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Regulating the water-energy-food nexus: Interdependencies, transaction costs and procedural justice

Shaun Larcom, Terry van Gevelt*

Department of Land Economy, University of Cambridge, UK

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ABSTRACT

There have been calls for an overhaul of regulatory and governance frameworks to incorporate the implications of the water-energy-food nexus. We map one small component of the regulatory space of the nexus and highlight its immense complexity. We draw on insights from the economics and socio-legal literatures to show that a decentralised approach to regulation based upon procedural justice can enable the trade-offs of the nexus to be considered and addressed. We use a nexus case study of micro hydro-electricity generation in Dartmoor National Park in England to show that when we take into account interactions between state and non-state regulation, the economic concepts of interdependencies and transaction costs, and a recognition that regulation of the nexus is a process involving decisions of procedural justice, some existing regulatory frameworks are already well-equipped to deal with the implications of nexus analysis.

1. Introduction

From the water-energy-food nexus' very early days some have argued that the adoption of nexus analysis by policy makers will require new regulatory and governance frameworks (Hoff, 2011). For instance, Sharmina et al. (2016: 81) call for 'a radical overhaul of the current system of policy- and decision-making' to avoid the current practice of compartmentalised government policy and regulation (see also Leck, 2015). While the form of the 'radical overhaul' called for is not always spelled out, there is an implicit (and sometimes explicit) expectation that current regulatory frameworks should be replaced by centralised and technocratic decision making processes that aim to draw on objective science (e.g. Bazilian et al., 2011; Cairns and Krzywoszynska, 2016).

This paper provides a framework for thinking about how to regulate the nexus and how to map the regulatory space of the nexus. We conclude that while regulators have much to learn from nexus analysis, in particular the identification and quantification of interconnections and interdependencies, the nexus does not require a radical overhaul of regulatory and governance frameworks as some have suggested. Using micro hydro-electricity generation on farmland in Dartmoor National Park in England as a case study, we show that a regulatory framework built around the principle of procedural justice and that recognises the concepts of interdependence and transaction costs has the ability to generate efficient outcomes and consider trade-offs among the sectors of the nexus.

1.1. Regulation and its sources

In order to understand how to regulate the nexus, it is important to consider what regulations are and where they come from. At their most simple, regulations are constraints on behaviour. These constraints consist of rules that often carry sanctions for non-compliance.[1] These rules can prohibit certain actions (such as the dumping of animal waste in waterways) or impose imperatives that require certain actions to be done (e.g. requiring that planning permission is obtained before building a hydro-electric power plant on your farm).[2]

The state is the most obvious source of regulation. It generates regulation in almost every sphere of life; including the use and production of water, energy, and food. In many societies, there are multiple tiers of state regulation, including at the national/federal,

* Corresponding author at: 19 Silver Street, Cambridge CB3 9EP, UK.
E-mail address: tav22@cam.ac.uk (T. van Gevelt).

[1] North (1990: 3) defines institutions as the 'rules of the game in a society', or 'constraints that shape human interaction'. North sees institutions (or regulation) as structuring the incentives associated with human exchange, whether it is political, social, economic, or environmental.

[2] In addition to regulation (that constrains behaviour) there are also governance tools that aim to provide rewards/incentives to encourage certain behaviour. In terms of the case study presented below, the most prominent would be agricultural and renewable energy subsidies. This study focuses solely on the regulatory aspects of the nexus.

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province/state, and local/council levels. In addition, there are many international agreements and treaties that regulate the consumption and production of water, energy, and food that are normally enforced by nation states.

However, the state is not the only source of regulation. Ostrom (1990) famously highlighted how non-state organisations (with varying degrees of formality) regulate natural resources in a variety of situations and societies. Ellickson (1994) has shown how the cattle ranchers in California largely govern themselves using informal rules (or social norms) that have been developed and are enforced without the state or any other centralised authority. Social norms can be enforced by other members of society who adhere to the same norms; for instance, when a litterer or queue jumper is rebuked by a member of society when a norm is broken. However, many norms (and laws) are internalised by individuals. In these instances, once a rule is internalised a psychological penalty (e.g. guilt, shame) can apply to the act, which can regulate the behaviour in question (Cooter, 1998; McAdams and Rasmusen, 2007). In addition to social norms, any individual that belongs to an organisation, whether it be a farm, family, company, religious group, club, university will be regulated by them. While many of these may have little impact on water, energy, or food – many do. For instance, some firms adhere to sustainability principles that generate prohibitions and imperatives at the workplace in terms of energy use, recycling, and waste disposal that go beyond state regulation (Karassin and Bar-Haim, 2016). Many religious groups impose imperatives and prohibitions that influence the consumption and production of food (McCullough and Carter, 2013).[3]

In terms of how state and non-state regulations interact, they may substitute or complement one another, or even generate dissonance effects. In terms of complementarity, non-state regulations may be in force in addition to state regulations.[4] In other cases, there may be no social regulation attached to a certain activity, as it may be deemed to be morally neutral in a given community, whereas such behaviour may be prohibited under the state regulatory framework.[5] The reverse can also be the case, where a given behaviour is deemed to be wrong under the prevailing social norms of a given community but state regulations may not prohibit it.[6] Indeed, there may even be cases where state and non-state regulations push people in opposite directions, generating legal or regulatory dissonance (Larcom, 2015).

