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Promoting low-carbon transitions from a two-world regime: Hydro and wind in Québec, Canada

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HIGHLIGHTS

- A socio-technical exploration of wind and hydro synergies.
- Discusses technological complementarity in sustainability transition frameworks.
- History of Quebec hydro and wind energy development.
- Details transition pathways and niche shielding, nurturing, and empowering dynamics.
- Explores potential futures of wind-hydro development block.

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ABSTRACT

Technical synergies exist between wind energy and hydroelectricity because conventional hydro plants can effectively store wind in their reservoirs. However, the presence of low-cost, lowcarbon hydro resources could also inhibit wind energy development. This paper examines the tension between wind-hydro complementarity and competition through a case study of Québec, Canada. The case highlights that debate over the societal conception of the hydroelectric system, or "regime", and its potential to enable wind, creates different innovation pathways. The paper calls attention to the value of shielding and nurturing renewable energy niches to create transformative pressures that activate the complementary potential of existing technologies. To maintain momentum a wind-hydro development block will need to expand towards incorporating new technologies and geographies.

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1. Introduction

Preventing dangerous climate change requires transitioning from conventional fossil fuel to low-carbon technologies. New renewable energy sources can significantly reduce greenhouse gas emissions (GHG) (IPCC, 2011). However, the variable output of sources such as wind is often presented as a barrier to large-scale diffusion (IEA, 2011; Sovacool, 2009). Places like Canada and Norway are already endowed with electricity systems based on waterpower. In addition to generating renewable, low-carbon electricity, traditional hydro resources could complement newer renewable energies by balancing their resource variability. As stated in an International Energy Agency report, "the inherent flexibility of [hydro] generators and the potential for energy storage in their reservoirs make them well suited to integrate wind into the power system. As wind penetration increases, the agile hydro generation can address wind integration impacts and this service represents an economic opportunity for many hydro generators" (Acker, 2011, xv). Due to these distinctive technical features, hydroelectricity could play a role in promoting global low-carbon *transitions* by generating synergies with variables renewables such as wind.

Even though there are potential technical wind-hydro complements, actors within hydro-rich jurisdictions will need to adapt network operations, find political and social support for this technological configuration, and change institutional structures where necessary. It might be difficult to build sufficient societal momentum. For instance, Gullberg's (2013) study on the political feasibility of Norway's hydro resources acting as a "green battery" found insufficient actor support, in the short-term.

In Canada, weak inter-industry linkages from natural resource industries, such as hydroelectricity, is a traditional problem (Watkins, 2007). Hydroelectricity has been successful in complementing the development of consulting engineering (Niosi and Faucher, 1987) and attracting downstream industries like aluminum (Dales, 1957; Carpentier, 2006). However, hopes that hydro would enable secondary manufacturing expansion have gone unrealized (Froschauer, 1999). With climate change, natural resource linkages that support low-carbon technologies should be explored (Haley,

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2011). To date, no study in the Canadian context has investigated the prospect of complementary linkages between hydroelectricity and other renewable generation technologies from a socio-technical perspective.

This paper will use a case study of the Canadian province of Québec to consider how and why complementarity is achieved between wind and hydro technologies and to explore the factors that induce or block wind development within a hydro-intensive system. It will outline the treatment of technological complements in transition theory and provide a research approach to explore the characteristics of Québec's hydroelectric system and the history of wind energy development, thus far. It will discuss Québec's transition pathways and the factors that enabled wind energy, and then consider theoretical and policy implications. The paper finds that wind-hydro technological complements are possible, but are activated through tension filled technical, social, and political processes.

2. Transitions, niches, and technological complementarity

Low-carbon transition studies are interested in processes of change. In place of economic approaches emphasizing equilibrium, transition scholars look to evolutionary economic concepts (van den Bergh et al., 2007). Evolutionary frameworks examine actor searches for new technologies and organizational routines. Technological and organizational choices then face selection pressure from existing policies, markets, and other characteristics of the structural context, or selection environment (Nelson and Winter, 1982). Moreover, socio-technical theorists emphasize that elements such as cultural symbols, regulations, and user practices influence transitions alongside technical changes (Bijker, 1995). The *direction* of change is shaped by multiple interactions between actors following existing routines and undertaking new searches, using the social and technological elements available to them. Rip and Kemp (1998) outline how different socio-technical *configurations* result in pathways or trajectories towards sustainable or unsustainable futures. Policy analysis from an evolutionary perspective considers the consequences of different pathways, and the potential to change pathways by creating new system configurations (see Lehtonen and Kern, 2009).

The multi-level perspective (MLP) helps represent and analyze complex social and technical interactions (Geels, 2002). The MLP describes transitions with reference to three socio-organizational levels: regime, niche, and landscape. The *regime* outlines the dominant technological trajectory and accepted social practices involved in the provision of a societal function or service, such as electricity or communications. Geels (2006b) says a regime's structural elements consist of technologies, organizational actors, and rules or institutions. The *niche* is a space, protected from the selection pressure of the regime, where novel innovations can improve their performance. The *landscape* refers to macro phenomenon such as global events and cultural values, and can be treated as exogenous changes that influence the other levels. Transition patterns are explained via landscape pressures creating an opening within the regime for the adoption of niche-level innovations. Geels and Schot (2007) outline different patterns based on the timing and nature of interactions between these three levels.

