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Original Research Paper

Landscape matters: Insights from the impact of mega-droughts on Colombia's energy transition

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ABSTRACT

Mega-droughts can cause disruption to the affected society sparking a transition. We explore the causes and effects of the 2015 – 2016 mega-drought in Colombia. Using the multi-level perspective as a framework, we found that the mega-drought sparked an energy transition in Colombia whose dynamics were impacted both by the institutionalization of niches as well as the ability to predict the next drought. We were able to trace, using the current understanding of anthropogenic forces, the cause of the mega-drought to socio-technical landscape development influenced by human-induced warming and land use change. We found that the regimes in Bolivia and Brazil were able to influence the landscape through deforestation, and hence contribute to the intensity of a mega-drought in Colombia. The knowledge that a regime can cause disruption in regimes in other geographies and sectors has implications for transition research as well as decision-making for coping with droughts and other disasters.

1. Introduction

Beginning in 2005, three once-per-century droughts ('mega-droughts' as described in Marengo and Espinoza, 2016) have occurred in South America in a period of ten years. These mega-droughts cause extreme climate conditions with impacts on ecosystems and livelihoods. They left communities without basic water access and resulted in substantial agricultural and hydroelectric losses (FAO (Food and Agriculture Organization of the United Nations), 2015; OCHA (UN Office for the Coordination of Humanitarian Affairs), 2016; UNGRD (Unidad Nacional para la Gestión del Riesgo de Desastres, Gobierno de Colombia), 2016a). The more frequent occurrence of mega-droughts increases the need for a societal move towards sustainability[1] in the face of future disasters[2]. Often, these changes include altering the socio-technical system composed of agri-food, energy, transport, and other sectors. These profound changes are referred as socio-technical transitions (here after transitions) in the literature (Rip and Kemp, 1998; Geels, 2004).

Transitions towards sustainability (hereafter 'sustainable transitions') are 'goal-oriented' in addressing future problems (Smith et al., 2005; Gibson, 2006). Since they do not necessarily offer obvious and immediate actor benefits, it often requires new policies

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[1] As defined in 1987 the United Nations Brundtland Commission "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (UNAI, 2019)

[2] In the present study, disaster follows the United Nation definition: "[a] serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources" (UN (United Nations), 2004)

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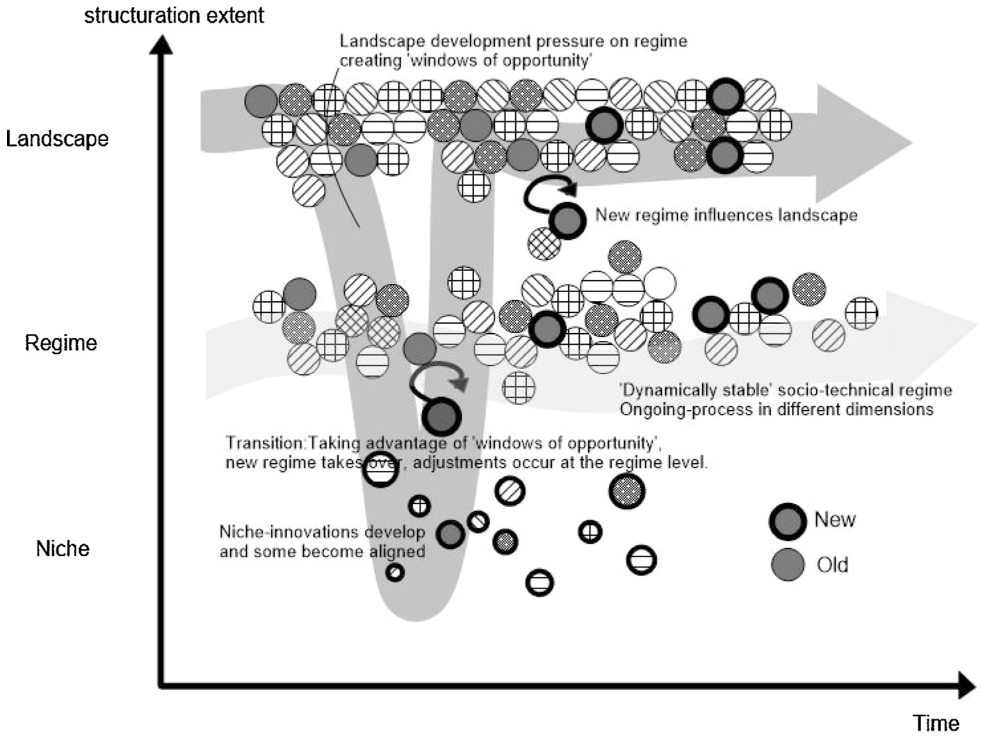

Fig. 1. Multi-level perspective on transitions introduced by Geels (2002), the different filling patterns of the circles represent multiple socio-technical dimensions, e.g. culture, policy, industry, and technology dimensions.

introducing extra economic and regulatory frameworks, e.g. subsidies, taxes, and rules to facilitate sustainable transitions (Geels, 2011). These policies are however, constrained by a larger physical and socio-economic environmental setting (Driel and Schot, 2005). By restricting possibilities for action and responses, the larger social, political, economic, and natural environment influences the policy changes and their approach to sustainability (Thelen, 2014; Geels et al., 2016). For instance, prolonged heatwaves limit the effect of electricity saving subsides for air conditioning users. Elections and macro-economic trends which influence decision-making are also examples.

Disasters play a dual role in influencing a sustainable transition. Firstly, it may shock the systems and provide an opportunity for initiating or accelerating a transition (Birkmann et al., 2010; Becker and Reusser, 2016). Secondly, the nature of the disaster also shapes the actions and responses involved in the transition. Therefore, it can be a factor in determining whether a transition occurs and leads to the overall target of sustainability.

So far, the role of disasters in providing opportunity for changes have been rather explored (Pelling and Dill, 2010; Becker and Reusser, 2016; Brundiers and Eakin, 2018) while the trajectory of a transition following the developments within the disaster is seldom investigated. The present study will focus on studying both aspects utilizing the multi-level perspective (MLP; see Fig. 1.), one of the leading frameworks for understanding transitions (Markard and Truffer, 2008).

Designed to explain socio-technical transitions (Geels, 2002), the MLP enables the conceptualization and the investigation of multi-dimensional and configurational changes of sustainable transitions following disaster events (Becker and Reusser, 2016). It operates under three analytical levels, listed here from highest to lowest structuration: landscape, regime, and niche (Geels, 2004; Verbong and Geels, 2007). The landscape level consists of slowly changing “deep structural trends" (Geels, 2002) and includes such things as the environmental setting in which the transitions take place (Rotmans et al., 2001; Geels, 2011). The regime level, is "a coherent configuration of technological, institutional, economic, social, cognitive, and physical elements and actors with individual goals beliefs or values" (Holtz et al., 2008). In this article, it will be used to explore societal rules and regulations. A disaster event is a result of hazard (here in this study: drought) at the landscape level and its interaction with the regime. The niche is where innovations are experimented with and shielded until they can gain enough momentum to challenge the regime (Kemp et al., 1998; Markard and Truffer, 2008; Smith and Raven, 2012). Niche-innovations can be seen as the innovative policies developed in response to disaster (Becker and Reusser, 2016) and to practices amplifying disasters (Schneider, 2013), as a contrast to the preexisting arsenal of policy measures used by the regime in disaster responses. A transition happens when a new regime replaces an old regime through the interaction of the different levels (Geels and Schot, 2007).

