging between 5 and 14 US cents/Kw. One explanation for the variation and range in these calculations is that there are regional differences. In regions where the most desirable locations for hydropower have already been developed (e.g. Europe), the cost tends to be higher. In regions with less existing development, SHP is competitive with fossil fuels as well as other renewable sources (IRENA, 2012). While LCOE is a common metric for comparing the cost of different energy sources, the IPCC (2011) cautions that it can be misleading in relation to hydropower. Plants that are designed to contribute to peak supply will have a relatively high LCOE due to their low capacity factor (i.e. not generating electricity during non-peak hours). However, since electricity prices will be higher when these plants are operating, they may offset this higher cost.

Fewer studies have specifically addressed the relative cost of SHP for reducing carbon emissions. Martins et al. (2013) conclude that emissions reductions are more cost-effective for isolated projects than for those integrated into a national or regional grid. In a case study focused on Mexico, Islas Sempirio et al. (2015) show that SHP is among renewable technologies that provide net economic benefits as a mitigation measure. They calculate the cost of SHP to be −4.3 USD/Ton of CO2 reduction, second only to geothermal energy in cost-effectiveness. Large-scale hydropower, by contrast, is estimated to cost 3 USD/T CO2.

3. Methods and approach

Our paper summarizes a review of peer-reviewed journal articles and international policy documents. The first three authors have ongoing research related to SHP in Chile, Mexico, and India, respectively, which led us to comparatively study the social and physical dimensions of SHP in diverse landscapes. Using the Web of Science search engine, we identified and read 3600 journal abstracts gathered through searching for “small hydropower,” (2092) “small hydroelectric,” (500) and “run-of-the-river” (1008). Over 100 additional articles were found and reviewed through online snowball sampling. We divided the 3600 abstracts of articles among the authors and filtered them according to whether they addressed any of our three major questions.[3]

All articles of potential relevance were combined into a pool of 248 articles, which we read in their entirety. Of these, 143 addressed small hydropower, 62 small hydroelectric, and 43 run-of-the-river (ROR), with some overlap between key word searches. We further filtered this pool in order to select and cite in this paper those that appeared to be most current, highly cited, empirically informed, and substantive for comparative understanding of SHP. Three of the authors independently reviewed each of the 248 articles using these criteria to produce the final set of articles cited in this paper (138 total). Overwhelmingly, the majority of empirical articles focus on environmental impacts through a case study approach. Most are written from engineering, physical science (ecology, hydrology) or economics disciplinary perspectives. Notably, very few articles are written by social scientists. Countries with extensive documentation include India, China, Turkey, Norway, and Canada.

To date, no comprehensive literature review of small hydropower exists. Published summary articles address distinct technologies, the history of large and small hydropower, environmental impacts, and broad trends in the literature. These include Abbasi and Abbasi (2011), Anderson et al. (2015), Kaunda et al. (2012a), Kumar and Katoch, (2014a, 2014b, 2015b), and Okot (2013). None, however, provide an overview that jointly considers the different technologies, their social, environmental, and cumulative impacts, and how they are regulated in policy. By systematically examining these SHP dimensions in both academic and policy literature, our paper synthesizes the current problems regarding SHP and provides policy recommendations. For readers with an explicit interest in SHP, we attempt to clarify areas of confusion in defining SHP and explain the corresponding social and environmental impacts for distinct system designs and ancillary infrastructure. For a broader readership, we situate SHP implementation within international trends of renewable energy development – the contradictory impacts of climate change policy, emerging dynamics in energy finance, and increased reliance on market mechanisms. Overall, our paper provides a timely and unique contribution to scholarship on small hydropower and conversations on the global transition to renewable energy.[4]

Other noteworthy overview articles include the IPCC (2011) report on hydropower, which remains the prevailing go-to review on hydropower generally. Bakken et al. (2012, 2014), Premalatha et al. (2014), and Zhang et al. (2014) present assessments of SHP environmental impacts in comparison to large hydropower (LHP). Kucukali (2014) provides an informative overview of environmental risks and discussion of Environmental Impact Assessment (EIA) improvement. Many of the SHP articles do not specify design type, and many of the ROR articles do not specify installed capacity or small versus large. Without this information, it was challenging to classify or compare impacts across projects.

Our review also surveyed international policy documents and relevant nongovernmental organization publications, primarily identified through snowball sampling of online publications. We began with United Nations websites, including the United Nations Framework Convention on Climate Change, Sustainable Energy for All, and Small Hydropower World. The International Renewable Energy Agency (IRENA) provided studies on the regional development of renewable energy, as well as background on national policy frameworks and market mechanisms. In this process we reviewed the debate that began

[3] (1) How is SHP defined in policy and academic contexts?; (2) What are main impacts identified in the literature?; and, (3) How is SHP addressed within climate change and energy policy, and what are the governance implications?.

[4] "Energy transition" is a much debated concept. We follow Bridge et al. (2013: 331) in treating energy transitions as efforts to bring about "a more sustainable energy system characterized by universal access to energy services, and security and reliability of supply from efficient, low-carbon sources" while recognizing that there are many conflicting visions of how to bring about such a transition, and that, as Bridge (2011) notes, renewable energy transitions are occurring alongside transitions to unconventional fossil fuels.

Table 1
Definitions of small hydropower in international policy context.

Organization responsible	Definitions of small hydropower
Clean Development Mechanism (UNFCCC, 2004)	1–15 MW
International Renewable Energy Agency (2016)	1–10 MW
International Energy Agency (2015)	1–10 MW
World Small Hydropower Development Report (Small Hydropower World, 2013) (collaboration of UNIDOS and ICSHP)	1–10 MW

in the early 2000s surrounding the definition and treatment of small hydropower within the Clean Development Mechanism (CDM) and the European Union Emissions Trading System. We also assessed how small hydropower is conceived in relation to large hydropower by international entities such as the International Energy Agency (2012, 2015) and the International Hydropower Association (2015). We surveyed how SHP has been addressed by international and regional Nongovernmental organizations active on hydropower. The California-based organization, International Rivers, provided important publications and links to other groups.

As both the academic and policy literature reviews progressed, it became apparent that small hydropower as a category is now primarily being defined as producing one megawatt or greater. However, some papers included mini (.1–1 MW), micro (5–100 kW) and pico (< 1 kW) hydropower within the small category (Barelli et al., 2013; Paish, 2002b; Smits and Bush, 2010).[5] Because the current academic literature primarily addresses small hydropower as above 1 MW, and the system designs, impacts, and governance questions are so different for these other categories, we decided to focus the review on small hydropower projects 1 MW or greater. Although pumped storage and hydrokinetic designs are now gaining interest (see Ardizzon et al., 2014; Loots et al., 2015), we chose to focus on the three system designs of SHP projects that are most prevalent in practice and in the literature (high-head diversion, low-head diversion and dam/reservoir, see Sections 4.2 and 4.3).