Smith and Raven (2012) suggest a framework to study the development of niches within transition processes. They ask where niche protection comes from and how niches evolve out of their protected space. They outline three functional properties that niches play in transitions: shielding, nurturing, and empowering. *Shielding* is the process that protects new technologies from regime selection pressure. They discuss *passive shielding*, where protected spaces exist because of contingent reasons such as geographic separation or institutional spaces such as consumer networks or public support for research activities. In contrast, *active shielding* results from actors strategically and deliberately creating protected spaces through policy interventions and political advocacy. *Nurturing* is a process that supports the development of the innovation, so it can increase its innovation capabilities or performance. Strategic Niche Management (Schot and Geels, 2008) and Technological Innovation System approaches (Bergek et al., 2008; Hekkert et al., 2007) outline activities or processes that strengthen technological performance. For example, technical and social learning; the creation of expectations and visions, or guidance of the search; and the creation of networks to share knowledge, build up human resources, and establish political actor coalitions. Finally, *empowering* refers to interactions between the niche technology and its wider regime environment. Innovations become competitive within the established selection environment (labeled *fit and conform*) or the niche influences the regime selection environment in a way favorable to itself (labeled *stretch and transform*). Smith and Raven emphasize that these processes are shaped by power struggles, and the agency of niche advocates. Actors seek to achieve institutional reforms by creating political narratives about the character of "good" performance, by "strategically re-telling the past to make new sense of the present and envision alternative futures" (Smith and Raven, 2012), and through claims about the niche in relation to the regime.

The technological histories that informed the MLP (see Geels, 2005, 2006a, 2006b) as well as studies in development economics (Chang, 2008) highlight the role of niche protection. However, since a political process often establishes protection it can be difficult to remove protection at the appropriate time (Krugman, 1987). Smith and Raven note that transition policy should focus support on niches accumulating "innovation capabilities", and suggest developing political institutions that can avoid capture by vested interests.[1] Moreover, empowering could maintain protections because they are institutionalized in a new regime configuration (Verhees et al., 2013). For instance, to promote a democratic, resilient, and socially acceptable energy system, a higher price paid to community energy projects might become routine and no longer be viewed as a subsidy.

The interest in niche developments stems from the understanding that the regime is not an optimal equilibrium, but rather the dominant structural configuration at a moment in time. A regime configuration could create socially undesirable trajectories, akin to problems resulting from lock-in or path dependence (Arthur, 1989; David, 1985). In the climate change era, the regime could promote carbon lock-in (Unruh, 2000). Thus green niches are frequently studied as an alternative to fossil based energy systems (Verbong and Geels, 2007; Hofman and Elzen, 2010).

While the dominant transition storyline involves niches "constructed in opposition to incumbent regimes" (Smith, 2007), transition typologies also include the potential for regimes to adopt symbiotic niches to solve particular problems (Geels and Schot, 2007). In addition, innovation scholars highlight technological complements within larger systems. Rosenberg (1982) emphasized that a technology's full contribution is often not limited to its immediate production performance, but its influence on larger systems through complements with other technologies and linkages with other industries. Sandén (2004) discusses bridging technologies capable of molding structures towards sustainability.

[1] See Jacobsson and Bergek (2011) on the need to study politics and public administration issues.

A two-world technology will already be accepted within existing regime configurations and could be the core technology of a regime. However a regime based on a two-world technology could still work against sustainability transitions. Conceivably, existing regime rules could exclude the development of other technologies that will ultimately be needed, and over-reliance on a seemingly desirable regime technology could result in a "dead-end" (Sandén, 2004). The problem relates to a lack of diversity, misaligned configurations, or lost opportunities for fruitful technological complements with the regime rather than a failure to completely undermine the regime itself. The regime's exclusionary tendencies might not solely relate to its technological characteristics. Sustainability enhancing changes to a regime could leave technological elements largely unchanged, and instead focus on transforming institutions or social rules, and organizational forms. Thus it would be valuable to have a closer specification of which regime characteristics will block sustainability transitions, and which ones provide opportunities to create useful technological complements. The potential for different structural characteristics to foster either competitive or complementary relationships with other technologies is discussed in Sandén and Hillman's (2011) framework for studying technological interactions. They outline how different interaction modes result from structural overlaps along levels of a value chain, as well as material, organizational, and conceptual dimensions.

The process of finding a desired hybrid or bridging configuration between technologies is likely to be a disruptive process. Here it is worthwhile recalling Dahmen's (1989) development block conception, which emphasized that tension between structural elements are essential to reach a beneficial complementarity between technologies and their related socio-institutional elements. The temporary unbalances introduced by a new technology create pressures that can ultimately result in transformation. Dahmén uses the example of the Swedish steel industry, where converter techniques were more advanced than blast furnace techniques, requiring a search for improvements in the latter. Another example involves the search for new markets and applications of steel to use the more efficient Bessemer process. Translating Dahmén's conception to the MLP suggests the benefit of achieving a complementary hybrid between technological systems rather than targeting the wholesale undermining of a monolithic regime as the sustainability transition policy objective.