To further analyze the trajectory of a transition following disaster events, we will use the typology of transition pathways entailed from the MLP (for more detailed explanation on the pathways see section 2.) which helps the examination of interactions between regime and landscape (Geels and Schot, 2007).

We examine the case of hydropower dependent Colombia following the mega-drought 2015 – 2016, as the energy sector under drought pressure has yet to be documented in discussions of sustainable transition (Geels, 2011; Turnheim et al., 2015; Köhler et al., 2019). To do this, we use the outputs of scientific studies to qualitatively analyze the dynamic physical climate (drought hazard) landscape, which is often conceptualized as nearly unchanging in the literature (Driel and Schot, 2005). This allows for insight into the developing landscape, a rather unexplored 'residual category' in the MLP literature, and its influences on transition typology (Geels, 2011; Geels et al., 2016).

Moreover, we will explicitly elaborate on the landscape development by also asking the reverse causality where regime shifts contribute to drought hazard landscape development to further contribute to the discussion on transitions in the context of landscape-regime interactions (Geels, 2006, 2011).

Observations on actors and institutional interplay within a sustainable transition will be included in our analysis of the pathway since their importance in understanding the typology of transition was highlighted by the literature (Geels et al., 2016). A particular focus will be on how these were influenced by landscape development.

The paper will explore the following research questions,

1 Was there a transition as a result of the 2015 − 2016 mega-drought in Colombia?
2 How did the nature of the shock influence regime institutions and transition development?
3 What landscape and regime developments can be traced as the cause of the 2015 − 2016 mega-drought in Colombia?
4 What does this new insight mean for the energy transition in Colombia and for the multi-level perspective?

In the following section, we first introduce the theoretical framework that enables analysis of the transition typologies responding to landscape development and the evidence selecting method used to track the transition. We then briefly present in section 3 the study event of the South American mega-droughts. In section 4, we describe the conceptualized Colombian energy transition pathways along with landscape development. This includes our observation on the institutional interplay and landscape dynamics influencing the transition pathway. In section 5, we present the interrelated landscape and regime development shown from the pathway analysis of our case. This includes a subsection (5.2) addressing the geographical contents critical in understanding transition as we found through our analysis. It then leads to section 6 where we discuss limitation and uncertainties in the present study (6.1), provide repercussions for managing power generation in Colombia (6.2), and present new theoretical insights from our analysis (6.3). We then summarize new theoretical insights and recommendations for policy before we conclude from the findings.

2. Tracking trajectories of transition under landscape development

To understand transition following landscape development, we used the typology of transition pathways (Table 1) constructed by Geels and Schot (2007) describing the multi-level (between landscape, regime and niche) interactions for our analysis. However while researchers often focus on the bottom-up, niche-driven aspects of transitions (Berkhout et al., 2004; Geels, 2011), we will use this typology of transition pathways to enable insight into landscape changes and their interaction with regime and niche levels following evolutionary and social-institutional aspects. The typology of pathways (Table 1) is based on the *timing* and *nature* of multi-level interactions. *Timing* refers to that of landscape pressure on regimes generating 'windows of opportunity' for transition. It also relates to the state of the niche at the moment, whether it is matured to take advantage of this window for transitions. The *nature* of the interactions refers to (1) a reinforcing (stabilizing existing regime, not driving transitions) or disruptive landscape (pressure on regime, opportunity for transitions) development and to (2) competitive niche-innovations (with an aim to replace existing regime) or symbiotic niche-innovations (as enhancement to the regime). Regarding landscape development, Geels and Schot (2007) employed Suarez and Oliva, 2005 characterization of environmental changes (see Fig. 2) to describe the different natures of landscape developments. Building from above points, Geels and Schot (2007) proposed the typology of transition pathways (Table 1).

Table 1
Typology of transition pathways (Geels and Schot, 2007).

Transformation	Moderate disruptive landscape pressure on the regime when niche–innovations have not been sufficiently developed. Changes enacted by regime actors modifying existing development paths. Changes are moderate and gradual. New regime grows out from the old regime with gradual adjustments and add-ons of symbiotic niche-innovations.
Reconfiguration	Symbiotic innovations initially adopted in regime to solve local problems trigger architectural changes creating space for new adoptions of niche-innovations. Sequences of component innovations add up to major changes in guiding techniques, beliefs, and practices. When a new regime in this path also grows out of an old regime, it differs from the transformation path via changes in the basic architecture enabled by cumulative adoption of niche component.
Technological substitution	Competitive niche-innovations are mature when windows of opportunity from disruptive landscape pressure open. The new niche will take the chance and replace the existing regime entailing power struggles.
De-alignment and re-alignment	Landscape changes (avalanche changes) lead to regime problems. The regime erodes, experiences collapse, and eventually de-align. Regime actors lose faith and no longer defend the regime. A vacuum occurs if no specific niche-innovation is sufficiently developed. At this moment, a lack of stable rules leads to the emergence and co-existence of multiple embryonic niche-innovations. There is a prolonged experimentation/competition period for attention and resources until eventually one niche-innovation becomes dominant and it re-aligns as a new regime.
A sequence of transition pathways	If landscape pressure has the form of 'disruptive change' which develops gradually while becoming disruptive, regime changes might experience a particular sequence of pathways beginning with transformation or reconfiguration and followed by substitution or de-alignment and re-alignment.

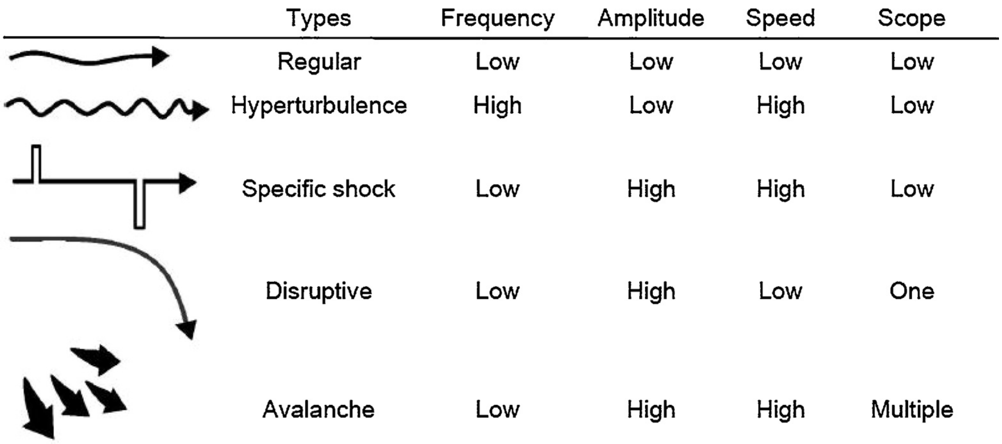

Fig. 2. Typology of landscape development (Geels and Schot, 2007) using the characterization of environmental changes from Suarez and Oliva (2005). Frequency: number of disturbances per unit time. Amplitude: the deviation of a disturbance from initial conditions. Speed: rate of change of disturbance. Scope: dimensions being affected by the disturbance.