There are many sources and forms of regulation and this can result in a multi-layered regulatory environment for even the simplest of activities. However, acknowledging this complexity is necessary; otherwise a distorted or incomplete picture of the regulatory environment will be generated. Combining this regulatory complexity with the complexity of the nexus, which explicitly aims to examine cross-sectoral interdependencies and complexities itself, is a formidable task. Fig. 1[7] provides a skeletal framework for mapping the regulatory framework of the nexus. The-left-hand-side lists the different sources of regulation, broadly categorised into state and non-state regulation. The right-hand-side lists the main components of each of the sectors of the nexus. As can be seen, there are 6 broad sources of regulation and 45 broad components within the three nexus sectors, of water, energy and food. While it will depend on the number of sources of regulation and number of regulations from each source for each specific component of the nexus, it can be seen that understanding the regulatory environment of the nexus is a complex task. Indeed, if each of the 6 sources of regulation had 10 individual regulations for each of the 45 broad components (a very conservative estimate), there would be 2700 individual regulations to consider. This demonstrates that regulation of the nexus is an incredibly complex task, and increases the complexity of nexus analysis by many magnitudes.

1.2. Procedural justice, interdependencies, and transaction costs

As Fig. 1 suggests, even for one component of one of the sectors of the nexus there are a multitude of regulations from multiple sources, and many of these regulations and their sources are place and activity specific. This raises an important question in terms of the nexus: how can we map and design a regulatory framework to account for all of the interactions and interdependencies of the nexus? The complexity of regulation surrounding each component of the nexus combined with the complexity of the nexus itself would seem to make it a formidable task. Despite the complexity involved, we argue that policymakers and regulators already have the tools at their disposal to account for the interdependencies and complexities that are highlighted by the nexus. In particular, we argue that a regulatory framework built around the principle of procedural justice and that recognises the economic concepts of interdependencies and transaction costs has the ability to generate outcomes that allocate resources in a broadly efficient manner, and that enables the various trade-offs among the sectors of the nexus to be considered. Before embarking on our analysis, we briefly define each of these three concepts and their relevance to nexus analysis in order to make them readily identifiable when we present our case study.

At its most basic, procedural justice is a decision making process that is recognised as being fair, where stakeholders can participate in the process and where their values and preferences are recognised (Schlosberg, 2009; Wood et al., 2016).[8] As the outcomes are likely to be more favourable to those who are afforded participatory opportunities, if a broad spectrum of stakeholders is able to meaningfully participate in the process and have their values and preferences accounted for, procedural justice has the ability to provide a path towards distributive justice and efficient resource allocation.[9]

The concept of interdependence refers to a situation where the choices of one agent influence the choices of another. Interdependence leads to conflict when the choices of agents are incompatible. By implication, resolving these conflicts necessitates making a choice over which agent's or agents' interests are prioritised and to what extent (Bromley, 1991; Adger et al., 2003).

[3] There is a vast literature on environmental regulation more generally and the factors that affect real world behaviour. For an overview for instance see Percival et al. (2013).

[4] For example, farmers who are known to dump animal slurry in waterways may be ostracised within farming communities and also face state regulations and penalties.

[5] One such example is that farming communities may be indifferent to tree clearing to increase beef production, whereas strict state regulations may apply (Seabrook et al., 2008).

[6] For example, in some communities those who build and operate wind turbines may face social sanctions due to concerns over loss of visual amenity, whereas they may be free to do so under the state legislative framework.

[7] Nexus relevant components of each of the nexus sectors is drawn from Bazilian et al. (2011) and adapted by the authors. Note that this relates to direct regulation and components, and does not include the effect of regulation on indirect drivers of nexus resource use, including demographics, economic growth, and science and technology.

[8] There are multiple models, ideas and definitions of procedural justice (e.g. see Rawls, 1999).

[9] Distributive justice helps understand which agent's interests will be affected and how they will be affected by establishing, changing or reaffirming regulation. Procedural justice, with its focus on understanding which agents are able to participate in the regulatory design process and the balance of power between agents and regulators, can help justify decisions that may be difficult to achieve from a purely distributive justice point of view (Paavola and Adger, 2005 and Sagoff, 2008).