Evidently, when exploring technological complementarities, a nuanced understanding of niche-regime interactions is required. One that takes a closer look at the particular elements of the regime and that fully incorporates the potential for complementary interactions, while still acknowledging the strength of the MLP in describing the momentum of the regime and the selection pressure it imposes on new technologies. The relevance of these concepts to the peculiar case of a regime based on a two-world technology deserves empirical exploration.

3. Methods and case selection

This paper studies wind niche development within a regime based on hydroelectricity, a "two-world" technology when considering transitions to a low-carbon economy. Québec presents an ideal case study because of its history of hydroelectric development and its influence on the Canadian wind energy sector. Québec is the Canadian province with the second largest installed wind capacity (Fig. 1). A historic case study enables analysis of the multiple contingencies and contextual conditions (Yin, 2009; Flyvbjerg, 2001) that led to the protection and development of the wind energy niche, and the manner in which the tension between wind-hydro complementarity and competition played out over time. Case data was collected from secondary literature, annual reports, technical and regulatory documents, news articles, and expert interviews.

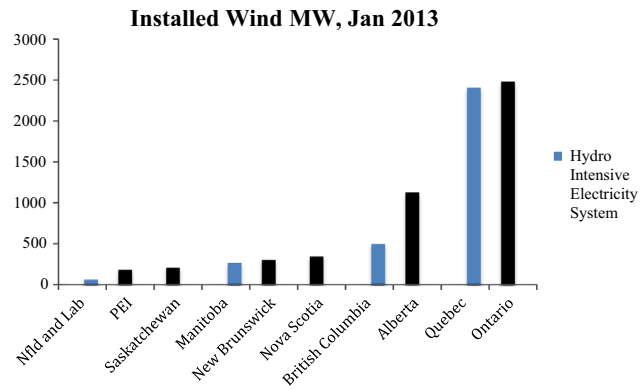

Fig. 1. CANWEA, 2013. Powering Canada's Future, Available at http://www.canwea.ca.

The paper will explore niche-regime interactions by first identifying regime socio-technical characteristics particular to Québec, grouped within technical, organizational (actors), and institutional (rules) dimensions. It will then trace the historic development of Québec's wind energy niche. Afterwards, the paper will analyze observed transition patterns, how the niche development processes of shielding, nurturing, and empowering occurred in Québec, and what blocking or enabling roles structural overlaps with elements of the hydroelectric regime played. This analysis will inform a discussion on implications for transition theory in the two-world case, future pathways, and policy directions.

4. Québec's hydroelectricity regime

4.1. Technology

35,125 MW (out of 35,829 MW) of Québec's installed capacity is hydroelectric (Hydro-Québec, 2012). There are 25 large hydro reservoirs within Québec, which can store water on a multi-annual basis and help manage electricity deliveries to internal and export markets. Due to the availability of inexpensive electricity and electric promotion activities, 76% of households in Québec use an electric heating system (Natural Resources Canada, 2010).[2] Québec has an extensive high-voltage transmission system, radial in shape, transporting electricity over long distances from mostly northern hydro dams towards southern demand centers (Fig. 2). The Québec transmission system operates asynchronously from neighboring markets in Ontario, New Brunswick, and the United States. Québec is an important exporter to the Northeast United States and its Canadian neighbors. Northern and island regions of Québec are not connected to the main electricity grid and are principally served by diesel generators.[3]

4.2. Organizational actors

Hydro-Québec is the government-owned utility that operates the generation, transmission, and distribution of electricity throughout the province. The utility gained province-wide scope after the nationalization of private electric utilities in 1963. The centralization of activities enabled a massive building period in the

[2] This compares with the next highest rate in Canada of 42% in the Atlantic region and the lowest penetration rate of 12% in the province of Alberta.

[3] In 2012 energy needs from these isolated regions were 411.7 GWh. About 164 MW of capacity is installed within these systems (Hydro-Québec, 2013c, tableau 2B-1).

Fig. 2. Hydro-Québec, 2012. Sustainability Report, p. 2. Annotated by author.

1960s and 1970s involving the construction of large-scale dams and transmission networks (Bellavance, 2003; Bolduc et al., 1989). The Québec government can exercise control over electricity policy through legislative means and its influence as the sole shareholder of Hydro-Québec. In 1996, the government created an arms-length electricity regulator, The *Régie de l'énergie*, to approve electric rates and transmission and distribution plans. Hydro-Québec also operates a research institute, named *IREQ*,[4] which invests about $100 million a year in R&D and employs 500. IREQ was created after the nationalization with the primary objective of optimizing and managing the high-voltage transmission grid; its founders also wished to develop Québec's general expertise in electric technologies and undertake "long-term" research (Masson, 1995).

Hydroelectric projects are situated within First Nations territory, and concerns over the social and environmental impacts have spurred opposition. Extensive consultations between Québec and First Nations created agreements prior to major hydroelectric developments.[5] Environmental organizations have interests ranging from climate change (e.g. équiterre) to the protection of rivers (e.g. Rivers Foundation). Both residential and industrial consumer interests support lower electric prices. In addition, the employees of Hydro-Québec can act as a separate political interest. For instance, the union representing IREQ researchers, named SPSI,[6] has made independent depositions to public policy processes.