3. Study event: the 2015 – 2016 mega-drought

The more frequently occurrence of mega-droughts in South America has motivated our exploration of the most recent (to the time when this paper is written) mega-drought event, that occurred in 2015–2016, and the related transition. During the 2015 – 2016 drought phase, deficient rainfall led to a low river level in the Amazon River accompanied by the strongest warming of the Amazon forest in the last century. The 2015 – 2016 drought surpassed the severity of previous strong El Niño events (e.g., 1982/1983 and 1997/1998) and mega-droughts (e.g., droughts that happened in 2005 and 2010) (Jiménez-Muñoz et al., 2016; Marengo et al., 2018). Substantial damages were reported from the Amazonian and adjacent countries (WFP (World Food Programme), 2016). In Colombia, a red alert, the highest level of disaster alert, was declared starting in December 2015 because of deficient rainfall in the wet season of October and November which resulted in extreme low levels of both the Magdalena and Cauca rivers, the major rivers of the country. By January 2016, over 124 municipalities were affected by the drought. People in Valencía of the Córdoba department were without potable water. Agricultural losses were reported from 45,000 producers in the Cesar region. Extreme dry conditions exacerbated the already poor access to food and drinking water in the department of La Guajira where malnutrition killed 93 children in 2016. As a result, various governmental actions were taken to recover from damages of the particularly severe drought disaster (UNGRD (Unidad Nacional para la Gestiön del Riesgo de Desastres, Gobierno de Colombia), 2016b).

Furthermore, as a country with over 70 % of its power mix from hydropower plants (see Fig. 3.), Colombia experienced a nation-wide energy crisis resulting from the drying of rivers during the record-breaking 2015–2016 mega-drought. This has led to significant national policy change aiming for a more sustainable power mix. The then Minister of Mines and Energy, Germán Arce Zapata stated "This government was, is and will be the government that promoted the energy transition towards a sustainable energy mix, adaptable to climate change, and that provides security in the power supply."(PV magazine, 2018).

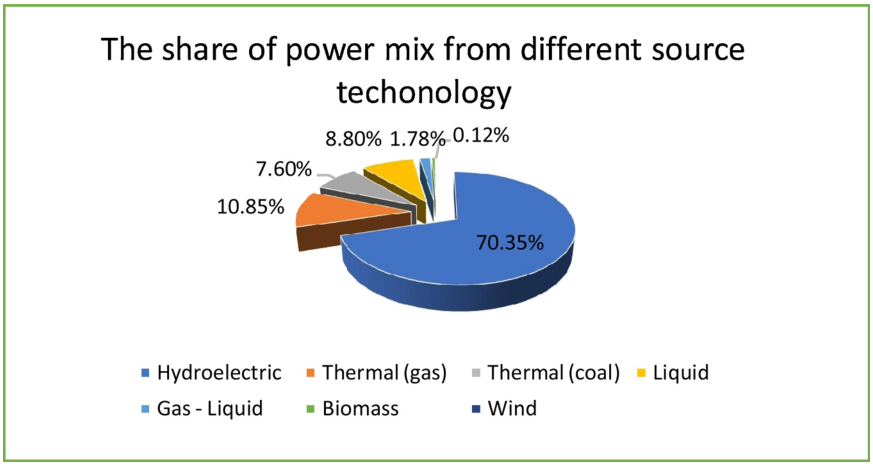

Fig. 3. The share of Colombian power mix from different sources in 2015. Data Source: Unit for Mining and Energy Planning (UPME (Unidad de Planeación Minero Energética/Unit for Mining and Energy Planning, Government of Colombia), 2015).

Therefore we choose this case and trace the Colombian energy transition along with the drought landscape development taking into consideration the transition pathways following the different typologies of landscape development (section 2., Fig. 2.). We not only explore trajectories of a sustainable transition under landscape pressure, but we also trace the regime influence on such landscape development and study their implications for regime-landscape interactions. We use a variety of sources to confirm the presence of evidence for each step in the conceptualized relationship between the regime and 2015 – 2016 drought disaster. In particular, evidence was located by examining peer-reviewed papers, working papers, book chapters, government reports and speeches, and media reports.

4. Analysis outcome: energy transition process in Colombia along with the developing drought landscape

Actors began to perceive changes within the environment when, starting October 2015, the level of the Cauca and the Magdalena Rivers gradually lowered; in December, a red alert of drought was issued. This beginning phase of changes had seen a moderate response among the actors. The XM, the company in charge of the country's energy system management, had originally projected to the public that the reservoir level was acceptable, but then declared an amendment in their projection when the drought crisis worsened later in March. Meanwhile, there was generally insufficient effort to save energy within the country before the drought worsened while energy consumption was higher in January and February than the same period in the previous year (neutral El Niño-Southern Oscillation phase) (El País, 2016).

Pressure on the regime continued to develop as the drying persisted. Accompanied by an unexpected fire at the hydro facility in Guatapé in March 2016, the drought resulted in a deep crisis in the country's hydropower generation. Though at a low speed, the drying condition increasingly worsened along with its impacts. Although normally an exporter of energy to neighboring countries, Colombia was on the edge of energy rationing and had to import energy from neighboring Ecuador (The Bogotá Post, 2016). The crisis resulted in the resignation of the minister of Mines and Energy (El País, 2016). Drought landscape pressure developing at a low speed gradually formed a disruptive change of energy crisis. This 'window of opportunity' however opened when niche-innovations (e.g. solar power and other alternative energies) were not sufficiently developed (El Tiempo, 2016) and *a sequence of transition pathways* (see Table 1) was observed.

Various changes in the regime were introduced by the regime actors corresponding to the gradual development of drought landscape pressure (see Fig. 4. for the regime changes along the drought landscape development). Initially actors appear to perceive a moderate drought landscape pressure. The government had provided incentives for households to save energy and imposed punishments on those using more energy than the average. This action reflects an incremental rule change (El País, 2016; Portafolio, 2016). In March 2016, the energy crisis became more prominent as a result of the length of time with deficient rainfall occluding hydropower generation. Then, newly approved guidelines enabling companies (cogenerators) to sell energy surpluses in stock price facilitated, for the first time, a considerable amount of cogenerators' contribution in Sistema Interconectado Nacional (SIN, National Interconnected System) (El Tiempo, 2016). These local symbiotic innovations were adopted by the regime and triggered architectural changes creating space for new adoptions of niche-innovations (*reconfiguration* pathway). In May 2016, there was the first approval from Unidad de Planeación Minero Energética (UPME, the Mining and Energy planning unit) of an energy project that exempts companies from VAT by investing in solar panels (El Tiempo, 2016). These cumulative changes, though triggering architectural adjustments in the regime were, however, considered insufficient by firms as viable energy model, according to Ser Colombia, the association of renewable energies (El Espectador, 2016).