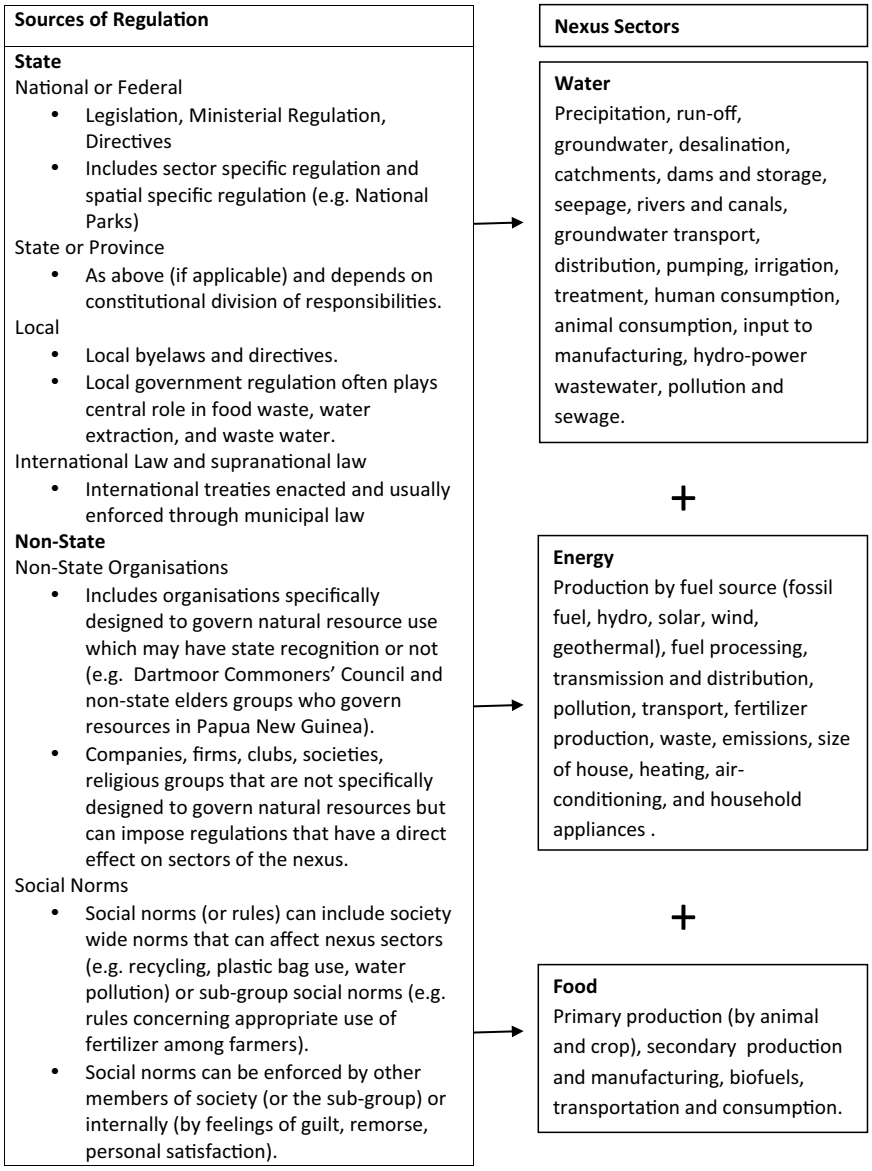

Fig. 1. Regulating the Nexus.

Source: adapted from Bazilian et al. (2011).

Depending on the particular situation of interdependence, which is largely a function of agent attributes, these choices are often codified as regulations. Regulation can therefore be seen to generate both winners and losers in situations of interdependence. The concept of interdependence is important in understanding the regulation of the nexus for two main reasons. Firstly, interdependence reasoning can suggest the scales at which regulations should be enacted. For example, for complex interdependence situations that span multiple sectors – such as the nexus – it is likely that regulation operating at different scales and enacted by different regulators will be required. Secondly, an understanding of the concept helps us to see regulation as a form of conflict resolution. This brings to the fore the subjective nature of regulation and the centrality of procedural justice in nexus regulatory decisions (Paavola and Adger, 2005; Paavola, 2007).

In regulatory terms we can think of transaction costs as the cost associated with collecting information necessary to inform, formulate, monitor, co-ordinate, and enforce regulations (Eggertson, 1990). The existence of transaction costs means that no regulation or regulatory environment can be perfectly designed (Williamson, 2009). Acknowledging the existence of transaction costs also means that sometimes it is optimal for an interdependence not to be corrected for – where the transaction costs outweigh the benefits that could be generated by regulation. It also means that it may be optimal for regulators with different regulatory objectives, for example, those concerned with different sectors of the nexus, not to perfectly co-ordinate their regulatory activities. This is particularly relevant for the nexus, as regulation covering multiple sectors and geographical scales is likely to require the convening of a number of sources of regulation operating at different scales thereby increasing transaction costs. The extent to which transaction costs will impact on regulator co-ordination will depend upon regulator attributes (including expertise and capacity) as well as the resources in question (including the degree of complexity). Taken together, including transaction costs in the analysis of regulation may alter the calculus and show that a regulatory situation that appears sub-

optimal from a modelling perspective can be optimal in reality (Paavola and Adger, 2005).

2. Materials and methods

In order to provide some concreteness toward mapping and better understanding the regulatory environment of the nexus, we drill down into the regulations for one of the 45 components of the nexus listed above and focus on a given location: micro hydro-electricity[10] in Dartmoor, England.[11] Micro hydro is seen as a key contributor to national renewable energy policy by the Environment Agency (Environment Agency, 2010). Broadly speaking, micro hydro is seen as the most benign of small-scale renewable solutions but its operation can have a number of impacts on water and food systems. For example, water is abstracted and diverted through a turbine resulting in temporary depletion of the water source. Some turbines may also alter water quality through aerating the water. Construction of weirs may change water levels and affect aquatic ecology dynamics. Resultant changes in water flows can also alter the risk of flooding with possible implications for agricultural production. Lastly, protected migratory fish species (e.g. salmon) may swim into the turbines or get caught in the tailrace (Devon Association for Renewable Energy, 2004).

We employ a regulatory mapping approach to provide concrete details of the incentive structure and constraints that agents face (e.g. Ostrom, 1990). We undertook our regulatory mapping in two stages. First, we searched to identify regulations at different geographic scales and from different sources. This involved a search of legislation directly relevant to the nexus at the national level and various levels of local government. We also searched for sources of non-state regulation within the study site. In undertaking the mapping exercise, we drew upon the relevant academic literature to augment and cross-check our search findings. Secondly, we analysed the official planning documents held by the Dartmoor National Park Authority concerning the establishment of a small micro hydro-electricity plant on the River Walkham at Huckworthy Mill. This in-depth analysis allowed for the regulatory process associated with micro hydro-electricity generation in Dartmoor National Park to be understood.