4.3. Institutional rules

The nationalization of Hydro-Québec was an organizational as well as a cultural change. Québec is the only province in Canada with a majority French-speaking population. Hydro-Québec became a symbol of the province's "Quiet Revolution", a new ideal of a "technological society led by French Canadians".[7] The nationalization replaced an English-speaking dominated industry with

[4] l'Institut de recherche d'électricité d'Hydro-Québec (IREQ).

[5] The James Bay and Northern Québec Agreement (1975) and "The Peace of the Braves" (2002).

[6] Syndicat professionnel des scientifiques de l'IREQ.

[7] Some prefer to identify as "Québecois" rather than "French Canadian".

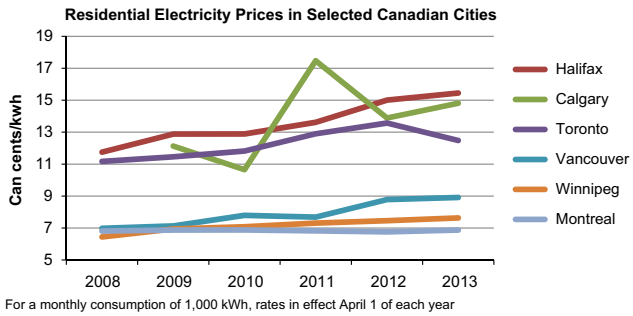

Fig. 3. Hydro-Québec, 2008–2013. Comparison of electricity prices in selected major Canadian and American cities.

a new francophone professional class (McRoberts and Posgate, 1980). The application of francophone technological capabilities in large production projects inspired the goal of making Québec renowned in electric technology. This history linked hydroelectricity with the social, political, and economic emancipation of Québec (Savard, 2010).

The government has frequently used Hydro-Québec as an instrument of economic development (Parenteau, 1986), as well as a source of revenue, principally through dividend payments, as well as taxes and water royalties. The role of Hydro-Québec in industrial policy has gradually de-emphasized the attraction of domestic industries and placed greater emphasis on revenue generation through exports (Froschauer, 1999). The utility is often referred to as the government's "vache à lait" (cash cow). The idea of a "social pact" to secure the benefits of hydro nationalization through low electric rates is prominent. The pact consists of (a) regionally uniform rates (b) rate stability (c) low rates, particularly for the residential sector and (d) public ownership (Hydro-Québec, 1999). Québec residential customers pay some of the lowest electric rates in Canada (see Fig. 3).

Québec's regulatory structure changed during North America's deregulation trend in the 1990s and the creation of the *Régie*. Québec did not decentralize to the same extent as other jurisdictions because hydro technologies were not easily divided up (Netherton, 2008; Nelles, 2003). In order to maintain access to export markets, Hydro-Québec unbundled its production, distribution, and transmission units. To maintain low domestic electricity prices in a deregulated North American market, the production and distribution divisions of HQ signed the "heritage contact" to guarantee a block of 165 TWh at 2.79 cents/kwh.[8] Hydro-Québec Distribution purchases energy greater than the heritage block amount through competitive tenders, which provides opportunities for private renewable energy producers. The Régie de l'énergie has the power to regulate the rates and plans of the transmission and distribution divisions of Hydro-Québec, but it does not scrutinize the production division's projects under the guise of a free market for energy generation (Raphals, 2000).

4.4. Energy costs in the regime

The technical, organizational, and institutional regime characteristics influence the selection environment faced by energy technologies. In electricity systems, technology choices are strongly influenced by costs. Table 1 lists publically announced Hydro-Québec electricity production costs. The table demonstrates that heritage hydroelectric developments have low average production costs. However, cost increases for new hydroelectric projects suggest that Québec is exhausting its low-cost hydroelectric potential.

Published wind energy costs are higher than hydro. While low production costs for hydroelectricity are certainly due to the technical and material realities of an established technology, the organizational features and institutional rules of Québec's electricity regime also influence the accepted cost structure in favor of the hydro technology. For example, the cost estimate for the Romaine subtracts water royalty payments to the government and HQ's profit margin. Regime rules and organizational set-ups legitimize the subtraction of these costs since they represent transfers between Hydro-Québec and the government as its sole shareholder. In contrast, wind energy costs include producer profit since Hydro-Québec Distribution purchases this energy from private producers to fulfill energy needs greater than the heritage block provision. The wind price also includes transmission costs. These costs are influenced by the technical decision to upgrade transmission to receive peak wind energy deliveries, rather than curtailing wind at certain times. The allocation of transmission costs is contentious since upgrades also benefit regional users and other generators (see Fischlein et al., 2013). The cost of wind also includes balancing wind variability, which is estimated based on the opportunity cost of hydro producers forgoing sales rather than the technology cost (Richard, 2007). As well, Table 1 shows the higher cost of the third wind RFP, dedicated to community projects. As we will see, Québec implemented carve-outs for community energy as well as local procurement standards, both of which could increase prices. If wind benefited from the same financial conditions as hydro (i.e. if HQ developed wind projects), and accrued economies of scale, scope, and learning, Saulnier and Reid (2009, 157–159, 319–335) argue that wind could be competitive with the Romaine hydro project.