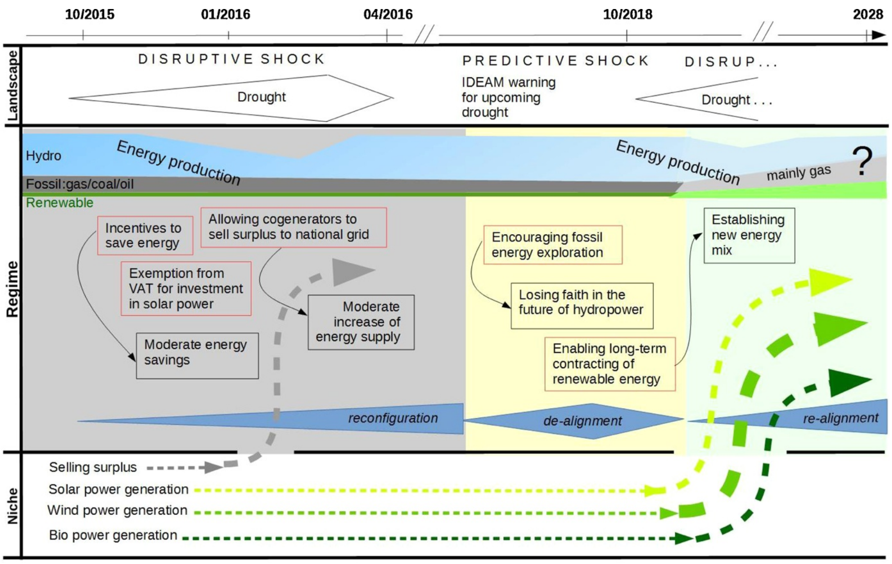

Fig. 4. Colombian energy regime changes along drought landscape development.

The rainy season that arrived in April 2016 temporarily alleviated the dry conditions and closed the window of opportunity from the 2015 − 2016 drought. Before this window of opportunity closed, only a few developing innovations were observed (El Espectador, 2016). This was from the result of a lack of investment guarantees, to support niche developments, according to the Derivex, company specialized in the market of derivatives of energy commodities (El Tiempo, 2016). Thus, regime improvements appear insufficient to deal with the next.

Then, after the 2015 − 2016 mega-drought and before the beginning of the next El Niño phase, there was a gradual increase in political pressure enabling the rise of niche-innovations. This pressure was not directly from the physical climate, but from the fear of next onset of El Niño (we call that a 'predictive shock', for details and definition see section 4.1). Aiming at power mix diversification, the Ministry of Mines and Energy issued decree 2253 (MinMinas (El Ministerio de Minas y Energía/Ministry of Mining and Energies), 2017) and decree 0570 (MinMinas (El Ministerio de Minas y Energía/Ministry of Mining and Energies), 2018a). While decree 0570 aimed to encourage long-term contracting of renewable energy projects, decree 2253 addressed incentives on investments of gas and oil reserve exploration. The then minister of Mining and Energy, Germán Arce Zapata, commented that "the diversification makes us less vulnerable in cases such as the El Niño phenomenon" (MinMinas (El Ministerio de Minas y Energía/Ministry of Mining and Energies), 2018b). In this opportunity window provided by predictive shock, incumbent actors lost faith in hydropower dominance. Hydropower de-aligns while niche-innovations are not yet sufficiently developed, featuring the beginning of a *de-alignment and re-alignment* pathway (Verbong and Geels, 2010). Here a policy strategy stimulating niche-innovations and nurturing the emergence of a new system has been observed (e.g. the enactment of decree 0570 and decree 2253).

The next El Niño phase occurred in late 2018 as forecasted and dry conditions again caused concerns over the water and energy supply (El País, 2019). When this window of opportunity presented, there was again no niche-innovation with the strength to outright challenge the regime. Meanwhile, multiple alternative energies gained momentum, competed for attention, and co-existed under the encouragement of the government (*pre re-alignment*). The first renewable energy long-term contract auction was held in February 2019. These projects consist of solar, wind, and biomass source generation and distribution aiming to boost the development of the renewable source share in 2021 to 10 % of the energy supply, according to María Fernanda Suárez, the minister of Mining and energy (Portafolio, 2019). On the other hand, the government was eyeing gas-fired power plants as the solution to the drought induced brownout (Umwelt Bundesamt, 2018). The government seeks to enhance natural gas-fired capacity by adding an additional 3841 megawatts (24 % of the current total supply) by 2028 (Oil Price, 2018). Consequently, gas-fired plants are currently gaining momentum. The growing consumption of power and the doubts about the newly introduced renewable energy projects have encouraged investment in both natural gas and oil reserves. Starting late 2017, Colombia began to regularly import natural gas despite a growing domestic gas production highlighting the gap between local supply and rising demand. This shortage saw energy companies such as Canacol (most of its natural gas production is from the Magdalena basin) expanding its investment in gas reserves and its operation in Colombia (Oil Price, 2018).

In sum, the trajectories of transition along with the gradual development of drought landscape pressure can be observed following *a sequence of transition pathways* (Table 1): Firstly, the regime actors addressed the problem by introducing incremental changes. Following the gradually worsening drought, a *reconfiguration* pathway where cumulative adoption of component innovations together contributed to major changes in guiding techniques and practices. Though the dry condition was temporarily solved by the coming rainy season at that point, a gradually increasing pressure before the next onset of El Niño opened up a second window of opportunity. This predictive shock (see section 4.1) sees regime actors losing faith in the hydropower regime (*de-alignment* pathway). It was only at this point the investment guarantees and viable business models to support niche developments were introduced. Niche-innovations did not become institutionalized to the point where they could challenge the regime. After the 2018 El Niño phase started, drought pressure on hydropower again opened a window of opportunity, however, the regime has not yet re-aligned with a new configuration. Currently, multiple innovations are competing for attention and resources, a clear sign of an ongoing transition. As transitions, even shock induced ones, can take many years, it is not unexpected that the transition caused by the 2015 − 2016 drought has not yet completed.

4.1. Landscape development beyond known typology-predictive shock

The drought landscape shock has a form of disruptive change according to the categories in Geels and Schot (2007), with a high amplitude and low speed typology (see Fig. 2.). A distinct characteristic of droughts from other studied landscape shocks in the MLP, e.g. cyclones (Becker and Reusser, 2016), societal values (Geels and Verhees, 2011) and changing trade patterns (Driel and Schot, 2005) is that drought reoccurrence is almost certain for the Andean country. This generates another type of drought related landscape pressure before drought actually occurs.

Between the 2015–2016 mega-drought and the onset of the El Niño phase in late 2018, climate model projection from the IDEAM (Institute of Hydrology, Meteorology and Environmental Studies) had already placed warnings for the then upcoming 2018–2019 drought phase and dry condition (Caracol Radio, 2018). This predictability at that time asserted pressure on the regime even before the drought phase began since it meant the hydropower crisis would almost certain reoccur (Hoy Diario del Magdalena, 2018; Wradio, 2019). This low amplitude, low speed pressure on the regime generated actual institutional changes guaranteeing contracts for niche developments, and we have given it the name 'predictive shock' (see Fig. 5). For a more detailed documentation of predictive shock as landscape dynamics please see 6.3.1.

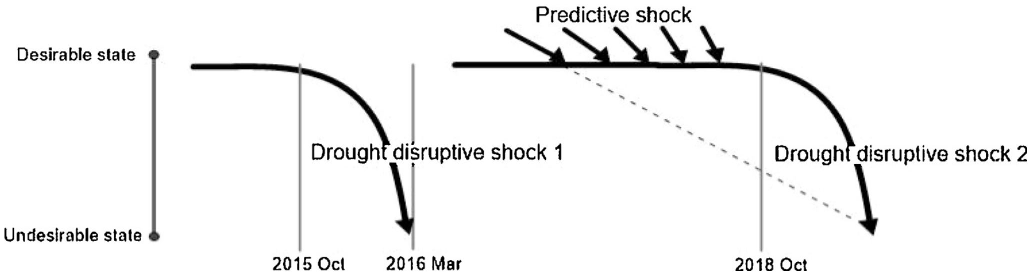

Fig. 5. Conceptualized drought related landscape shocks starting with the 2015-2016 mega-drought.