2.1. Study site

Dartmoor consists of approximately 1000 square kilometres of moorland in southern Devon, England. Much of Dartmoor is a national park, and land use of the national park is as follows: moorland grazing (47%), farmland (38%), woodlands (11%), reservoirs (1%), human settlement/other (3%). In addition, 38% of the national park is common land (see Fig. 2). The land within national parks in England is not owned by the state. Within the national park there are many private landowners, including the Duchy of Cornwall (a private estate established in 1337 that belongs to the Prince of Wales). There are approximately 34,000 people who live within the national park, with the largest settlement being Ashburton with a population of 4000 people (Dartmoor National Park Authority, 2016).

The moorlands within Dartmoor National Park are located at a relatively high altitude and serve as the catchment area for many of Devon's rivers which have traditionally provided a power source. Archaeological evidence suggests that as far back as the 15th century, tin mills used hydro power to power their waterwheels. Monks from Buckfast Abbey powered their church in the early 20th century using a small turbine, as did a number of farmers in the late 19th century. The 1920s and 1930s saw the application of more ambitious hydro-electricity generation proposals, such as the Mary Tavy hydro-electric power station which opened in 1932 (Hedges, 2002). As of 2016, there are currently 17 approved and operational micro hydro-electricity plants[12] and one pending application within Dartmoor National Park (Dartmoor National Park Authority pers. comm. 2016).

3. Results

As seen in Fig. 2, there are a number of sources and types of state regulation that directly affect the nexus within Dartmoor. At the national level, the UK government has designated certain places within Dartmoor National Park as Sites of Special Scientific Interest (SSSI) and certain areas adjacent or in close proximity to the National Park as Areas of Outstanding Natural Beauty (AONB). Both SSSI and AONB are subject to additional regulations administered and enforced by Natural England. With statutory authority from the national government, Dartmoor National Park is managed by the Dartmoor National Park Authority and regulates a wide range of activities with a focus on land and resource management within its borders through its own byelaws. As also illustrated in Fig. 2, Dartmoor falls into three local administrative units: West Devon, Teighnbridge and South Hams and the Devon County Council who regulate various activities at the borough and district level through their own byelaws. At an administrative level below, there are 49 parish councils within Dartmoor National Park. Parish councils are able to precept residents and have a number of miscellaneous powers, as well as the ability to make byelaws in a limited number of areas. While many of these byelaws do not have any direct relevance to the nexus, many do, including resource use, waste, and planning regulations. Furthermore, parish councils are required to be notified of all planning applications and are entitled to submit their comments to the planning authority which must be taken into account when a decision is made.

As more than a third of Dartmoor National Park is common land it is under the collective management of the Dartmoor Commoners Council who regulates nexus activity through its own set of regulations. There are also a number of non-state sources of regulation that relate to the nexus in Dartmoor – these include regulations from the Dartmoor Preservation Association, Dartmoor Farmers Association, Duchy of Cornwall, rules of private organizations and prevailing norms among different social groups. Such non-state sources can rely on a variety of mechanisms to enforce their regulations, including contractual penalties, threats of expulsion, and social sanctions.

3.1. Regulatory mapping for micro hydro-electricity generation in Dartmoor

Fig. 3 presents the results of our regulatory mapping exercise for micro hydro-electricity generation in Dartmoor. As can be seen, there are national statutes that are directly relevant to the supply of commercial hydro-electricity; including various electricity and

[10] Micro hydro-electricity generation refers generally to hydro-electricity power plants with a generation capacity of between 5 kW and 100 kW peak (Alstone et al., 2015).

[11] Dartmoor has been identified as an area with particular potential for economic and environmental win-wins with regards to micro hydro-electricity generation (Environment Agency, 2010).

[12] A well-publicised example is Old Walls Farm located in Ponsworthy. The owners of Old Walls Farm worked closely with the Environment Agency and Dartmoor National Park Authority to design and build a 90 kW micro hydro-electricity plant to provide an additional stream of income to farming by selling electricity to the national grid. The project was notably supported by the local Parish council and community (Hedges, 2002; Ashden Awards, 2010).