While price comparisons between wind and hydro highlight an arena for technological competition, there could also be complementarities. For instance social and technical constraints that limit hydro might cause the regime to adopt wind as an add-on technology. A hydro-based system can manage wind variability because of the flexibility of the plants and the potential to use reservoirs as storage. Wind generation coupled with storage could enable an energy producer to sell into the export market during high-price, peak periods and recoup revenues greater than wind production costs (Saulnier and Reid, 2009, 233).

These cost specifics and disparities demonstrate that hydro regime and wind niche characteristics matter. The cognitive frames associated with state-owned hydro projects and the organization of wind energy procurement and framing of wind energy costs influence prices. Niche dynamics also influence prices and could explain why wind might be selected even though its costs are perceived to be higher. For instance, while private sector and community-based projects could have higher costs, these attributes might be *why* the government provided protection.

5. History of wind niche development

5.1. 1975–2003 – wind niche protection and development

Québec's first venture into wind energy started in the mid 1970s when a number of countries were experimenting with different wind turbine configurations with the advent of the oil crisis. IREQ focused on vertical axis turbine designs, in partnership with Canada's National Research Council (NRC). IREQ erected a 40 kW turbine in 1975, and a 230 kW turbine in the Magdalen Islands in 1977, which broke down in its first year of operation and was replaced. In 1988, IREQ and NRC built the largest vertical axis

[8] For a discussion on the financial and distributive implications of the heritage contract see Clark and Leach (2007).

Table 1
Hydro-Québec reported technology costs.

	Levelized cost (cents/kwh)
Hydro	
Hydro-Quebec Production average cost of generation (2008)	2.2[a]
Eastmain-1-A/Sarcelle/Rupert Hydro Project (in operation 2009–2012)	5.1[b]
Romaine River Hydro Project (in operation 2014–2018)	6.4[c]
Wind[d]	
1st Request for Proposals (2004)	8.3[e]
2nd Request for Proposals (2008)	10.5[f]
3rd Request for Proposals (community) (2010)	13.3[g]

[a] Hydro Québec, Strategic Plan 2009–2013, p. 30.
[b] Hydro Québec, Financial Profile 2007–2008, p.17, 2011 dollars.
[c] Hydro-Québec, 2013, Projet de la Romaine: un projet rentable, 2015 dollars.
[d] All wind energy prices include transmission and balancing costs.
[e] Hydro-Québec, 2004, Appel d'offers pour l'électricité produite à partir d'éoliennes: Hydro- Québec retient huit soumissions pour un total de 990 MW, communiqué de presse, Oct.
[f] Hydro-Québec, 2008, Tender call for 2000 MW of wind power: Hydro-Québec accepts 15 bids.
[g] Hydro-Québec, 2010, Call for tenders for the purchase of 500 MW of wind power: Hydro-Québec Distribution accepts 12 bids totaling 2914 MW.

turbine in the world at that time (4 MW). Twenty-two people were working within Hydro-Québec on wind energy, but they could not produce cost-effective machines and the federal government's interest waned in the mid 1980s with the end of the energy crisis (Hydro-Québec, 2013b; Saulnier and Reid, 2009).

Hydro-Québec re-oriented its research activities towards Québec's off-grid northern and island communities. While these isolated systems use expensive diesel generators, residents of these communities pay the same electric rates as the rest of the province.[9] A horizontal axis turbine, modified to withstand cold climates, was erected in 1986 in the Inuit community of Kujjuaq. IREQ designed a coupled wind-diesel system capable of high wind penetrations, without the need for energy storage. The system installed wind capacity well above peak demand and managed periods of excess wind generation by servicing secondary loads, such as hot water. This configuration required sophisticated control systems and modeling techniques to maintain electrical frequency. The design was successfully commercialized in Alaska in 1999 (Saulnier, 2011).

The Québec government sent out a Request for Proposals (RFP) for non-hydro generation in 1991, stating that long lead times of hydro projects created short-term energy needs. Delays became more severe as the "Great Whale" hydro development faced First Nations and environmental opposition. One wind energy developer (Kenetech) submitted a proposal to the RFP. In November 1994, the same month the Great Whale was canceled, Hydro-Québec announced that an agreement to construct the 100 MW "Nordais" project on the Gaspé peninsula, at a cost of 5.85 cents/kwh, using Danish turbines (Philippas, 1996). A local test site for evaluation and promotion of technology transfer was created in 1997 and the project was inaugurated in 1999. This was a large-scale wind project in a hydro-intensive province, built by a private power producer. At the time, one journalist expressed surprise that a wind project succeeded, given the domination of the "castors" (beavers), a moniker used to express the cultural and technical supremacy of hydropower (Francoeur, 1999).