Our reading was informed by scholarship on climate change and energy transitions. Critical studies of climate change point out that policies cannot be understood in merely technical terms, but must address the exercise of power and politics which shape decision-making and risk distribution (Agrawal, 2010; Forsyth, 2014; Liverman, 2009; Phillips and Newell, 2013; Tanner and Allouche, 2011). Mitigation efforts have been faulted for creating negative social outcomes, and failing to deliver on promised emissions reductions (Bumpus and Liverman, 2008; Lohmann, 2008; Lovell and Liverman, 2010). Head (2010) argues that treating adaptation and mitigation separately can lead to contradictions. In her example, urban plans that encourage greater density to reduce GHG emissions could encourage development of flood-prone areas and could undermine a city's ability to adapt to the increasing severity of floods as the climate changes. As we read the SHP literature, it became apparent that its promotion as a mitigation strategy could exacerbate vulnerability of certain communities, ecosystems, and regions (see Section 5.1).

In response to efforts to scale up renewable energy globally, researchers of energy transitions have cautioned that renewable energy adoption does not guarantee socially equitable outcomes (Bridge et al., 2013; Calvert, 2016; Stirling, 2014). The shift toward energy systems based on renewable sources such as water, wind, and solar, implies profound alterations to land use and landscapes (Bridge et al., 2013). Instead of focusing only on sustainable outcomes in ongoing energy transformations, some scholars argue that citizen participation and engagement in policy- and decision-making must also be stressed (Shaw, 2011; Stirling, 2014). This literature helped guide us in identifying the four problems (lack of clear SHP definitions, lack of acknowledgement of SHP impacts, a disconnect between global climate initiative and local impacts; and the need for analysis of the integration of environmental institutions and energy development) discussed in the paper, and in formulating policy recommendations outlined in the conclusion.

4. Trends in the academic literature

In the following section we examine: (4.1) policy definitional confusion for SHP in relation to LHP; (4.2) system design definitions; (4.3) SHP impacts by system design; (4.4) potential irreversible impacts; (4.5) cultural and livelihood impacts; (4.6) energy grid integration influence; and (4.7) cumulative impacts.

4.1. Small hydropower definitions

Overall, there is still no universal international definition for SHP, but it is generally defined by generating capacity with upper limits varying from 10 to 50 MW. Among international agencies, there is a growing consensus that SHP is defined as having a capacity between 1 and 10 MW (Table 1). Yet despite the gradual recognition of SHP as a separate subset of hydropower, definitions still vary among nation states, international agencies, and NGOs. For example, in the International Energy Agency's (IEA) "Technology Roadmap: Hydropower" (IEA, 2012), the authors do not precisely distinguish between large and small. The International Renewable Energy Agency's (IRENA) "Renewable Energy Map 2030" (IRENA, 2014b) refers to hydropower as one category; in IRENA's Latin American report (IRENA, 2015: 19) variation in SHP definitions between countries is discussed[6]; and in the recent "Roadmap for a Renewable Energy Future" (IRENA, 2016) small hydropower is defined as generating less than 10 MW. The IEA, on the other hand, cites SHP's cumulative impacts as a reason to pursue more LHP development, but does not clearly define SHP. These inconsistencies pose difficulties for policy-making and comparative scholarship.

Studies of SHP impacts indicate that the broad assumption that SHP has lower negative impacts than LHP is misleading and based on little evidence (Abbasi and Abbasi, 2011; Bakiş and Demirbaş, 2004; Bakken et al., 2012, 2015; Benejam et al., 2016; Bilotta et al., 2016; Egré and Milewski, 2002; Erdogdu, 2011; Frey and Linke, 2002; Gleick, 1992; Islar, 2012; Kaunda et al., 2012a; Kibler and Tullos, 2013; Kumar and Katoch, 2015b; Kucukali and Baris, 2009; Premalatha et al., 2014; Punys et al., 2015; Skinner and Haas, 2014). Some authors propose that the environmental impacts are greater per MW generated in SHP than LHP (Abbasi and Abbasi, 2011; Gleick, 1992; Hennig et al., 2013; Kibler and Tullos, 2013; Kumar and Katoch, 2015a; Premalatha et al., 2014). Premalatha et al. (2014) argue that SHP has been associated with "cleanness" in contrast to LHP based on no empirical evidence, a practice reminiscent of historical attitudes toward LHP.

Small hydropower has been approached differently from LHP for policy-making based on the assumption that SHP projects do not generate the impacts typically associated with large dams and reservoirs: i.e. reservoir-forced relocation. Similarly, "small" is labeled "clean" because there is usually no reservoir associated. As we outline in Section 4.2, this distinction of small versus large, and small as a cleaner technology, does not accurately describe the scale and spatial distribution of impacts among different system design types. Existing literature demonstrates that environmental impacts of SHP are highly

[5] As with "small," there are varying definitions of micro, mini and pico hydropower. For instance, Smits and Bush (2010) define pico as < 1KW, while Paish (2002a) states that mini is typically defined as < 2MW, micro as < 500KW, and pico as < 10KW.

[6] 10MW: Colombia, Panama; 20MW: Chile, Costa Rica, Peru; and 50MW: Argentina, Brazil. Argentina's definition varies provincially.

variable, locally significant, and magnified with multiple projects in a basin. Literature also indicates they are often given little consideration in river basin planning and regulation, and that land use change, cumulative impacts, and affected populations are largely overlooked.

Affected populations are defined in the IPCC (2011) chapter on hydropower as:

> Project-affected people are individuals living in the region that is impacted by a hydropower project's preparation, implementation and/or operation. These may be within the catchment, reservoir area, downstream, or in the periphery where project-associated activities occur, and also can include those living outside of the project-affected area who are economically affected by the project (467).

We add that altering landscapes imbued with cultural meaning, such as indigenous territory and conservation sites, can also affect populations who live outside the project-affected area.

Despite their differences, SHP and LHP both continue to be promoted. Many of the countries building SHP are also constructing LHP, sometimes in the same river basins. In their review of hydropower globally, Zarfl et al. (2015) write that small and medium-scale hydropower projects (1–100 MW) will constitute more than 75% of future hydropower projects. Yet, they also note that large dams (greater than 100 MW) will supply the majority of the energy production (93%). The IEA (2012) similarly suggests that LHP in developing countries will supply the bulk of hydropower energy growth. They argue that through integrated river basin management, multipurpose dams, and valuation of benefits and costs, the "sustainable development of hydropower" can be achieved (2012: 28).

In relation to large hydropower projects, the World Commission on Dams (WCD) (WCD, 2000) proposed a rights-and-risks-based framework for decision-making that is instructive for improving governance of SHP projects. The WCD advocated for moving beyond the "balance sheet" approach to decision-making that lists costs and benefits of a dam project, arguing that it was inadequate for protecting human rights. The WCD urges that human rights be respected in development decision-making, and that stakeholders be included in the decision-making process based on the potential risks generated by hydropower projects. Although the relevance of WCD recommendations for dam development has been debated (Baghel and Nüsser, 2010; Bosshard, 2010; Fujikura and Nakayama, 2009; Pittock, 2010), these recommendations offer a viable framework to improve SHP decision-making and policy.