4.2. Institutional interplay under landscape development

Colombia's power mix features a strong centrally planned infrastructure including the dominating hydropower. This ensures Colombia's energy operations during normal times, but its strong structuration can act as a barrier to transition. This structural barrier is especially revealed when the hydro-power lost its ability to function during the drought. In the opportunity window because of the 2016 drought (see Fig. 5, the valley of the first disruptive drought pressure), a decentralization of the power mix was observed. Local solutions, such as energy surplus generated from enterprises and energy saving incentives, were imposed to incrementally cover the gap of the hydropower brownout (following *reconfiguration* pathway).

However, the highly centralized energy institution was able to suppress the niche developments that challenged the incumbent regime. This was because the legal basis for niche developments was not established. E.g. because of a lack of legal support for long-term contracts and investments in clean energy, firms did not consider further investments a viable business approach.

Clear institutional actions that removed caps for alternative energy development was only seen during the second window of opportunity provided by the predictive shock. Prediction of the then arriving 2018 drought brought actors the appearance of a malfunctioning hydropower system during drought times and clearly displayed undesirable outcome of the hydropower-dominant path. This has resulted in the de-alignment of the hydropower regime and the removal of institutional cap for niche developments in the opportunity window of the predictive shock. Here long-term contracts on investing renewable energies were guaranteed by decree 0570 for the first time. Gas-firing capability was strengthened and encouraged then (Oil Price, 2018), which has solved past constraint of a lack of firing facilities blocking the development of gas energy sources. These were however only the beginning of the re-alignment process. Multiple niches now compete and coexist, until one fully aligns.

The 2018–2019 drought (the real hit of drought after the predictive shock) opened another opportunity window, but no prevailing solution was able to replace the hydropower regime yet. The reason may be the close timing of this window of opportunity to the last one provided by predictive shock. Path-dependency may play a role as well (David, 1994; Berkhout, 2002).

A full re-alignment of a new regime will need time, given that key institutional structure paving ways for new innovations was only introduced at the time of the predictive shock and is still developing. For example, in the first renewable energy auction in February 2019, few contracts were awarded despite a large interest from firms. It was partly because that the newly introduced auction mechanism was not yet properly implemented (Reuters, 2019). In October 2019, another auction with improved infrastructure was hold where seven firms successfully obtained long term power purchase agreements (UPME (Unidad de Planeación Minero Energética/Unit for Mining and Energy Planning, Government of Colombia), 2019).

Nevertheless, it is possible that the ongoing transition will experience an acceleration under the pressure from future El Niño phases. The realignment of niche-innovations and their survival will depend on their structuration, how they stretch (Ramos-Mejía et al., 2018) or are empowered to transform the regime (Smith and Raven, 2012) under the landscape pressures that the country faces. One of those landscape pressures is the occurrence of more frequent droughts, which will be examined in the following section.

5. Contribution of regime shifts

5.1. Tracing regime influences on drought landscape developments

It is almost certain that droughts will generate future shocks to hydropower systems given reoccurring El Niño phases. In this section, we use outputs from scientific studies to qualitatively analyze the dynamic drought landscape and ask the causality where regime shifts have contributed to drought landscape development that influences energy transition in Colombia.

Regulated by the natural variability of El Niño South Oscillation (ENSO), El Niño phases usually lead to droughts in Colombia. Along with the El Niño phase, the warmer than normal Tropical North Atlantic Ocean has been known to lead to past 'once-per-century' mega-droughts (Marengo et al., 2011).

Despite the above mentioned sea surface temperature forcing, anthropogenic factors linked with the terrestrial process are known to have contributed to the development of more recent droughts (Moore et al., 2007; Lee et al., 2011; Bagley et al., 2014; Alves et al., 2017; Erfanian et al., 2017). Erfanian et al. (2017) found the severity of the record breaking 2015 – 2016 mega-drought which resulted in Colombian energy crisis, cannot be explained alone by the oceanic forcing. They highlighted the contribution of human-induced warming and deforestation (Erfanian et al., 2017).

These two anthropogenic factors with different governing regimes influence drought landscape development in Colombia via different atmospheric physical mechanisms. Human-induced warming is mostly a result of the growing atmospheric carbon concentration. Carbon dioxide, a major contributor to past warming, accumulates in the atmosphere and distributes rather homogeneously around the globe (IPCC, 2013). The concentration of atmospheric carbon is thus determined by the collective global contribution, addressed by emitters around the world possessing equal individual effect. Human-induced warming has been regulated by global conventions limiting carbon emissions and worldwide temperature rise, such as the Paris agreement aiming at a 2 degree range above pre-industrial level (UNFCCC (United Nations Framework Convention on Climate Change), 2015). The influence of the warming factor on development of the drought hazard landscape relies on the alliance of global entities in the conventions, including Colombia's own regime (UNFCCC (United Nations Framework Convention on Climate Change), 2016).

On the other hand, deforestation, another anthropogenic factor known to govern drought severity has regionally specific contexts. Through aerial rivers,[3] the drought landscape of Colombia (sink area) is influenced by land users from a particular location (source area) (Bagley et al., 2014; Keys et al., 2014; Weng et al., 2018). In the present study, we use the terms 'sink' and 'source' from the aerial river community to conceptualize the receivers and providers of a certain flow. The flow referred to here is the effect of land use change on dry climate condition.

Furthermore, these source areas can be located remotely from the sink areas. Bagley et al. (2014) uncovered the remote contribution of deforestation to dry climate condition in South America using coupled land-climate modelling. Their simulation revealed that deforestation in a major moisture recycling[4] area in South America (mostly out of the country Colombia, see pink box in Fig. 6a) explains most of the land use induced drying in Colombia (Fig. 6a.). It is worth noting that the past land use changes within this area (pink box of Fig. 6a) were concentrated in Brazil and Bolivia. Another forward trajectory simulation by the same authors which specifically focusing on Central-Western Brazil and Eastern Bolivia more clearly underscored the remote influence of deforestation in this area enhancing the drying condition in Colombia and Peru (see Fig. 6b.).

5.2. *Remote regime influencing Colombian energy transition*

The aerial rivers connect the drought hazard in the sink area (Colombia) to the deforestation[5] in the source area (Bolivia and Brazil for example) within the environmental landscape. This connection at the analytical landscape level has also bridged the regime across sectors in different geography. In our example, the source regime shapes land use/land cover in the source Brazil and Bolivia, which is connected to the drought hazard in the sink Colombia in the landscape. Via this, it influences as well the transition process following drought shocks in Colombia. In this section, we first trace the regime influencing drought landscape development in Colombia, then we provide a conceptualization of remote regime influence learned from our case.

5.2.1. *Source regime shapes connected landscapes*

The deforestation in the source area is known to be governed by various factors. Regions which had undergone deforestation in source area were mostly converted into pasturelands or croplands (De Sy et al., 2015) driven by the global demands for maize, soybeans, and beef (Nepstad et al., 2006; Laurance, 2007; Barona et al., 2010). Along with the global agricultural market influence, regional markets in wood, land, biofuel, and forest certificates (CRAs) are also known to have directly (on the production sites) and indirectly (elsewhere than the production sites) caused forest losses (Lambin and Geist, 2002; Lapola et al., 2010; Soares-Filho et al., 2016). It is however not only the market regime that has shaped the deforestation landscape in the source area and influenced recent mega-droughts in Colombia. Since 1960s, population growth (mostly from immigration) and the related logging and mining activities along with the need for transportation network development have seen a constant increase in forest loss in the source area (Laurance et al., 2001; Hansen et al., 2013).