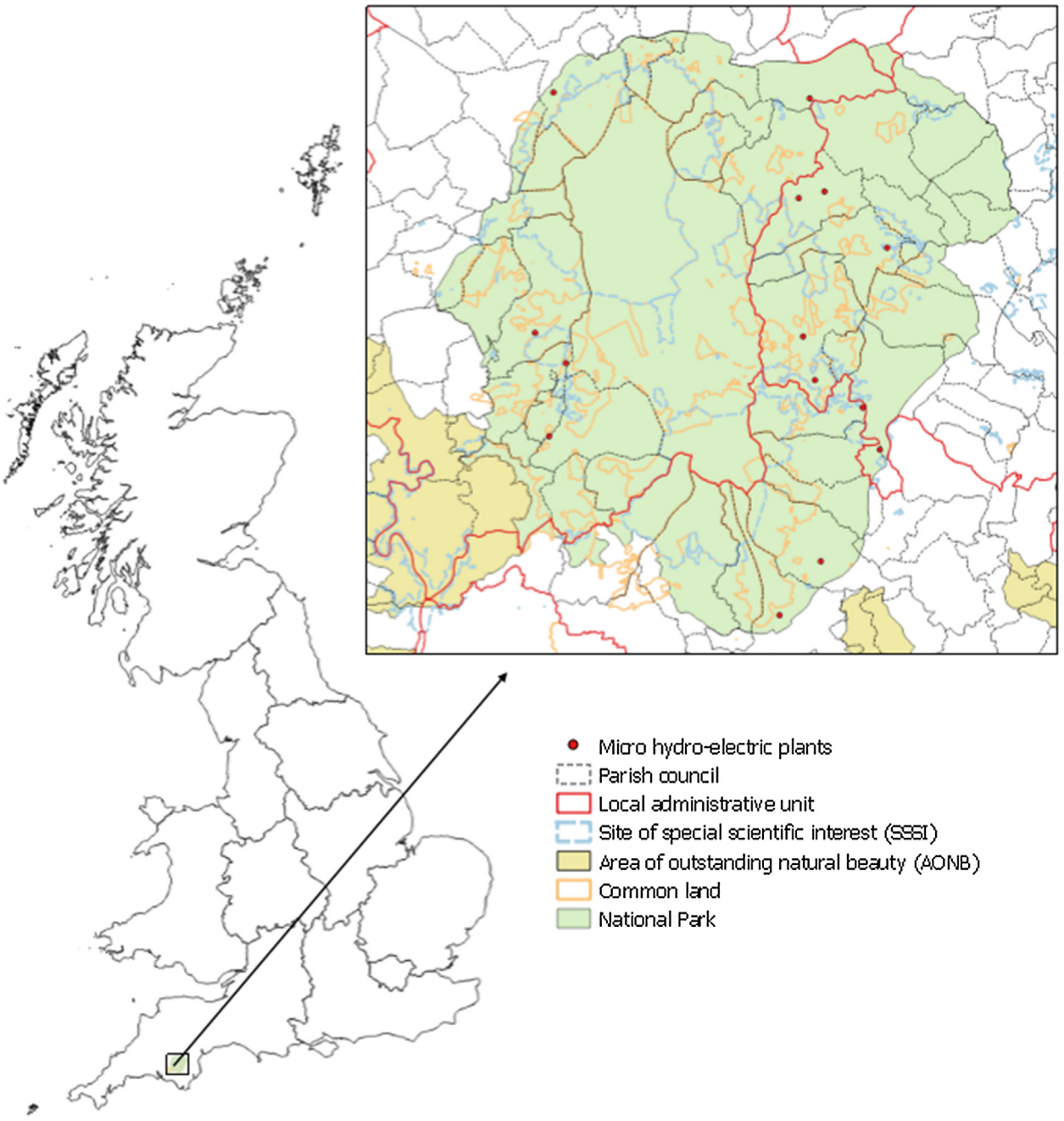

Fig. 2. Sources and Types of State Regulation in Dartmoor.

energy acts, planning and countryside acts, water acts, and environmental acts. In addition, as much of Dartmoor is common land, there are acts relating to the use and registration of common land (which includes the use of waterways). There are area specific pieces of national legislation that relate to Dartmoor and which regulate land and water use. There are also sources of local state regulation, including the Devon County Council and district/borough councils with their own byelaws. Particularly important is the Dartmoor National Park Authority. The National Park Authority is a special purpose local authority created under the Environment Act 1995 and plays an important role in planning permissions. In addition, it enforces its own byelaws (which includes prohibiting inhibiting or diverting of the flow of watercourses and regulation of commercial activities). In addition, there is also the Dartmoor Commoners' Council which, under the Dartmoor Commons Act (1985), represents commoners and makes and enforces regulations concerning the management of the commons within the national park (see Fig. 2). While the Council regulations mainly relate to livestock husbandry, they do contain a prohibition on damage to 'the natural beauty of the commons' that has the potential to affect the production of renewable energy.

In terms of processes, in order to be granted permission to construct and operate a micro hydro-electricity plant, an agent has to ensure that they have rights of access to the river at the point where they intend to build their plant. Secondly, the agent is required to consult with organisations, such as the British Hydropower Association, to ensure that the preliminary design of the scheme is suitable and takes measures to reduce any negative impacts on the environment, local communities and other users of the same water source. This is followed by applying