In 1996, Québec launched an energy policy supportive of wind power due to the promise of economic development, quicker project realization periods, low environmental impact, and the potential to effectively store wind within hydroelectric reservoirs.[10] In 1998 the government asked the newly created energy regulator to provide advice on wind energy. Hydro-Québec's stated position was that the private sector should develop wind, that it would be difficult for Québec to find an industrial niche given the lead of countries like Denmark, that energy purchase costs should not be higher than its average supply cost ($2.81 cents/kwh at the time), and that the government should support additional costs associated with developing wind. HQ recognized the opportunity to store wind within hydro reservoirs, but also noted potential negative environmental impacts of wind "intermittence" leading to fluctuating river flows. The Régie de l'énergie (1998) stated that while higher in price than hydro, there was a window of opportunity for Québec to create an industry and promote regional development. The regulator derived its wind target from estimations of volumes required to create a viable manufacturing sector, suggesting 50 MW per year between 2002 and 2011. It also tasked HQ with studying the feasibility of integrating 1000 MW in the Gaspé region. The government asked for a purchase price that would be socially acceptable and economically viable, and the Régie suggested that the price not exceed 5.8 cents/kwh, the cost of Nordais.

In 1998 a group of political actors and municipal officials in the Gaspé asked the provincial government to make their region a priority for wind development. After experience with the Nordais project, regional actors hoped to encourage more research and manufacturing jobs. In 2000, the government provided a tax credit for the manufacture of wind turbines and components, and the Wind TechnoCentre was created in 2000 to support the industry. In April 2002, the region was hit with closures of a mine and copper smelter. Shortly before an election, the Premier announced a plan to launch a 1000 MW RFP for wind projects in Gaspé (Dufour and Feurtey, 2008). The approved projects would need to spend 40–60% of their costs within the region. As a result, new companies located in the Gaspé, principally involved in

[9] In 2012, production costs in isolated grids ranged from 34–132 cents/kwh (Hydro-Québec, 2013c, tableau 3-2), while the residential electric rate was 6.8 cents/kwh.

[10] The physical reality is better described as local demand centers consuming available wind energy, resulting in less hydro plant utilization, which allows water to be conserved within reservoirs.

manufacturing tower and blade components (OECD, 2012, chap 7). A regional cluster was formed with a research and technology transfer center focused on wind in cold climates, training programs, and local university involvement (MDEIE, 2009).

5.2. 2004–2006 – wind vs. gas

In 2004, the Québec government authorized the building of an 800 MW combined-cycle natural gas plant in the region of Suroît. Hydro-Québec said the new plant was needed since environmental assessments and negotiations with First Nations had delayed hydro project construction. They anticipated energy shortfalls between 2006 and 2008; afterwards the plant would export energy. To make their argument, HQ eventually released data showing low reservoir levels (Simard et al., 2004).

Hydro-Québec (1999) had earlier outlined a strategic orientation to invest and participate in the production and distribution of natural gas. At that time the CEO expressed an expectation that hydroelectric potential would diminish in about ten years, and Québec would jump towards distributed generation based on gas (microturbines, fuel cells) (Caillé, 2000). Natural gas was represented as an environmental choice, since American states were substituting it for coal to reduce GHG emissions (Savard, 2010). Combined cycle gas plants were an attractive technology for utility companies in deregulated markets (Watson, 2004).

The counter-argument produced by environmentalists and energy experts, including IREQ employees, emphasized the complementarity of wind and hydro. Wind production is the highest during winter, when hydro reservoirs are at their lowest. Wind generation could allow water to be conserved in reservoirs during this critical period (see Denault et al., 2009). In addition, wind strength is correlated with heating demand as higher winds lead to convective heat loss from buildings. In the Québec system a 5 km/h increase in wind can increase heating demands by 500 MW (Saulnier and Reid, 2009, 221). Québec has a high penetration of electric heat, incented by the availability of cheap hydro. Furthermore, by now the wind RFP procured 990 MW at an average price of 6.5 cents/kwh (8.3 cents adding transmission and balancing costs), a price that could be competitive with estimates of the gas plant option (see Dunsky, 2004).

The most prominent argument against the Suroît gas plant concerned GHG emissions. Canada ratified the Kyoto Protocol in 2002, and it would come into effect in February 2005. Environmental activists noted Québec's unique situation. While other jurisdictions considered gas as a cleaner alternative to coal or oil, for a hydro-intensive system natural gas was a “step backward” with respect to GHG emissions (Guilbeault, 2004). In February 2004, the *Coalition Québec Vert Kyoto* organized the largest environmental protest Québec had ever witnessed. Greenpeace released a poll showing 67% opposition to the project (Boutin, 2004).

The controversy required the Minister of Natural Resources to ask the energy regulator for advice on the natural gas plant. In the Régie de l'énergie's June 2004 decision, it characterized the project as not essential, but perhaps desirable. It also noted that the first wind RFP produced a number of bids at reasonable prices. By November 2004, the Québec government announced it was abandoning Suroît and that a new strategy would focus on hydro, wind energy, and energy efficiency. In January 2005 a report showed the potential to integrate 4000 MW of wind power by 2015 (10% of peak demand) within current technology and transmission constraints (RSW Inc., 2005). A second RFP was issued in October 2005 for 2000 MW within all regions of Québec, with local content rules favouring Gaspé and the entire province. The May 2006 Energy Strategy included a 4000 MW target, noting the possibility to add an additional 100 MW of wind for every 1000 MW of new hydroelectricity.