4.2. Small hydropower system design types

While SHP is generally defined for policy purposes according to generating capacity, as a means of differentiating and understanding impacts this approach is misleading and problematic. System design is of greater relevance, according to the empirical literature. Unfortunately, there is no standard set of categories for the classification of SHP design. For example, projects may be categorized as high or low-head – a measure of the distance water drops before generating power (Kaunda et al., 2012a).[7] Or they may be classified by the amount of storage, where a project that stores little water is called "run-of-river" (or "run-of-the-river") and one with a large reservoir is called a "storage type" (Egré and Milewski, 2002). The challenge with these categories is that hydropower is an extremely site-specific technology (Frey and Linke, 2002; IEA, 2012; IPCC, 2011; Kumar and Katoch, 2015a; Paish, 2002b; Yuksel and Dorum, 2011), meaning that features such as the height of a dam or weir, storage capacity, and diversion infrastructure are unique to each project. Consequently, system designs and their social and environmental implications vary by project (Figs. 1 and 2).

Overall, SHP development impacts both water and land resources with implications for human and natural systems. Barriers across the width of a channel reduce river connectivity by physically impeding aquatic species migration and altering streamflow (Anderson et al., 2015; Csiki and Rhoads, 2010; Vannote et al., 1980). Changes in the timing and amount of streamflow alter sediment transport, river geomorphology, water temperature, nutrient cycling, and water quality, all of which can have rippling effects on aquatic species and habitat (Anderson et al., 2006; Csiki and Rhoads, 2010; Robert, 2014). Changes in land use can cause ecosystem degradation and fragmentation and negatively affect landscape aesthetics (Bakken et al., 2012; Kucukali and Baris, 2009; Gunn and Noble, 2011; Kömürcü and Akpinar, 2010; Kumar and Katoch, 2014b; Kumar and Katoch, 2015b; Pinho et al., 2007; Shaw, 2011). These alterations to the natural environment in turn generate social impacts, particularly regarding access and availability of natural resources (Baker, 2014). Based on these studies we conclude that even though hydropower system designs may be relatively "small", social outcomes and cumulative impacts of multiple SHP projects in one river basin can be severe.

The category "run-of-river," (ROR) for example, can include two very different types of projects: "high-head" and "low-head". High-head projects divert the flow of a stream into a secondary man-made channel, which may take the form of a pipe ("penstock"), canal, or tunnel excavated in the surrounding landscape (Egré and Milewski, 2002; IPCC, 2011). If the design is a high-head scheme, this diversion infrastructure generally spans at least 1 km (and often much longer) in order to create enough elevational difference between the diversion weir and the powerhouse to generate enough force with the flowing water to spin the turbine and generate electricity (Anderson et al., 2015). A low-head ROR project, by contrast, diverts a greater amount of water, but over a much shorter distance. And while SHP may be high- or low-head, a dam and reservoir storage design may also fit into the SHP category.

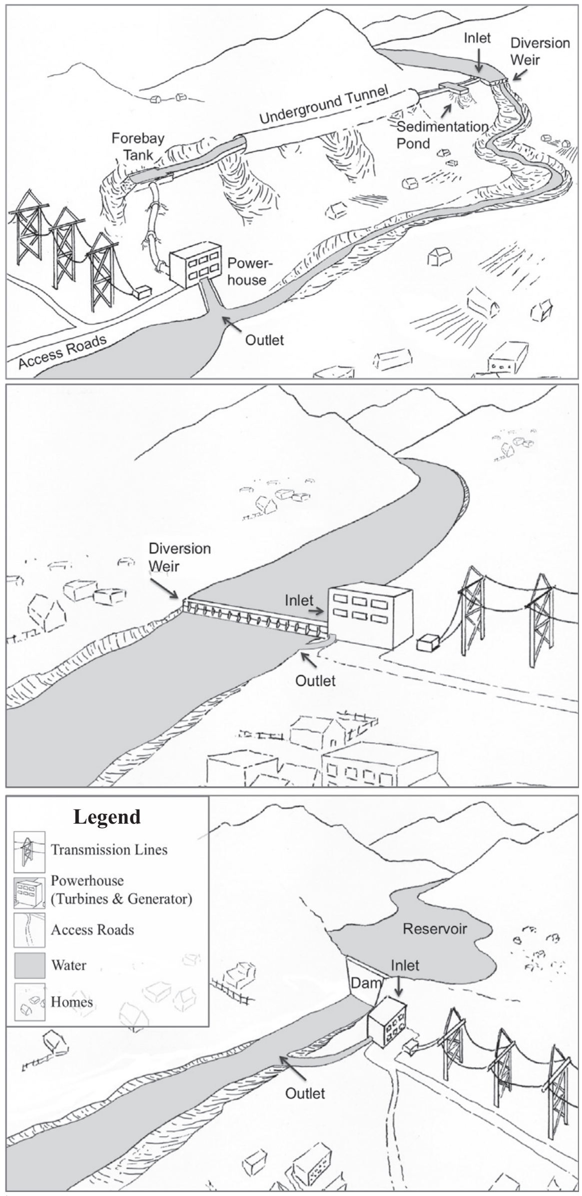
Adding to the confusion, SHP projects can fall under multiple classifications. For example, a SHP project that has an installed capacity that is defined as "small", could require a dam that exceeds the WCD (2000) definition of a "large" dam (greater than 15 m tall). In Turkey, reservoirs less than 15 km^2 are classified as "renewable". This characterization allows for large hydropower projects (installed capacity greater than 10 MW) to be classified as renewable (Baris and Kucukali, 2012; Durson and Gokcol, 2011; Erdogdu, 2011; Kucukali and Baris, 2009). And as a result, there has been an increase in LHP private investment (Baris and Kucukali, 2012).

Since SHP is treated as one category in academic and policy literature, in this paper we use the term SHP to address all of the system designs. Much of the literature does not specify system designs, so it is challenging to adopt more specific language. However, we suggest that system design is the most important variable to compare across SHP projects. Diversion – the volume of water removed from a stream and the infrastructure required to do so – is a key variable for understanding the relative impacts of each SHP project. Considering the challenge of categorizing SHP types, we propose that several key features of project design and operation should be considered in evaluating any project.[8] These include:

- Height of dam or weir,
- Length of diversion,
- Amount of water diverted relative to the streamflow,

[7] Head is measured between the inlet (headrace) and outlet (tailrace) of the hydropower project. The European Small Hydropower Association (2004) distinguishes high head as 100m or above, medium head as 30–100m, and low head as 2–30m (Kaunda et al., 2012a).

[8] Until more detailed international guidelines are developed, in light of documented SHP impacts in the literature we suggest nation-states lower SHP definitions to projects generating 1–10MW and subject projects to EIA review.