Source of Regulation	Types of Regulation
State regulation at national level	Electricity Act 1989 Climate Change Act 2008 Planning Act 2008 Energy Act 2013 Salmon and Freshwater Fisheries Act 1975 Water Industry Act 1991 Water Resources Act 1991 Flood and Water Management Act 2010 Water Act 2014 Wildlife and Countryside Act 1981 Natural Environment and Rural Communities Act 2006 Conservation of Habitats and Species Regulations 2010 Enclosure Act 1857 Commons Act 1876 Countryside Act 1968 Countryside and Rights of Way Act 2000 National Infrastructure Planning Act 2008 Environment Act 1995 Dartmoor Commons Act 1985 National Parks and Access to the Countryside Act, 1949 Town & Country Planning Act 1971 Local Government Act 1972 Local Government Act 1980 Dartmoor Commons Act 1985 Dartmoor National Park (Designation) Variation Order 1990 Environment Act 1995
State regulation at local level Devon County Council West Devon Borough Council Teignbridge District Council South Hams District Council. Dartmoor National Park Authority Dartmoor Commoners' Council	 County Council and Borough/District Council Byelaws Local Development Plan and Planning Guide Byelaws include the regulation of the obstruction and diversion of water courses and commercial activity. Dartmoor Commoners' Council Regulations (which includes the obstruction of leats or watercourses)
Non-state regulation by organisations Dartmoor Preservation Association	 Policy 9. The DPA is opposed to the disfiguration of the moorland landscape by television masts, mobile telephone masts and wind farms. Small scale wind generators serving a single farm or hamlet will be judged on the merit of the planning application.
Dartmoor Farmers Association Duchy of Cornwall South West Water	Dartmoor Farmers Association Production Criteria and Aspirations (Farmers should aspire to develop renewable localised energy generation and shared disposal of waste). For land owned by the Duchy of Cornwall, lease agreements can prohibit certain activity. Internal corporate governance and sustainability regulations including 25-year Water Future Vision.
Social Norms	These can be at the national, local, farmer, individual level and enforced by groups, sub-groups or internally. Social norms particularly relevant are the appropriate use of agricultural land and notions of environmental responsibility.

Fig. 3. Hydro Electricity Generation in Dartmoor.

for an abstraction or impoundment license and flood defence consent from the Environment Agency, and for planning permission from Dartmoor National Park Authority. Although there is no specific requirement to do so, applicants are encouraged to consult the local community, water users and their representative groups (e.g. the Canal and River Trust), environmental groups (e.g. wildlife trust), the company responsible for distributing electricity in the area, and local parishes to obtain letters of support (Dartmoor National Park Authority, 2016).

In addition to state regulations, there are also non-state regulations that can impact micro hydro-electricity generation in Dartmoor. Non-state organisations include the Dartmoor Preservation Association, that has a number of 'policies' it aims to enforce, including averting the disfigurement of the moorland landscape (Policy 9); the Dartmoor Farmers Association that has membership production criteria and aspirations, including that farmers should aspire to develop renewable localised energy generation (Aspiration 4); and the rules of private entities and companies who may own land or operate infrastructure, such as the Duchy of Cornwall and South West Water. Finally, there are also likely to be various norms that regulate behaviour relevant to the generation of hydro-electricity, enforced by internalisation, sub-groups or more widely within Dartmoor. These may include notions of what the land and water resources should be used for, with some farmers or families for instance holding strong beliefs that farmland should be used exclusively for farming in a certain manner. For instance, Short and Dwyer (2012:5) highlight the 'very strong cultural attachment' many upland farmers in England have 'to their way of life and the traditions associated with hill farming' and that a high degree of emotion can be involved.

Our regulatory mapping results in five important findings. Firstly, mapping the entire regulatory framework of the nexus is a formidable task. Secondly, the regulatory environment is spatially contingent, as many regulations are localised. Thirdly, many regulations are from non-state sources, and in the case of social norms, are unwritten. Fourthly, it should also be apparent that many of the sources of regulation and regulations themselves are overlapping. In relation to the Dartmoor exercise, there are clearly multiple sources and multiple regulations that concern the obstruction/diversion of waterways and visual amenity. Determining the degree that the regulations complement or substitute for each other is not straightforward and may be case specific. Finally, it is unclear which regulations are enforced and which are merely on the books. Regulations that are unenforced may be merely 'surface law' (Twining, 2009) and there is a vast literature highlighting the importance of enforcement activity on regulatory compliance (Polinsky and Shavell, 2001).

3.2. The case of Huckworthy Mill

Permission for the 100kWp Huckworthy Mill micro hydro-electric plant was granted conditionally in 2012 by the Dartmoor National Park Authority and construction commenced in early 2013. The plant is currently operational and produces, on average, enough electricity to power around 100 houses (CGP, 2016). The agent behind Huckworthy Mill followed the standard application procedure in Dartmoor National Park. This consisted of first obtaining rights of access to the River Walkham. This was achieved through the formalisation of rights of access to the intake, forebay and powerhouse through a lease agreement including easements for all construction areas located outside the boundary of the leased land (e.g. for transmission cables). The agent contracted a hydro power consultancy and a fishery impact assessment consultancy to ensure that the preliminary design of the scheme was suitable and took measures to reduce negative impacts on the environment. This was followed by applications for an abstraction licence and a fish pass approval from the Environment Agency, flood defence consent from Devon County Council and planning permission from the Dartmoor National Park Authority. Applications were accompanied by consultations with West Devon Borough Council, Burrator Parish Council, Dartmoor National Park Authority, Natural England, South West Water, and local community members (Dartmoor National Park Authority, 2014).

Approval was granted by the Environment Agency for a water abstraction licence and for construction of a fish pass, and from Devon County Council for flood defence consent. The planning permission application to Dartmoor National Park was considered by the Dartmoor National Park Authority's Development Management Committee. The Committee, which meets monthly to make decisions on planning applications, consists of 24 members. Five members are appointed by Devon County Council, two by West Devon Borough Council, two from Teignbridge District Council and one from South Hams District Council. Four members are appointed by parish councils to represent the interests of parish councils in Dartmoor. The final five members are appointed to represent the national interest by the Secretary of State. In making their decision, the Committee decides on whether or not to grant planning permission on the basis of how the impacts of construction and operation of the micro hydro scheme affect relevant policies from the Devon Structure Plan (CO), the Dartmoor National Park Core Strategy (COR), and the Dartmoor National Park Development Management Plan (DMD). Fig. 4 summarises the policies found relevant by the Committee with reference to granting planning permission for micro hydro-electricity generation at Huckworthy Mill (Dartmoor National Park Authority, 2012, 2014, 2016).