There was also a regime in the source area that decelerated forest loss. After the deforestation rate peaked in 2004, a combination of strong legal forces managed to successfully slow down forest loss in the source area. This regime includes close monitoring, which enhances enforcement of laws, interventions on supply chains through soy and beef moratoria, restrictions on access to credit, and expansion of protected areas (Nepstad et al., 2014; Gibbs et al., 2015). However, a recent shift in this regime via a revision of the Brazilian Forest Code (2012) has led to massive ongoing investments in road paving, and a reduction in established protected areas which have seen a rebound in the deforestation rate since 2013 (Soares-Filho et al., 2014; Arima et al., 2014; Hansen et al., 2013). Intensification of deforestation in the Bolivian Santa Cruz department has also been observed since 2008, likely linked to the leakage from Brazilian soy moratoria (Kalamandeen et al., 2018). Given that the Brazilian deforestation rate also hit a new high in 2018 (INPE, 2019), if no further changes or transition is to take place in the source area, the current source regime will continue to influence the environmental landscape towards a furthering of the dry condition in the sink Colombia.

[3] Aerial rivers are the main pathways of moisture flow in the atmosphere, termed in Arraut et al. (2012) as an analogy to the surface rivers. Opposite to surface rivers, aerial rivers gain water through evaporation and lose water from precipitation. Aerial rivers include the moisture recycling process in footnote 4.

[4] The moisture recycling process describes the process in which the moisture that is evapotranspirated again becomes precipitation, and the moisture that is precipitated again becomes evapotranspiration within one given spatial domain.

[5] Deforestation and forest losses in source area are conceptualized as part of the environmental landscape following its characteristic "deep structural trends" (Geels, 2002) as environmental setting of socio-technical regime.

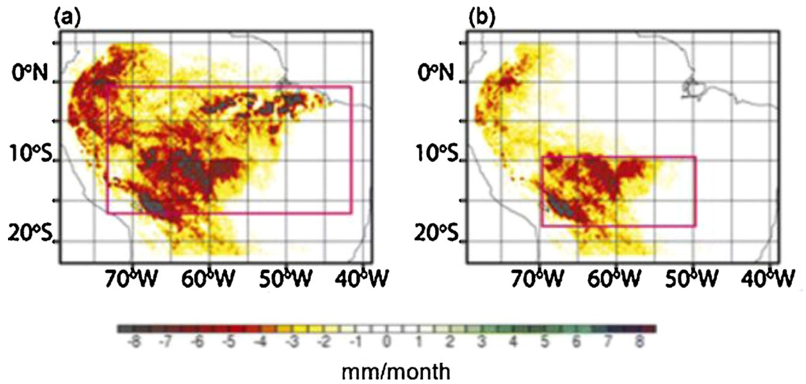

Fig. 6. Dry season simulated impact of deforestation on forward trajectory precipitation in Bagley et al. (2014). They show geography of precipitation reduction in the dry season resulting from land cover change in the pink boxes of: (a) major recycling area in South America, (b) Central-Western Brazil and Eastern Bolivia.

5.2.2. Conceptualization of remote regime influence

The above case inspired our conceptualization of how the regime in one locality can influence the regime in another through the landscape (Fig. 7.). Because this necessarily means referring to two regimes, we will refer to the regime doing the influencing as the source regime and the regime being influenced as the sink regime. Moreover, the source regime and sink regime need not be in the same sectors, as the case for our case study. Thus, the process begins in the source regime where the current regime is causing deforestation; this could be potentially through specific policies or specific actors. Through aerial rivers, the influence of this process crosses over administrative and international boundaries, meaning that the source area which has influence over this process does not necessarily feel the repercussions of their regimes practices through this path. The increasing deforestation in the environmental landscape intensifies the drought hazard in the sink area which asserts pressure on the sink regime and opens a window of opportunity for transition process to begin with.

It is worth noting that the physical climate landscape here is in fact not 'unchanged' as in the literature (Driel and Schot, 2005). Connecting regimes in different geographies, its development is a mechanism through which the source regime triggers the sink regime shift.

A transition in the sink regime as a result of the landscape shock occurs then through different pathways depending on the timing and form of landscape changes as well as the strength of the niches. Once through this process the old sink regime is replaced by a new sink regime, a transition has occurred.

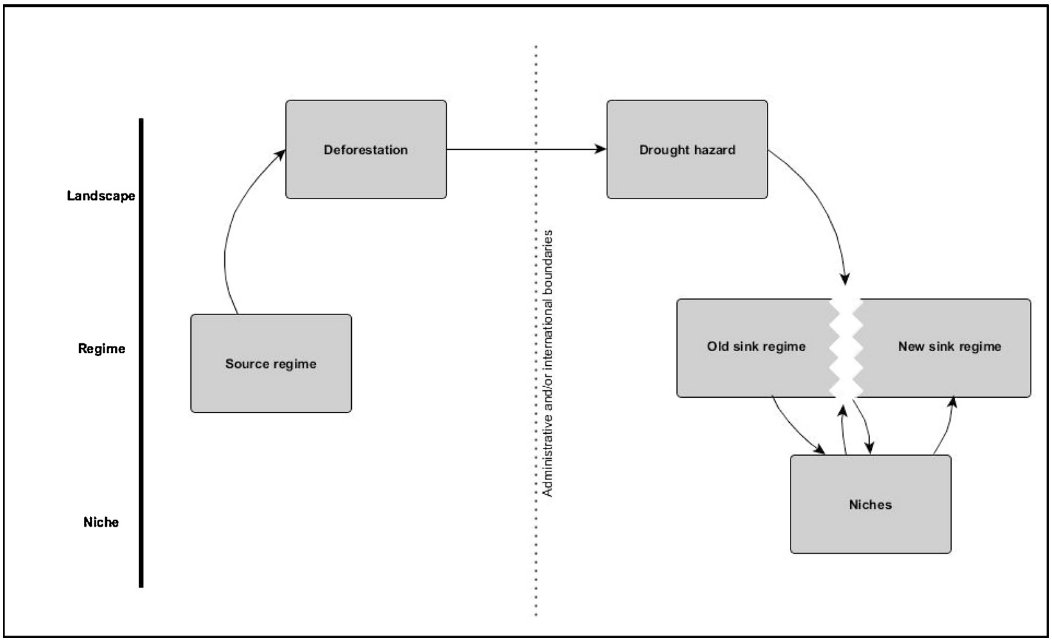

Fig. 7. Conceptualization of how one regime influences another through the landscape. Arrows represent impact flows.

6. General discussion

6.1. Limitations and uncertainties

In the present study, we have paid attention to uncertainties that reside in the data and the process analysis. In section 4, 18 reports from the media have been used in the analysis. These media reports served predominantly as sources for the occurrence of events such as the drought alarm, the resignation of a minister, and the energy auction; in order to lower impacts from potential bias of reporting perspectives. Four exceptions were made while the media reports were used to refer to statements rather than the phenomena recorded in the material. These exceptions were made since they were interviews of actors showing their actions and attitudes in response to the drought development. In these cases, materials with the original statements quoted from the actors were chosen. These exceptions are 1. the PV magazine citing the statement from the Minister of Mines and Energy Germán Arce Zapata, 2. El Espectador citing Ser Colombia's response on changes of rules for energy market during drought time, 3. El Tiempo citing Derivex's statement on a lack of investment guarantee, 4. Portafolio citing the Minister of Mines and Energy María Fernanda Suárez for her statement on renewable energy policy. Altogether, this procedure minimizes potential bias induced by non-peer reviewed sources in cases where no alternatives are available.