5.3. 2006–2012 – wind integration

In 2006, the first wind project from the 1000 MW RFP came into operation and the wind target was established. Hydro-Québec's CEO announced an intention to become “the world benchmark for quality and reliability of wind integration on a large electric network” (Vandal, 2005). Hydro-Québec faced some unique issues with respect to wind integration. First, there was a need to analyze the influence of wind on the hydro system. Second, Québec is one of only two grids in North America that operate asynchronously (DC transmission links with neighbors). This means that short-term supply-demand differences, expressed as frequency deviations, must be managed within their system alone.[11] While the flexibility of hydro generation can quickly balance supply and demand, achieving such balance requires detailed planning. Furthermore, the Québec system is “radial” with primary demand centers focused in the Montreal-Québec City area and major transmission routes extending towards hydro plants in the north. Most wind projects would be geographically concentrated on the Gaspé peninsula due to its wind resource and regional economic development objectives. The peninsula is at the end of one of the spokes of this radial network, and is an electrically “weak grid”, more vulnerable to local supply-demand deviations. Gaspé would change from being a net importer to a net exporter of electricity (Robitaille, 2009; Forcione, 2013).

In 2006, IREQ recommended the creation of a corporate wind committee, with a budget under the “strategic initiatives” file, to coordinate activities and explore issues of concern to all Hydro-Québec divisions (production, distribution, transmission) (Forcione, 2013). R&D efforts focused on examining how to adapt hydro reserves and operational processes, exploring the reliability of wind plants, and supporting the creation of a centralized wind forecasting system. To explore wind integration, IREQ researchers deployed their expertise in simulation and modeling of power systems. IREQ hosts a power system simulation laboratory, and developed software tools for real-time and off-line simulation, across various timeframes. They built from these platforms to create a simulator for measuring the impact of wind on power system operation (see Sybille et al., 2010). In 2011, the Utility Wind Integration Group, recognized HQ's research expertise by granting it three prizes for “large-scale real-time simulation of wind power plants”, “a new simulation approach for the assessment of wind integration impacts on system operations”, and “computation of dynamic operating balancing reserve for wind power integration”.

There is also potential for Hydro-Québec to build from its traditional attentiveness to weather and climate. The utility has an interest in closely monitoring weather patterns to anticipate demand changes in export markets as well as domestic demand given the high penetration of electric heat; to assess the availability of hydro given fluctuating water levels; to explore issues with wind development in cold climates; and to predict adverse weather effects on generation, transmission, and distribution assets that are stretched over long distances in a harsh climate. Thus far the wind forecasting system created in partnership with Environment Canada explored the influence of wind on turbines in “complex terrains”. Environment Canada improved its atmospheric modeling capabilities, and wind data can be collected in real-time (Forcione et al., 2008; Balvet et al., 2009).

The incorporation of wind into Hydro-Québec's portfolio also introduced institutional issues. The regulations governing the first 1000 MW RFP required coupling wind with a hydroelectric capacity guarantee through a balancing contract. A contract was

[11] Asynchronous systems have lower “inertia” than systems where AC links allow supply and demand to be physically balanced over a large geographic area.

established between the production and distribution divisions of Hydro-Québec in 2005. While the energy from wind contracts is sold to the distributor, the agreement saw the producer incorporate the wind into its portfolio and use its hydro resources to smooth out variations. The generator guaranteed uniform energy deliveries to the distributor, based on the annual wind capacity factor. The original estimate of the balancing service cost to the distributor was $5/MWh (Richard, 2007). Critics of the agreement questioned if having a uniform delivery structure neglected the value of allowing greater wind deliveries during winter peak demand (Raphals, 2008). In 2010, HQ proposed a new agreement to allow greater variation of wind utilization by the distributor between the summer and winter, while still permitting the distributor to effectively deposit and withdraw energy from the hydro reservoirs. The regulator acknowledged these improvements, but recommended that HQ launch a competitive RFP for some of these services.

In addition, the wind policy faced criticism regarding the prominence of large projects to the exclusion of municipalities and First Nations. In 2009, the government issued a 500 MW call for proposals targeted to community and First Nations projects. As argued by Jegen and Audet (2011) this demonstrated a willingness of regime actors to make concessions for "soft path" energy visions, prioritizing decentralized, "grassroots" participation over lowest cost.

5.4. 2013 – electric surplus and new energy debate

In December 2012, Hydro-Québec projected that they could find themselves with a surplus of electric supply until 2027 because of decreased industrial demand and low export returns created by lower natural gas prices. This triggered intense debate. Consumer advocates questioned the need to procure more renewable energy and sell it at a loss (Couture, 2013). Up until this point, the rate impacts of wind were not prominently debated (Jegen, 2008). Hydro-Québec was a "cash cow" because of the lucrative export market. However collective benefits from export profits could now turn into collective losses with domestic energy projects (including wind) with costs higher then export revenues. In response to these concerns, wind energy advocates argued that the surplus was an opportunity to expand electrification to new markets, such as transportation and new industries (Samray and Legendre, 2013). Environmentalists questioned why HQ was still moving forward with the construction of the 1550 MW Romaine River hydroelectric projects.