The Committee also takes into account the outcomes of consultations. In this case, South West Water, the Environment Agency and Nature England had no objections to the proposed plant. Burrator parish council and two members of the community supported the proposal and its potential to contribute to the generation of renewable energy. Plasterdown Grouped parish council, Dartmoor National Park Authority, the Dartmoor Society, the Council for the Preservation of Rural England (CPRE), the Council for British Archaeology, as well as 69 community members objected to the proposal due to historic, landscape and environmental concerns. Historic concerns focused on the loss of historic buildings, particularly the weir which dates back to the 16th century. Landscape concerns centred on the negative visual impact of the proposed fish pass on Dartmoor River. Environment concerns centred on the negative impact the micro hydro-electricity plant would have on salmon populations and concerns regarding increased flooding risk. Notably, many consultations objecting to the plant acknowledged the benefits of renewable energy but argued that the amount of electricity generated would not be sufficient to offset the negative impact to historic buildings, the natural landscape and the environment. In April 2012, the Committee refused planning permission for the construction due to concerns over the fish pass. Specifically, the Committee decided that the construction of the fish pass would be to the detriment of the appearance and character of Dartmoor National Park and was therefore contrary to policies CO2, COR1, COR3, COR4, DMD1 and DMD6 (see Fig. 4). The Committee also judged that the proposal would involve the destruction of a heritage asset (the weir) and that this was contrary to policies CO2, CO8, COR1, COR3, COR4, COR6, COR7, DMD1, DMD6 and DMD11 (Dartmoor National Park Authority, 2012, 2014).

In response, a revised application was submitted that included reports from a structural engineering consultancy, an archaeological survey by historians, and a fishery impact assessment consultancy. The report from the structural engineer found that the historical weir was lacking in structural integrity and in immediate need of repair (Bastone, 2012). The archaeological survey found that, although the weir was first built in the 16th century, there was evidence that the weir had been rebuilt in the 19th and 20th centuries using cement (Brown and Andrew, 2012). The fishery impact assessment found that the design of the plant and a change in water levels due to abstraction would have minimal impact on salmon population (Kibel and Coe, 2011). Upon receipt of this second application, the Committee moved to conditionally grant planning permission for construction of the

Devon Structure Plan (CO)	CO2: National Parks
	CO8: Archaeology
	CO9: Biodiversity and Earth Science Diversity
	CO12: Renewable Energy Developments
	CO13: Protecting Water Resources and Flood Defence
	CO16: Noise pollution
Dartmoor National Park Core Strategy (COR)	COR1: Sustainable Development Principles
	COR3: Protection of special environmental qualities
	COR6: Protecting Dartmoor's Archaeology
	COR7: Providing for the conservation of biodiversity
	COR8: Efficiency and sustainable use of natural resources
	COR10: Providing for small-scale renewable energy
Dartmoor National Park Development Management Plan	DMD1: Delivering National Park purposes
	DMD4: Protecting local amenity
	DMD5: Protecting the National Park landscape
	DMD6: Protecting Dartmoor's moorland and woodland
	DMD11: Demolition of listed buildings and other heritage assets
	DMD13: Archaeology
	DMD14: Biodiversity and geological conservation
	DMD15: Small-scale renewable energy schemes

Fig. 4. Policies relevant to Huckworthy Mill Based on: Dartmoor National Park Authority (2014).

mini hydro plant in November 2012. The Committee found that, in light of the new findings concerning historic buildings and the environmental impact, the benefit of renewable energy generation provided justification to grant planning permission despite the negative visual impact that it would cause (Dartmoor National Park Authority, 2012, 2014).

Through our analysis of planning documents, we have shown how the current regulatory framework operates with regards to a tangible nexus issue: the establishment of a small micro hydro-electricity plant on the River Walkham. Our analysis has shown how a highly decentralised and fragmented regulatory framework with different sources of authority and competing objectives has effectively dealt with each component of the nexus and its interactions through a process largely based on procedural justice.

4. Discussion

Our analysis has highlighted that even for one component of one of the sectors of the nexus there are a multitude of regulations from multiple sources, and that many of the regulations and their sources are place and activity specific. We have also shown that mapping the regulatory framework of the nexus, even for a small area of England such as Dartmoor is a formidable task. By focusing on the issue of micro hydro-electricity generation in Dartmoor, we have shown that regardless of the complexity involved, policy-makers and regulators already have the tools at their disposal to account for the interdependencies and complexities of the nexus. In particular, we have shown how a regulatory framework built around the principles of procedural justice and that recognizes the economic concepts of interdependencies and transaction costs has the ability to generate outcomes that allocate resources in a broadly efficient manner, and that enables the various trade-offs among the sectors of the nexus to be considered.