(a) High-Head Diversion

Water Availability & Quality
Change in streamflow (quantity and timing) in impacted reach (>1 km) can affect physical, chemical and biological characteristics of the st ream[1]

Stream Habitat Fragmentation
Diversion weir and impacted reach contribute to habitat fragmentation[1]

Land Habitat Fragmentation
Infrastructure and ancillary infrastructure contribute to habitat fragmentation[2]

(b) Low-Head Diversion

Water Availab ility & Quality
There may be changes in streamflow, which can affect physical, chemical and biological impacts. Minimal changes in streamflow will reduce negative impacts[1]

Stream Habitat Fragmentation
Diversion weir contributes to habitat fragmentation[1]

Land Habitat Fragmentation
Infrastructure and ancillary infrastructure contribute to habitat fragmentation[2]

(c) Dam/Reservoir

Water Availability & Quality
Dams and reservoirs affect the physical, chem ical and biological characteristics both above and below the dam[3]

Stream Habitat Fragmentation
Dam and degraded stream habitat contribute to habitat fragmentation[1,3]

Land Habitat Fragmentation
Land use changes from inundated reservoir and infrastructure a nd ancillary infrastructure contribute to habit fragmentation[3]

[1] Anderson et al., 2015; Csiki and Rhoads, 2010 ; Anderson et al., 2007
[2] Bakken et al., 2012; 2015; Ba şkaya et al., 2011
[3] WCD 2000; IPCC 2011

Fig. 1. SHP system design types.

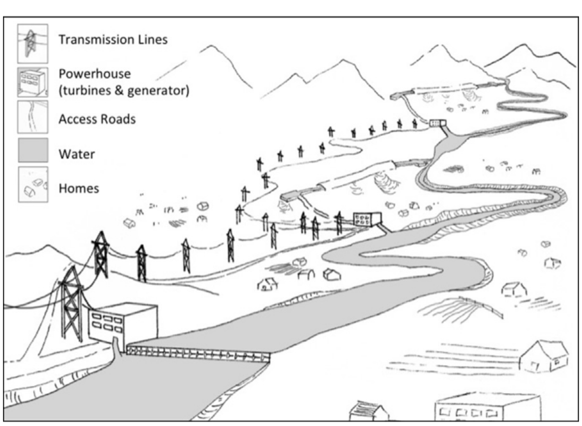


Fig. 2. Cascading SHP projects in one river basin.

- Ancillary infrastructure associated with the project, and
- Mitigation measures adopted (e.g. use of fish ladders).

Below, we discuss how these features influence the environmental and social impact of a project.

4.3. *The influence of different system designs on impacts*

The system design of SHP projects is a critical factor influencing water and land resources. Below we outline typical impacts, as described in the literature, in terms of high-head diversions, low-head diversions (which are both often termed "run-of-river" in the literature), and dam/reservoir designs (Fig. 1).

4.3.1. *High-head diversion*

Water resources impacts from SHP high-head diversion projects (Fig. 1) largely stem from changes in streamflow through the impacted river reach (from the inlet to the outlet) (Anderson et al., 2008, 2015, 2006; Erlewein, 2013; Kentel and Alp, 2013; Pang et al., 2015; Premalatha et al., 2014; SHW, 2013). Kumar and Katoch (2015b) found that SHP river diversions in India can divert the entire flow during the dry season, leaving no water in the natural channel. In the Himalayas, these SHP diversion projects have impacted irrigation, watermills, fish farming, subsistence farming, and religious ceremonies (ibid; Baker, 2014). In Canada, SHP diversion projects are competing with river flows for recreation, conservation efforts, and indigenous peoples' territorial claims (Jaccard et al., 2011). In Costa Rica, SHP diversions were found to remove 90–95% of average annual flow from the Sarapiquí River (Anderson et al., 2008). These diversions are reshaping ecosystems and fish assemblages (Anderson et al., 2006). Additional case studies examining impacts on fish and other aquatic species include Benejam et al. (2016), Bilotta et al. (2016), Kubečka et al. (1997), Larinier (2008), Shaw (2004), Wang et al. (2013), and Wu et al. (2009). Ensuring adequate streamflow in the natural channel is essential to protect river systems – especially during periods of low flow. However, maintaining environmental flows is a major challenge associated with diversion projects (Kumar and Katoch, 2015a, 2015b; Lazzaro et al., 2013) and rules have proven difficult to enforce (Başkaya et al., 2011; Islar, 2012).

In the Himalayas, the drying of natural groundwater springs has been attributed to water diversions and tunnel blasting for high-head diversion projects (Rana et al., 2007); however, hydropower companies have argued that these changes are naturally occurring (Chopra et al., 2014; Erlewein, 2013). In that region, Kumar and Katoch (2014b) suggest the relationship between ROR and groundwater should be investigated. We agree –studies of the impacts of SHP on surface water-groundwater interactions are absent in existing literature and more research is needed.

4.3.2. Low-head diversion

While low-head SHP designs exist (IPCC, 2011; Fig. 1), case studies that explicitly examine impacts are limited. If project operation does not significantly affect streamflow timing or amount, then there will likely be fewer impacts on water resources than other types of SHP designs. However, the type and distance of the diversion will be critical in assessing impacts. It is also important to note that low-head system designs will still contribute to river fragmentation and alter the physical habitat (Anderson et al., 2015). Furthermore, despite the likely less severe social and environmental impacts, aquatic species can still be significantly impacted by low-head system designs (Fievet et al., 2001; Hayes et al., 2008).

4.3.3. Dam/reservoir

Impacts from impoundments or dams, are well documented for large dams (WCD, 2000) and small non-hydroelectric dams (see Mantel and Muller, 2010), but there is a dearth of data for SHP dam/reservoir projects (Punys et al., 2015). We hypothesize that SHP dams/reservoirs, which have similar infrastructure as large dams/reservoirs (on a smaller scale; Fig. 1), will have similar water and land impacts as LHP impoundments. Since the physical infrastructure of a SHP impoundment will have comparable physical alterations to the river as a LHP project, the social and environmental issues associated with creating a reservoir and the downstream implications are expected to be similar. However, one major difference is that SHP reservoirs may be managed differently than LHP. For example, Punys et al. (2015) discusses how small reservoir water levels in Lithuania are generally consistent, so the water discharge from SHP dams do not fluctuate as much as LHP dams.

Despite differentiated impacts, our review indicates that the system design is regularly overlooked in SHP literature. For example, Bakken et al. (2012) provide a list of the most referenced environmental impacts from SHP in Norway but do not discuss the design characteristics of the 27 SHP projects included in their study (see Table 2).

Table 2
Most documented environmental impacts from 27 small (1–10 MW) hydropower plants in Norway (adapted from Bakken et al., 2012).