Regarding process uncertainties, we noted during the analysis of regime-landscapes interactions, that other landscape developments may also influence the changes in the Colombian energy regime apart from the drought influences. For example, the political pressure from presidential election of 2018 may accelerate the regime changes during the period of predictive shock. Increasing distrust in hydropower following the El Quimbo (Semana, 2012), Sogamoso, and Ituango controversies (Mongabay, 2018) may also generate pressure on the hydropower regime. However, the nation-wide energy crisis during 2015 − 2016 mega-drought arguably plays the key role for the hydro-power regime de-alignment as also stated by officials (see section 3). As for the analysis of regime influencing drought landscape, the uncertainties are located in the modelling and empirical studies of droughts used here for back-tracing, the discussions of which is beyond the scope of the present study. However, according to the literature (Van der Ent et al., 2014; Marengo and Espinoza, 2016; Marengo et al., 2018; Herrera-Estrada et al., 2019) the results seem sufficiently robust to justify the presented argumentation.

6.2. Repercussions for approaching a sustainable power mix in Colombia

The current strategy of diversifying power generation was developed under the precondition that drought is influenced by the El Niño phenomena (PV magazine, 2018). Given the above mentioned anthropogenic influences on the intensity of drought, this strategy may need to be rethought. Investment in carbon related energy, including natural gas, should be especially reassessed since it *is not* sustainable as releasing atmospheric carbon intensifies droughts.

Colombia has ratified the Paris agreement by the implementation of ley 1844 República de Colombia (2017). Following the Colombian nationally determined contribution (NDC), Colombia has a target of reducing its greenhouse gas emissions by 20 % with respect to the projected Business-as-Usual (BAU) Scenario by 2030 (INDC (Intended nationally determined contributions) Colombia, 2015; Ley 1931, República de Colombia, 2018). This determined target is not ambitious when the estimated emission in 2030 will still be higher than the 2015 level. While natural gas has rather low emissions compared with other fossil fuels, replacing coal with natural gas can help efficiently reach the NDC target. However, it should stay as a temporary solution as continuous emission can gradually enhance the atmospheric carbon forcing that intensifies droughts.

Currently carbon-related sources are competing with the renewable energies. A full re-alignment of renewable energies is the only approach to avoid domestic augmentation of the drought hazard through the human-induced warming mechanism. Though Colombia as one individual country encouraging carbon related energy may have limited influence on the warming of the planet, each country that does so makes it more acceptable for others to do the same. This might lower more countries' willingness to comply with global conventions on reducing carbon emissions (a rotten apple can spoil the barrel). Should, as a result, more countries choose carbon related energy, there would be considerable effects on augmenting warming and an intensification of droughts can be expected.

Governance to a sustainable power mix should firstly be realized by policy interventions to phase out carbon-related sources, including natural gas, in the power mix (Verbong and Geels, 2010). This effort will complement the existing instruments for enhancing national security (e.g. CONPES 3700 DNP (Departamento Nacional de Planeación), 2011; UNGRD(Unidad Nacional para la Gestión del Riesgo de Desastres, Gobierno de Colombia), 2015; INDC (Intended nationally determined contributions) Colombia, 2015) and that for fulfilling the sustainable development goals, i.e. CONPES 3918 DNP (Departamento Nacional de Planeación), 2018, because of their effects on reducing drought intensity.

However, even with a pure renewable energy approach, Colombia as a sink country is still passively influenced by the source regime through the environmental landscape. Given that the source regime currently continues to develop in the direction of intensifying the dry condition in the sink Colombia, water and food security will continue to be threatened by the coming increasing mega-droughts. Furthermore, the country's current path dependence on hydropower before re-alignment of new energy regime will continue to be prone to energy crisis. Mitigation measures not only reducing carbon emissions, but also slowing source countries' deforestation should be taken.

The governance of remote regime influences will rely on cross-border cooperation. This can be realized through negotiation between source and sink countries directing source regimes toward land conservation and land trading measures that had successfully decelerated forest loss in source areas in the past, e.g. interventions in supply chains through soy and beef moratoria or restrictions on access to credit (Arima et al., 2014; Gibbs et al., 2015; Nepstad et al., 2014).

It is worth noting that, according to the results of Bagley et al. (2014), the environmental landscape as influenced by source area's deforestation is also able to affect drought severity received by source areas themselves. Thus it is in the interest of source countries to change the regime as well, given that these countries also reported serious damage from the record breaking 2015 – 2016 drought. Additionally, the 2017 regional call for combating drought already offers a regional platform for co-management (UNCCD (United Nations Convention to Combat Desertification), 2017). However, the current regional combat against droughts focuses on the preparedness rather than collaborative mitigation to halt intensification of drought through mechanisms of deforestation and carbon emissions. A shift of paradigm will require a raise in awareness of the anthropogenic factors intensifying droughts among regional authorities.

6.3. Theoretical insights

6.3.1. Pre-drought landscape shock

In our case, two types of landscape shock from droughts were observed triggering the process of Colombian energy transition (see section 4), they can be distinguished from the character of the shock. The first type is the landscape shocks during the drought of 2015 – 2016 and 2018–2019, featuring a slow but large amplitude change which resembles the disruptive landscape shock in Geels and Schot (2007). Another type of the landscape shock features small scale and mild speed triggers, observed before the onset of the 2018–2019 drought. This type of landscape shock originates from the predictive capability of modern science (modelling capability on the onset of El Niño phase) accompanied with the threat of upcoming drought phase. In our case *a sequence of transition pathways* (internal changes - *configuration pathway - de-alignment and re-alignment pathway*) was observed, triggered by both types of shocks. The mechanism triggering *a sequence of transition pathways* in our case is different from that described in Geels and Schot (2007) where the de-alignment was triggered by increasing level of disruptive changes. In our case, the de-alignment of the hydropower regime happened at a time when hydropower was stable and the 2015 – 2016 drought disruptive shock had passed. However, actors lost faith in a fear of the next, forecasted drought. The small but gradually growing pressure of the predictive shock resulted in the de-alignment and re-alignment phase of Colombian energy regime. This type of shock, can be useful in understanding other informed (forecasting equipped) pre-disaster transitions that takes place before low speed but high amplitude environmental hazards e.g. floods and heatwaves.

The predictive shock originates from the vision of "what the future might be like" (Beckhout, 2006). In our case, this pressure has resulted in regime de-alignment. While the literature mainly focuses on effects of expectation on innovation alignment, the findings from our case bring new insights into discussions of technological expectation. Nevertheless, that expectations for the future can influence the direction of technological development and the rate new innovation aligns (Rosenberg, 1976; Geels and Smit, 2000; Borup et al., 2006; Berkhout, 2006) implies possible development of competing energy regimes in our case. For example, the expectation for wind-power potential in Colombia might strengthen wind power outcompeting other energy sources for re-alignment. For a counterexample, when knowledge that atmospheric carbon is one cause of mega-droughts is diffused, a carbon-powered future may be less desirable among actors. This may make the realignment of carbon-related sources more difficult.