From the case study of Huckworthy Mill (a concrete example of the kind of water-energy-food nexus issues faced today), it was shown that the existing highly decentralised and fragmented regulatory framework, with multiple sources and forms of regulation is able to accommodate each sector of the nexus and their interactions, and produce a well-balanced regulatory outcome. Indeed, due to the presence of transaction costs the decentralized and fractionalised regulatory framework may actually be optimal as there are likely to be many informational and cost advantages that smaller scale regulators have, both in terms of regulatory scale and nexus sectors. More localised regulators can have much better information in terms of the practical needs of those who they regulate and be able to enforce the regulations much better than a centralised and distant regulator. There may be distinct informational and cost advantages for regulators specialising in different sectors of the nexus due to cognitive limitations of individuals – who ultimately set and enforce regulations (Wichelns, 2017).

We have shown that current regulatory practices can produce a well-balanced outcome in terms of the nexus and that this balance is largely driven by a process based on procedural justice that allows preferences and values from a wide spectrum of stake-holders to be taken into account. We have also shown that this outcome is achieved despite the existence of different regulators, at different scales, with different objectives, and with different sources of authority. We consider this finding to be an important contribution to the nexus literature, and one that suggests that calls for a radical overhaul or greater centralisation or regulation on the grounds of nexus analysis may be misplaced. This finding could only feasibly be achieved by drilling down into one component of the nexus in one specific part of one country, and therefore highlights the benefits of the specificity of this study. However, it must also be noted that our regulatory mapping exercise also highlighted that many regulations and their sources are both place and activity specific.[13] While this limits the generalisability of our findings in terms of well-balanced regulatory outcomes, it does not diminish our most important result – the importance of *process* when regulating the nexus. Nonetheless, it is hoped that our method and results will spur similar exercises for other components of the nexus and in other places to ascertain whether

[13] Given that the nature of interdependencies, the level of transaction costs and processes are likely to differ across components of the nexus and geographies this result is to be expected. This variation may be the result of specific resource characteristics (e.g. the degree of subtractability and exclusion) and the characteristics of resource users (e.g. preference heterogeneity, power relations, social capital) (Paavola and Adger, 2005).

their respective regulatory frameworks produce well-balanced outcomes as we have discovered or require a radical overhaul as some others have suggested. In terms of the existing literature, Stein et al. (2014) also emphasise the use of existing arrangements to govern the nexus, in the very different regulatory context of Ethiopia. Our analysis is also consistent with Wichelns (2017), who taking a historical approach, concludes that efforts aimed at improving policy co-ordination along nexus lines is not always possible or warranted.

Importantly, we do not wish to suggest that better regulation cannot come about through nexus analysis. Quite the opposite: as long as regulators account for transaction costs and procedural justice practices, they can gain significant benefits from nexus analysis that identifies and quantifies interdependencies that can then be addressed by various regulators. Indeed, examples of nexus analysis that have the potential to support regulatory decision making can already be found. For instance, Daher and Mohtar (2015) apply their Water-Energy-Food nexus tool 2.0 to a case study of food security in Qatar and Welsh et al. (2014) apply the Climate, Land, Energy and Water Strategies (CLEWs) modelling approach to ethanol production in Mauritius. FORSEER, another modelling tool, has been used to analyse the future supply and demand of water resources in California where it has enabled policymakers to better understand the competing uses of water at different scales, as well as potential opportunities for improving management of water, energy and food resources that would most likely be overlooked in a sector-based approach (Curmi et al., 2013). Importantly, if nexus analysis is to support local level decision-making, where many important regulatory decisions are known to be made, modellers will need to develop decision support tools that can be easily scaled to this level. Promisingly, some tools such as FORSEER allow for different spatial scales to be considered. This raises the potential for such tools to be used to enable local level regulators to make better informed decisions based on all sectors of the nexus.

If such decision support tools could be provided cost-effectively, they could even be incorporated into the local planning process. However, rather than driving decisions by themselves, such tools should be used to enable informed local level decision-making within a process based upon procedural justice. This view is consistent with Howarth and Monasterolo (2016) who argue that a transdisciplinary approach with active engagement of stakeholders from the water, energy and food sectors would improve the exchange of information and improve the decision-making process. Such stakeholder engagement allows the exchange of information and the expression of preferences and values that can lead to more shared decision-making and action. At the same time, the benefits of increased stakeholder participation and dialogue must be balanced against the well-documented transaction costs involved in moving beyond discipline-specific knowledge (Harris and Lyon, 2014), which could reduce the ability to undertake productive regulatory activities of pressing nexus issues.

5. Conclusion

Using the case study of micro hydro-electricity generation on farmland in Dartmoor National Park in England as a vehicle, we have shown how a regulatory framework built around the principle of procedural justice and that recognises the economic concepts of interdependence and transaction costs has the ability to generate efficient outcomes and consider trade-offs among the sectors of the nexus. Our findings suggest that while regulators have much to learn from nexus analysis, the nexus will not necessarily require a radical overhaul of regulatory frameworks as has been suggested by some in the literature. Instead, stakeholders engaged in regulating the nexus can learn from the insights of the rich pre-existing literature on regulation. In particular, an awareness of the interactions between state and non-state regulation, the economic concepts of interdependencies and transaction costs, and a recognition that regulation of the nexus is a process involving decisions of procedural and distributive justice can provide a more nuanced approach to understanding the contributions of current nexus analysis and provide meaningful advice to regulators and policymakers. Finally, due to the existence of transaction costs, a centralized regulatory framework for the nexus may not actually be appropriate, even if it were possible. Instead, an increase in transaction costs may be generated from a loss of informational advantages from localized regulators who specialize in individual components (or sub-components) of the nexus suggesting that the current 'siloed' approach may have both theoretical and practical benefits.

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