Type of environmental impact	Percent of cases with reported impact
Reduction in water flow	100%
Fish fauna affected by the project	78%
Areas with no prior encroachments	67%
Cultural heritage sites affected	44%
Pipelines causing landscape impacts	11%
Changed water quality	11%
Aquatic organisms affected	7%
Reduced riverine habitat for birds and fish	7%
Protected sites impacted due to landscape value	7%
Changed water temperature	7%

4.4. Construction and ancillary Infrastructure Impacts

While many hazards associated with SHP can be mitigated, poor planning, construction, operation, and maintenance can result in significant impacts (Islar, 2012; Pang et al., 2015; Zhang et al., 2014). The infrastructure needed for SHP (i.e. roads, tunnels, impoundments/weirs, power stations, transmission lines) require considerable engineering and labor (Pejovic et al., 2007). Tunnels are increasingly being used to transport water from the inlet to the turbines for diversion projects, due to significant reductions in the cost of tunneling technology (IPCC, 2011). Blasting for roads and tunnels has resulted in landslides, rockfalls, and tremors that have damaged land and homes in adjacent communities (Baker, 2014; Kentel and Alp, 2013; Kumar and Katoch, 2014b, 2015b; Sharma et al., 2007). The excavation of tunnels for diversion produces large quantities of earthen material or "muck". If this waste is disposed of within the stream channel or floodplain, it can be detrimental to water and land resources and hazardous to downstream communities, particularly during flood events (Bobat, 2013; Sharma et al., 2007; Kumar and Katoch, 2015b). In an assessment of 49 SHP diversion projects in India, Baker (2014) discovered that 40 workers were killed from work-related accidents. Several studies from India and China indicate that companies building SHP often have little experience or accountability in construction (Hennig et al., 2013; Kumar and Katoch, 2015a, 2015b). With limited oversight, workplace injuries and deaths and issues such as illegal dumping may be underreported (Baker, 2014; Kumar and Katoch, 2015b).

Bakken et al. (2012) argue that the infrastructure associated with SHP, including transmission lines, sedimentation ponds, roads, and landfills are often underreported in EIAs. This ancillary infrastructure can have major impacts. For example, Table 3 lists the impacts to local communities and environmental systems from SHP transmission lines.

Table 3
Transmission line impacts from small (1–10 MW) hydropower plants in Portugal (adapted from Pinho et al., 2007).

Impacts	Phase of project	Affected parties
Tree cutting/ deforestation	Construction	Local Community; Terrestrial Fauna & Flora
Bird collisions	Construction & operation	Terrestrial Fauna and Flora
Creation of magnetic field	Operation	Local Community; Terrestrial Fauna & Flora
Visual intrusion (aerial lines)	Operation	Local Community
Soil occupation	Operation	Local Community

4.5. Cultural and livelihoods impacts can be significant

By altering landscapes, hydropower projects have historically affected places and landscapes that have cultural and spiritual significance for indigenous communities (Trussart et al., 2002). SHP development – particularly with transmission lines and multiple projects – is similarly faulted for negatively impacting cultural landscape values (Bakken et al., 2014; Başkaya et al., 2011; Pinho et al., 2007; see Table 3). In rural regions where local populations rely on resource-based livelihoods, disturbing forests and biodiversity conservation areas can engender profound social and ecological effects at multiple scales (Abbasi and Abbasi, 2011; Baris and Kucukali, 2012; Bakken et al., 2012; Karunarathna, 2013; Kumar and Katoch, 2014b; Intergovernmental Panel on Climate Change (IPCC), 2014). Negative social outcomes include livelihood impacts on activities such as farming, hunting, fishing, and ecotourism, and effects on other social values such as indigenous autonomy, biodiversity conservation, and landscape aesthetics (Abbasi and Abbasi, 2011; Baris and Kucukali, 2012; Bakken et al., 2012, 2014; Hennig et al., 2013; Karunarathna, 2013; Kumar and Katoch, 2014b, 2015a, 2015b).[9] In Turkey, Baris and Kucukali (2012) find that SHP development on forested lands negatively affects local people's land access and livelihoods. In India, Kumar and Katoch (2015b), highlight illegal activities such as logging, dumping, and hunting activities affecting forests where SHP is developed. Destruction of natural resources in sensitive areas in such diverse settings as Turkey (Islar, 2012; Kömürcü and Akpinar, 2010), Sub-Saharan Africa (Kaunda et al., 2012b), Canada (Jaccard et al., 2011), and India (Erlewein, 2013) has incited protest against SHP development.

4.6. Energy grids and compensation influence distribution of costs and benefits

Some scholars have concluded that SHP is capable of providing social benefits under certain conditions; these benefits include job creation, extension of road networks in rural areas, low cost electricity access, economic development, and reduction of GHG emissions (Adebayo et al., 2013; Ahlborg and Sjöstedt, 2015; Baris and Kukucali, 2012; Hennig et al., 2013; Kumar and Katoch, 2014b; Tiago Filho et al., 2011). SHP has been found to be a cost-effective way to promote rural electrification (Ahlborg and Sjöstedt, 2015), and local grids are documented as offering more stable electricity prices than those of national grids that are subject to market fluctuations (Ardizzon et al., 2014; Kaunda et al., 2012b; Khan, 2015). When electricity is accessible to local populations, rural electrification can spur economic development. For example, Ahlborg and Sjöstedt (2015) discuss the benefits of SHP, including increased grain production, lower electricity prices, and job creation in Tanzania. However, agricultural activities may not be enough to justify the cost of an SHP investment, meaning that development of other industrial activities (i.e. mining) often occurs in tandem with SHP (Paish, 2002b) or electricity generated from SHP is sold to national grids.

The potential for electricity from SHP to be exported beyond where it is generated is often overlooked. Even in their critical review, Abbasi and Abbasi (2011) operate under the assumption that high-head diversion SHP development takes place in remote regions where connecting to a national grid is not feasible. This is contrary to the authors' knowledge of projects in Chile, Mexico, and India that are connected to high voltage transmission lines, which connect electricity from SHP stations to national grids. When SHP is connected to a national grid, the assumed energy benefits associated from SHP (i.e. increased energy availability and access) are not realized locally. In Veracruz, Mexico, proposed SHP installations would be connected to the national grid so the electricity generated can be used in distant sites by consumers from manufacturing, mining and other industrial sectors (Silber-Coats, 2015). Further research is needed to assess the technical, institutional, and funding arrangements that successfully provide more local benefits, particularly given hydropower's record (state and private-owned) of under-delivering on its promises of compensation to affected populations (Pittock, 2010; Skinner and Haas, 2014; WCD, 2000).

Energy transmission and distribution are critical in determining costs and benefits of energy production. It is important whether energy generated remains in a local grid or is transmitted for consumption elsewhere. IPCC (2011) lists a number of economic benefits alongside hydropower development that can be shared with local affected populations, including preferential electricity prices. Based on our reading of the literature, we suggest that there is more potential for local economic benefits with local grid connection.

Overall, the key factors influencing SHP impacts include:

- physical site characteristics and system design;
- spatial distribution of technologies in a river basin;
- energy distribution and access (high voltage transport versus local network);
- process of implementation including project consultation, planning, construction;
- risks associated with natural hazards;
- operation and maintenance (water availability and quality, environmental flows, cultural values);
- regulatory oversight and compliance; and
- integration of environmental laws and institutions with energy finance and development

4.7. Cumulative impacts of multiple projects within a River Basin

Habitat fragmentation and deterioration increase with the addition of SHP projects in the same river basin (Anderson et al., 2008; Bakken et al., 2012, 2015; Başkaya et al., 2011), which can have profound impacts on biodiversity (Kömürcü and Akpinar, 2010) and conservation efforts (Şekercioğlu et al., 2011). These are considered cumulative impacts, defined here as the combined social and environmental impacts resulting from the construction of multiple SHP projects in a given river basin (Fig. 2). Even in countries and regions where SHP projects are subject to EIA review, projects are most often approved individually, without considering cumulative effects of hydrologic or associated infrastructure and land disturbance, or regulating the distance between projects (Anderson et al., 2008; Islar, 2012; Kumar and Katoch, 2015b).