It is worth noting that expectation defined and diffused by some actors (the government, for instance) can be more impactful (Brown and Michael, 2003; Berkhout, 2006). A strategic management of visions (Alkemade and Suurs, 2012) for a non-carbon future by critical actors can be a key to sustainable energy transition in Colombia. In addition, the reoccurrence of droughts and the predictive shocks ahead of them will surely provide windows of opportunity.

6.3.2. Uninformed decisions away from sustainability: remote regime influences

The physical landscape as a backdrop is not 'not changing' (Driel and Schot, 2005; Geels, 2011) but its dynamics link remote or cross-sector (in our case the land sector and the energy sector) regimes and these could be key to transitioning to sustainability. This 'telecoupling' (Liu et al., 2013) through both social (e.g. global market chains) and natural (e.g. atmospheric, hydrological or biological) processes is often not recognized by current regimes but it could be crucial for achieving sustainability. In our case, that Colombia is not informed about the remote regime influences (Bolivian and Brazilian land use policies/market influences) on the drought leads to its adaptation-focused policy. It is not sufficient regarding continuously growing droughts under remote regime influences. Furthermore, without recognizing the effects of human-induced warming on the drought hazard, a decision to encourage more carbon related energy in the power mix will very likely contribute to stronger domestic droughts rather than mitigating them.

This calls for more investigation into other telecoupled systems that can be strategic for approaching sustainability. The MLP can provide a good analytical structure to understand the relationship between telecoupled source and sink regimes and the causality of source regime (Geels, 2011) on sink regime changes. The geographical nature of these linkages should be in particular underscored for further managing these source-sink linkages, which usually requires transboundary and trans-sectoral cooperation. Experiences from cross-border governance (Perkmann and Sum, 2002; UNCTAD (United Nations Conference on Trade and Development), 2002) such as integrated basin management (Hooper, 2003) and convention on air pollution (Sliggers and Kakebeeke, 2004) can be useful for facilitating these actions.

6.3.3. Power of the regime influence

The source and sink regime linkage through deforestation influences demonstrates a power structure of one-side influence. Similar to a rather well-understood upstream-downstream power hierarchy, the remote regime in the source countries of Bolivia and Brazil exerts influence on the sink regime in Colombia. However, another anthropogenic factor influencing Colombia drought hazard, the human-induced warming through atmospheric carbon forcing, has a different power structure configuration. Due to the nature of carbon dioxide (the dominant output gas that causes the warming effect), a source area located anywhere on the planet (including Colombia itself) has the same level of influence on the sink regime. This underscores the importance of understanding landscape development and the power structure residing in the landscape bridge between the source and sink regimes. Reverse causality investigations in transition studies asking how regime shifts contribute to landscape changes (Geels, 2006, 2011) can be useful to identify those sink-source regimes. The management of these different structures can be linked with international relation studies and political ecology. For example, the Convention on Long-Range Transboundary Air Pollution (United Nations Economic Commission for Europe (UNECE (United Nations Economic Commission for Europe), 1979; Sliggers and Kakebeeke, 2004)) which facilitates co-management by upwind and downwind regions-which also has a clear power hierarchy-may provide a feasible framework for developing management of the source and sink regime linkage through deforestation.

7. Conclusion and outlook

We examined the dynamics of a drought landscape influencing the trajectory of Colombian energy transition process. We observed that the predictive shock, which resulted from a fear of repeating a past mega-drought disaster experience, provided a key window of opportunity for the regime shift. It has seen hydropower de-aligned and a current coexistence of multiple embryonic niche-innovations competing for realignment. The expected future droughts along with predictive shocks before them could provide windows of opportunity for a new regime to accelerate re-alignment in the future.

We also traced the source regime affecting those landscape developments which is rarely done in transition research. In doing so, the origin of the disaster-induced transition process in Colombia is in part traced to regime pressures in Bolivia and Brazil on the environmental landscape across countries. A part of the origin has been traced to regime influencing global atmospheric carbon. This shows that the current adaptation focus of Colombian energy policy to cope with future occurrence of droughts is inadequate, given remote regime crossing boundaries persists in intensifying droughts. Furthermore, current policy encouraging fossil fueled power including natural gas could indirectly enhance drought intensity and should be reassessed.

Our results have added insights into the rather rare discussion of regime-landscape interactions in transitions studies. We have also highlighted geographical content within the multi-level interactions being critical to understanding the transition. Our findings have consequences for the governance of a transition responding to landscape shocks and the remote regime influencing the transition.

Having done this, we are able to provide both recommendations for policymakers as well as future research.

The knowledge that through influencing the landscape, regimes can influence other regimes across geographies and sectors has repercussions for how policymakers should respond to landscape events:

1 Policy-makers should have oversight of remote regime influences on the stabilization of their local regimes. This is relevant for the governance of the transition. For example, using our case study, the Colombian power mix has been pressured from the drought landscape that can be traced to influences from Brazil and Bolivia deforestation. Attempts to reach the relevant regime in Brazil and Bolivia for reducing these influences will be strategic for Colombian governance of the energy transition.
2 There needs to be a growing awareness that by putting pressure on the landscape, decision makers may be causing destabilization in other geographies and sectors. This may change the cost-benefit analysis of policies as the ramifications of those policies may change if potential sink regime effects are considered.
3 Given that regimes are able to influence each other through the aerial rivers, consideration should be given to forming international cooperation to manage the moisture flows (Weng et al., 2019) similar to international cooperation for surface rivers and air pollution (Ellison et al., 2017; Keys et al., 2017).

However, the knowledge gathered from understanding that landscapes can transmit influence from one regime to another leads to further questions which should be explored in future research.

Firstly, other transitions beyond our case should be traced to examine the processes of different types of landscape dynamics and remote regime influences. This could provide further insight into the processes of transitions and their causes. Furthermore such knowledge would also help policymakers in deciding where to put pressure to reduce destabilization in their districts. Future research from a natural science perspective on mechanisms and geography of teleconnection (Lima and AghaKouchak, 2017; Boers et al., 2019) will be essential for tracing those processes and the development of efficient management tools. Regimes and transitions being remotely related by landscape dynamics can provide analytical insights into discussions of telecoupling in the Geography and the Earth system science community (Liu et al., 2013; Friis and Nielsen, 2017). While iteratively, contribution from these fields will also enlarge the understanding of landscape and remote regimes, rather unexplored areas in transition studies.

Secondly, future research could explore how the prediction of a landscape event, not limiting to disaster, influences the chances and dynamics of a transition. That Colombia began acting before the actual drought means that the predictability of the landscape events pressures the regime and influences the transition. In this research, the multi-level perspective has been a good analytical tool to observe pressures from the presence and representation (prediction) of landscape events and their interaction with the regime. This may be particularly interesting as much of the effects of climate change have not yet come to pass and knowing how the prediction of those effects influences transitions may be insightful for sustainable transitions.

Lastly, this research further highlights that so called “natural” hazards are not necessarily natural in their origins (UN (United Nations), 2004; World Bank, 2010). While up to this point the non-natural aspect of disasters was often the vulnerability of the affected society (Cannon, 1994; Thomalla et al., 2006; IOM (International Organization for Migration), 2010; World Bank, 2010), this research implies that remote non-natural influences also contribute to "natural" drought hazard. Further research could trace these "unnatural" causes of hazards complementing the knowledge in reducing the vulnerability which will both help to make headway in preventing disasters under a rapidly changing climate.

Declarations of Competing Interest

None.

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