Although impacts of SHP are highly variable and further research is required, scholars suggest that cumulative effects of cascading projects (multiple projects within a river basin system) are likely greater than the sum of the impacts from each individual project (Abbasi and Abbasi, 2011; Bakken et al., 2012; Başkaya et al., 2011; Hennig et al., 2013; Kibler and Tullos, 2013; Kumar and Katoch, 2015a, 2015b; Lazzaro et al., 2013). Furthermore, Anderson et al. (2008) suggests that changes in these headwater streams can have rippling effects downstream. We hypothesize that multiple projects in a basin likely have unaccounted-for negative impacts that disproportionately affect local populations and ecosystems. As the density of SHP increases, there is a particular need to understand these cumulative impacts. In the next section, we turn to a policy discussion that brings academic and policy literature together.

5. Policy discussion: SHP in a changing biophysical, financial, and regulatory climate

As a renewable energy source and a climate mitigation strategy,

[9] Although Baris and Kucukali (2012) state that fewer jobs were created than promised.

SHP is influenced by the governance of climate, energy, and the environment at multiple scales. Newell (2011) emphasizes the role of climate and energy finance in the procedural and distributional dimensions of international energy governance. Similarly, our review found that governance greatly influences distribution of the costs and benefits of energy production, and thus social equity. The arrangements that attract capital to finance SHP projects have implications for national environmental institutions. Case studies of conflicts prompted us to focus our analysis on the environmental governance implications of energy finance at the national level.

By analyzing academic literature and international climate change and renewable energy policy, we identified two recurring problems. We begin by addressing the generally separate and parallel development of climate change mitigation and adaptation frameworks, and the implications for adaptation of promoting SHP as a climate mitigation strategy. Then we discuss the implications of the current trend toward market mechanisms in the promotion of renewable energy. International policy and financial mechanisms influence energy and environmental policy, regulation, and decision-making from national to local levels. In both instances, there are divergent or insufficiently connected policy agendas, such as national renewable energy portfolios and existing environmental laws and regulations. These problems highlight issues with the design and implementation of climate change policies, and underscore the importance of coordinated governance arrangements within the global transition to renewable energy.

5.1. Climate change paradoxes: divergent policy agendas

The challenges and questions facing small hydropower indicate profound tensions in the arenas of adaptation and mitigation that are being promoted internationally to address climate change (see Fig. 3). As Marino and Ribot (2012) argue, climate change mitigation and adaptation policies can have negative effects for vulnerable communities that are already experiencing the impacts of a changing climate. The literature reviewed here indicates this can be true for SHP, which is often promoted as a mitigation strategy. Policy proposals for transitions to low carbon sources by multilateral agencies, national governments, and others have consistently included a significant role for SHP (see, e.g., IPCC, 2011; IRENA, 2014a, 2016). While SHP in particular has rarely been addressed, this raises the concern that climate incentives will be provided for "maladaptive" hydropower projects—i.e., those that increase local or regional vulnerability (Pittock et al., 2008; Pittock, 2010).

Construction and operation of SHP infrastructure can expose rural communities to numerous hazards, thereby increasing their vulnerability to climate change. Furthermore, since many SHP projects are built in mountain ecosystems, the technologies themselves are at risk to natural hazards and variable water flows that may impact electricity-generating potential. Site geology and related hazards can pose significant risks for hydropower developers (Kucukali, 2014). Many mountainous regions are subject to seismic activity, landslides, and extreme events such as flooding (including glacial lake outbursts). These natural hazards can damage hydropower infrastructure, postponing the benefits of energy production (ibid). For example, the earthquake in April 2015 that shook Nepal damaged 16 hydropower facilities, affecting about a third of the nation's hydroelectric generating capacity (Moss et al., 2015). Moreover, replacing or repairing parts is often time consuming and expensive in remote area and can result in long delays in energy production (Taele et al., 2012).

Although more research is needed, SHP (across all system design types) may increase risks for local populations as the effects of climate change increase. For example, droughts coupled with water diversions could further exacerbate seasonal water shortages for communities and ecosystems. Diversions associated with high-head projects will particularly enhance local-level impacts associated with climate change such as increased water temperatures and reduced low flows. SHP can also diminish regulating services such as flood control. In June 2013, a devastating flood killed more than 5700 people in Uttarakhand, India. The amount and timing of precipitation was not abnormal for this region and yet, this flood was the deadliest one on record. Research suggests that the cumulative hydropower infrastructure as well as the associated deforestation and slope cutting contributed to the severity of the flood and landslides (Chopra et al., 2014; Kala, 2014). Transmission lines and road construction for SHP can lead to flooding, landslides, introduction of non-native species, and habitat fragmentation. Furthermore, damage to SHP infrastructure can put downstream communities at risk of dam or pipeline breaches.

In addition to large reservoir dams, projects with little storage (diversion and ROR) will also become less productive as precipitation becomes more intense and variable, since these projects are typically designed according to historical flow measurements rather than predictions of future conditions that take climate change into account. International Rivers (2016) argues ROR projects are more susceptible to variable rainfall. Wang et al. (2014) found projected precipitation patterns in China to adversely affect hydropower production, and Gautam et al. (2014) strongly urge decision makers to consider climate change in hydropower development as risks of hydroclimatic change are expected to increase. These contradictions suggest that promoting

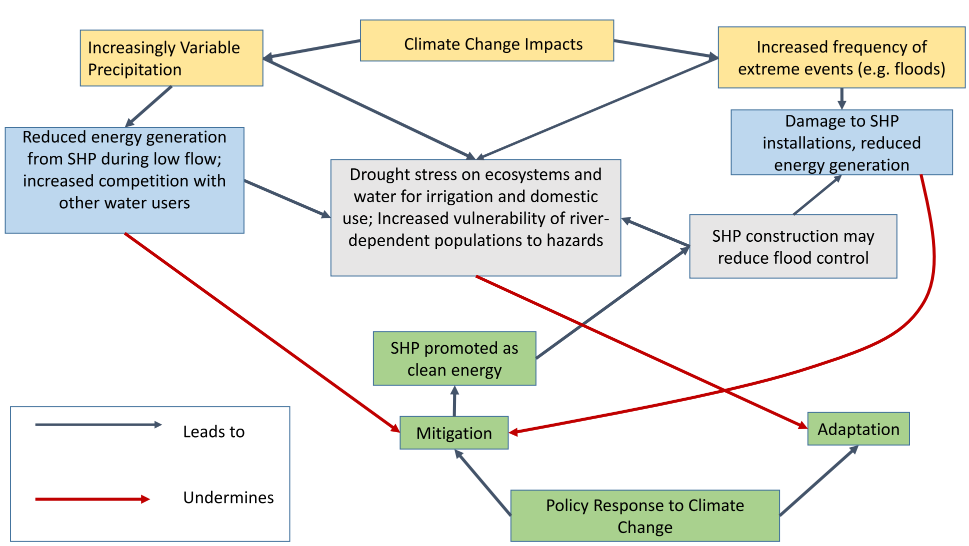


Fig. 3. SHP climate change impacts and responses.

SHP as a mitigation measure may actually increase the vulnerability of communities as well as freshwater and mountain ecosystems that are already affected by climate change. Such impacts may also reinforce unequal power relations between affected communities and power generators, distributors, and consumers. A more thorough debate of the climate-related tradeoffs of SHP is needed, and there is a particular need for consideration of the distribution of tradeoffs in the effects of mitigation and adaptation between global and local levels.

Based on our reading of the literature, we echo Pejovic et al.'s (2007) assertion that SHP design is a difficult, multifaceted task that deserves a detailed review process. We suggest that small hydropower should be subject to Environmental Impact Assessments (EIAs), or an equivalent approval process. Because SHP is a site-specific technology, policies that can account for the unique characteristics of each project while still being translatable to different contexts are urgently needed. For example, Kucukali (2014) suggests that EIA statements must be improved to address site-based impacts including biodiversity, ecological and river characteristics, riverine impacts, and the monitoring system post-implementation. A barrier to the creation of policies that will guide SHP in a more sustainable direction is the lack of a consistent definition of the technology. Furthermore, the design characteristics of each hydropower system play a major part in determining its social and environmental impacts.

5.2. Financing SHP

Along with renewable energy more broadly, trends in SHP finance are quickly changing. Finance plays a critical role in determining the distribution of energy costs, supplies, and how environmental externalities are addressed (Newell, 2011). How to govern energy finance poses a complex problem because private and public finance for energy projects are shaped by different relationships to private and public institutions at multiple scales (ibid). International capital flows, efforts to steer investment, and calculations of investment risk are crucial in determining which renewable energy projects get built, when, and where. In this section, we present new trends in energy (also defined as climate or green) finance, discuss the role of market mechanisms in SHP growth, and argue that the combination of market-based policy and current approaches to finance do not adequately address the environmental and human rights concerns associated with SHP development.[10]

The Clean Development Mechanism (CDM) is the most well-established channel for "climate finance" investment in hydropower.[11] Hydropower is the single largest source of emissions credits in the CDM, and SHP makes up a significant portion of those. As of February 2016 there are 2229 hydropower projects in the pipeline or developed (UNEP DTU, 2016).[12] Martins et al. (2013) suggest that the CDM structure is more favorable to LHP than SHP. However, the European Union makes it easier to develop SHP by exempting it from stringent WCD criteria that are required for hydropower projects over 20 MW (Haya and Parekh, 2011). Much of the debate about hydropower in the CDM has focused on large dams, including the question of "additionality" – whether they would have been completed anyway without CDM funds – and issues of human rights abuses (see Carbon Market Watch, 2012; Finley-Brook and Thompson, 2011; Haya, 2007; Haya and Parekh, 2011).

[10] Examining hydropower, Klimpt et al. (2002) foresaw that restructuring of electricity laws toward market-based arrangements would override national environmental frameworks. Following the rise of neoliberalism, markets are often the main regulating mechanism for natural resources.

[11] See Bøckman et al. (2008) for an overview on investment timing and SHP capacity decision-making.

[12] The official account is divided into 1610- 'run of the river'; 105 -'existing dams'; 4-'higher efficiency hydro', and 507-'new dams.' Erlewein (2014) found that out of 1454 hydropower projects, 781 were classified as small (under 15MW).

While CDM is the most discussed climate finance institution in the literature for hydropower, a number of emerging initiatives have the potential to greatly expand investment in SHP. A fast-growing source of capital for new hydropower projects comes in the form of private "green" investment. Many institutional investors (such as pension funds and insurance companies) are searching for "climate-friendly" investment opportunities with a long-term stable rate of return, which include a variety of infrastructure projects (Kaminker and Stewart, 2012). One way this is achieved is through so-called "green bonds," which are simply loans with a fixed interest rate that are paid off over a set period of time. Initially developed by the World Bank in 2007, green bonds issued by private corporations have recently taken off with the total value approaching $20 billion in 2014 (IHA, 2015).

However, there is no universal standard for what constitutes a "green" investment, and many issuers of these bonds explicitly exclude LHP but include SHP (ibid). As these funds develop new financial instruments such as "asset-backed securities" that aggregate investments in multiple small-scale projects (Kaminker and Stewart, 2012), they can potentially provide a major pool of capital for the development of SHP. Yet investment in hydropower is subject to financial risks that can deter investors. In this new financial landscape, International Financial Institutions like the World Bank have shifted to providing financial products to hedge these risks, such as "political risk insurance," while the main financial backing is increasingly provided by private equity firms (Merme et al., 2014). Smaller projects may be seen as less risky and more attractive to private investors, due to their shorter timeframe and presumed lower likelihood of facing social resistance – which, as we have suggested above, is not necessarily a valid assumption.

The movement from primarily public funding to significant private sector investment in hydropower over the last 25 years is an important trend (Oud, 2002, 1217). More than simply complementing public funds with private investment, this reflects a trend of "marketization," that is, the "restructuring of the state…as markets and market forces transform state enterprises, agencies and services" (Birch and Siemiatycki, 2016: 178). In the case of SHP, the interactions of state and market take a number of different forms that require empirical study.

Generally speaking, it is the combination of national-level market-based reforms and financial drivers that make SHP's rapid development possible. Reforms are encouraged by international intergovernmental agencies' efforts to stimulate renewable energy development. The recently created UN initiative, "Sustainable Energy for All," calls for private sector participation and advocates market-based mechanisms including feed-in tariffs and auctions (defined below). The International Renewable Energy Agency (IRENA) (2014a, 2014b, 2015), an intergovernmental agency established in 2009, also advocates market-based reforms.

The structure of the hydropower industry has changed significantly since the 1990s with the shift to private investment (Moore et al., 2010). In order to be financially viable and attract investors, SHP – like other renewable energy sources – requires government intervention to establish special tariff incentives (Meier et al., 2011). This is particularly so with SHP because of the up-front capital investment required (SHW, 2013). Incentives can take a number of forms, with the most common internationally being the "feed-in tariff" (i.e. a fixed, higher price for energy from renewable sources). In Latin America, however, other mechanisms such as auctions and certificates have been favored (IRENA, 2015). In an auction, project developers bid on a long term contract (a Power Purchase Agreement, or PPA) that fixes the price of electricity. Certificate systems resemble carbon offsets – generators, utilities and consumers are required to subsidize renewable sources by purchasing credits. In addition to these regulatory instruments, publicizing long-term plans for infrastructure development and renewable energy targets play an important role in attracting investors, because they reduce credit risk by signaling a favorable institutional context (ibid). The primary purpose of these mechanisms is to attract institutional investors by creating the conditions for stable cash flows rather than to increase competition within the electricity market. In some cases, uncertainty about implementation of these policies has been shown to delay investment in SHP as investors anticipate higher profits once incentives are in place (Heggedal et al., 2014; Linnerud and Holden, 2015).

It is important to note that these incentives and market mechanisms interact with public planning and financial institutions at the national level. While multi-lateral development banks no longer occupy a central position in hydropower finance, national level development banks still play an important role in directing infrastructure investments, despite liberalizing reforms (Hermann, 2010). Rather than suggesting that either state planning, international institutions, or private investment is the main driver of interest in SHP, we suggest that the relationship between these forces, and their impact on decision-making for SHP, is an area that requires further investigation in specific cases.

National and sub-national energy governance also influence the viability of market mechanisms in transitioning to renewable energy (Phillips and Newell, 2013). Creation of incentives for SHP and other renewables can coincide with broader efforts to restructure energy sectors, as in the case of Turkey where reforms in the early 2000s promoted privatization and liberalization (Baris and Kucukali, 2012). In this case, feed-in tariffs for SHP were combined with exemptions from certain licensing requirements and laws that facilitate private appropriation of land, water, and forests needed for development (ibid; Islar, 2012). Chile, which restructured its energy sector according to free market principles in the 1980s, is now credited with achieving rapid renewable energy development without financial subsidies (Sanders and Dezem, 2016). However, enduring and increasingly intertwined water and energy conflicts pose major governance challenges (Bauer, 2009, 2015; Prieto and Bauer, 2012), particularly with an EIA process which supports market functioning and fails to diminish conflicts (Tecklin et al., 2011). On the other hand, multiple authors report administrative delays due to confusing or overlapping regulations among administrative agencies (Kaldellis, 2007; Panić et al., 2013). These examples highlight the implications of energy governance for control of and access to water and other resources, and the potential for SHP development to facilitate the seizure of resources by powerful actors (Islar, 2012).

The fast-changing financial environment for SHP, and energy governance in general (Newell, 2011), raises a number of issues. Scholars working with the concept of *financialization* point to some of the relevant concerns here. First, investment in infrastructure projects such as SHP installations can be a way for financial institutions to secure steady rates of return on investment that fuel high-risk ventures in other sectors (Leyshon and Thrift, 2007). The insertion of SHP investments into complicated financial instruments further raises the possibility that investors may be able to derive profits from speculation in hydropower that do not actually contribute to electricity generation (Ahlers et al., 2015; Loftus and March, 2015). Although questions remain regarding SHP's economic future, the increasing prevalence of market-based mechanisms and financial actors suggest decisions are being reduced to economic calculations. While the consideration of risk is inherent to this approach, it is generally a limited and financialized notion of risks that overlooks the potentially uneven social distribution of known environmental risks such as greater exposure to hazards like floods and earthquakes (see, Kucukali, 2014) among affected populations. Alternatively, investment risk may also deter the development of new technologies and smaller-scale projects, capable of generating fewer impacts. Policy makers must find ways to balance the need to attract investment with institutional arrangements that are able to address such issues.

6. Conclusions and policy implications

Debates over small hydropower (SHP) have to date neglected important governance considerations. This is due in large part to the unwarranted assumption that SHP is a lower impact or innocuous technology. This review suggests that much greater consideration of impacts and policy frameworks is merited, and in particular we recommend that policy-makers and researchers address the four problems highlighted in this paper. First, the confusion in SHP definitions (both in terms of system design and installed capacity) are convoluting SHP debates, preventing comparative studies and preventing a more comprehensive understanding of SHP impacts. This complication is compounded by the second problem; that there is a lack of knowledge and acknowledgement of SHP's social, environmental, and cumulative impacts. Third, SHP can profoundly affect local communities, creating tradeoffs between GHG mitigation at the national level and adaptation at the local level. In particular, developing SHP projects in sensitive mountainous areas with biodiversity and cultural importance can hinder adaptation and increase vulnerability. Finally, the introduction of market-based renewable energy policies and related financial actors does not often include the institutional planning needed to facilitate integration with existing environmental laws, or more broadly to ensure sustainable energy development.

Our review establishes further research is needed, particularly from the social sciences, interdisciplinary research teams, and policy studies. We have suggested that both policy-makers and scholars should more carefully consider SHP system designs, and that extent of diversion is a key variable in system design. In particular, there is need for deeper qualitative understanding of SHP impacts in diverse contexts. River diversions for hydropower have a different set of impacts than large dams, and identifying who the relevant stakeholders are may not be as straightforward. While it may be obvious that villagers in the flooded area behind a dam are stakeholders, the severity and extent of the effects of changing natural flow regimes (quantity and timing) from diversions are still poorly understood and identifying impacted stakeholders may be more difficult. As the literature indicates, the potential impacts on groundwater, as well as cumulative impacts in a river basin may have broader implications for water availability, ecosystem integrity, and human populations beyond the area immediately impacted by project construction. In addition to further study of these issues, there is a need for policies that account for these risks, identify the stakeholders, and allow for meaningful participation in decision-making and access to the benefits that SHP can provide.

This review leads us to conclude that calls to rapidly scale up SHP development tend to skirt the important questions of governance that should be raised during this process, such as the right of affected populations to be at the table during decision-making at stages when they can influence project outcomes (WCD, 2000). The viability of the set of system designs grouped under the heading of SHP greatly depends on governance arrangements, i.e., policy, regulation and processes of decision-making. Greater attention to questions of governance – on the part of both scholars and policy-makers – is needed. To critically assess the uneven distribution of risks and burdens that SHP creates is not to argue against the use of this technology, much less in favor of large dams or fossil fuels as an alternative. However, at the local level, the balance of benefits and burdens from SHP often appears to be negative particularly with regard to rural populations who are already vulnerable to climate change. This suggests the need for standards and policy measures to establish greater local-level safeguards and compensation measures.

Given the issues raised in this review, we recommend two policy steps to improve small hydropower development. First, that an international standard be created to facilitate lower impact SHP development. Global standards for renewable energy should seek to integrate the mitigation and adaptation sides of climate change policy. Without the expectation that the intensive World Commissions on

Dams (WCD) process be replicated for SHP, we suggest the use of the WCD key elements that ensured rigor and legitimacy for that process; the attention to balancing stakeholder participation and the emphasis on developing an empirical basis of impacts through a two-level procedure (a broad comparative assessment of multiple projects in different geographic areas, and in-depth independent case study assessments of a few prominent cases). Second, until more detailed international guidelines are developed, we suggest that nation-states lower SHP definitions to projects generating 1–10 MW; conduct case by case analysis of projects via Environmental Impact Assessments; and connect project-based assessments to river basin-wide planning to coordinate multiple water uses and assess cumulative impacts. Within this analysis, it is critical that the fit of system design be assessed in relation to site (location) characteristics, and that alternative locations are assessed. Without these steps, the current trajectory of SHP expansion and climate policy incoherence leads us to conclude that social conflicts and negative impacts will proliferate at a startling rate.

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