In May 2013, the newly elected government announced its intention to issue an 800 MW RFP to fulfill the 4000 MW target. Some projects would be produced by Hydro-Québec Production and the rest would be targeted towards First Nations, the Gaspé and Lower Saint Lawrence regions, and community-based projects. The Minister cited the need to maintain manufacturing jobs in the Gaspé region, and the government's long-term strategy to promote complementary wind-hydro development (RNQ, 2013). In July, the government announced public consultations on energy issues, leading towards a new energy strategy. In August, HQ filed for a 3.4% rate increase, stating that "purchasing power from new wind farms" presented the largest cost increase.[12] This, once again, triggered public debate over the future of wind.

[12] The increase is for the 2014–2015 rate year. Hydro-Québec states that a 2.7% cost increase is due to energy purchases, principally from wind. Other factors include a 1.4% increase in costs due to demand growth, and 0.8% due to indexing heritage block deliveries to inflation. A 1.5% "efficiency gain" reduces the rate impact (Hydro-Québec, 2013d). Hydro-Québec estimates 6.9 TWh of wind energy deliveries in 2014 (Hydro-Québec, 2013a), and we can expect the final wind target to generate 11 TWh.

6. Discussion: transition patterns and niche development

The case history revealed a number of technical complements that go beyond hydro balancing wind variability. While wind varies over short periods of time, and hydro plants can ramp up and down to compensate, water resources vary by season and over multi-annual periods. Since wind energy can insure against reservoir shortages and help meet seasonal demands, the wind also "backs up" hydro.[13] The combination of the two resources gives the potential for an energy provider to market 100% renewable or firm wind energy for export. In addition, the case demonstrated that hydro plants frequently faced lengthy construction and approval processes, and that wind energy projects were able to fill anticipated supply gaps.

The realization of these technical potentials did not naturally occur. Rather they were achieved via a transition process involving political struggle, landscape pressures, and niche protection and development. The transition pathways outlined in the case study were most closely related to "transformation", producing a "hybrid grid" (Verbong and Geels, 2010). In this pattern moderate landscape pressure occurs at a time when niche innovations are not prepared to displace the regime. Social movements voice criticism and regime actors adopt symbiotic elements of niche technologies and adjust regime rules. The case history demonstrated that between 1975 and 2003, the Nordais project took advantage of a window of opportunity opened up by long lead times associated with hydro construction and opposition to the Great Whale project. Between 2003 and 2006, the Kyoto Protocol introduced landscape pressure, and internal regime problems of delayed hydro dam construction led to the need for a complementary technology. Social movements mobilized to oppose natural gas and pushed Hydro-Québec and the government to adopt wind as a symbiotic niche. The regime then made internal modifications to integrate this new technology. By 2013, new landscape factors triggered another debate over wind power. The further empowerment of the wind energy niche and its influence on energy transitions is still unfolding.

Throughout the case, hydro regime rules remained dominant, with wind playing a subservient role. This was exemplified first in the 2006 Energy Strategy target of developing 100 MW of wind for every 1000 MW of hydro. Secondly, while the balancing agreement provides an interesting example of how a hydro-wind combination can deliver firm energy, it also demonstrated the dominant mental mode of regime actors who viewed wind as a burden because of its "intermittence".[14] A full exploration of wind-hydro complementarities would have considered the benefits of wind's correlation with winter demands, insurance against reservoir shortages, and risk-reducing benefits of using a more modular technology with quicker construction periods. Finally, the construction of the Romaine River projects after HQ had already committed to purchase 4000 MW of wind, and despite concerns over an energy surplus, demonstrates the momentum for further hydro development.

While the hydro regime maintained its relative strength and momentum, the case also demonstrated the potential for complementary niche-regime interactions and peculiarities associated with niche development within a two-world regime. To more fully

[13] Note that reducing hydropower production in winter could more closely mimic natural downstream river flow patterns with less flow in winter and higher flow in spring/summer. For discussion see Assani et al. (2006).

[14] A discursive battle exists between the term "intermittence" vs. "variable" to describe wind energy resource availability. Intermittence suggests that resource availability is completely up or down, and difficult to predict. It implies that wind is unreliable and unmanageable. Variability suggests subject to change, but potentially predictable and manageable.

understand the nature of the niche-regime interactions that brought about the observed transition pattern, we will now explore the wind niche development processes of shielding, nurturing, and empowering. To reflect the extent of socio-technical complementarity or competition, I will discuss the enabling or blocking role played by hydroelectric regime structures, where relevant.

6.1. Shielding

The case demonstrated examples of both passive shielding, where niche protection resulted from contingent historic and geographic factors, and active shielding achieved via policy and politics. IREQ provided a protected space for wind energy research, a form of passive shielding within a pre-existing organizational niche. The organization's capacity for research, and partnership opportunities provided by federal agencies, were more important than the influence of the 1970s oil crisis, since Québec's electricity system was not dependent on oil. Later, isolated grids offered a geographic niche for further wind experimentation (passive shielding). The justification of wind energy for regional economic development during the 1990s energy planning processes, presented a conceptual niche, resulting from active shielding by policymakers and advocates. The additional importance of low-GHG energy sources following Kyoto created another conceptual niche. Wind was thereafter actively protected through the adoption of the 4000 MW target.

Some characteristics of the hydroelectric regime blocked wind development through negative selection pressure, while other characteristics helped enable the niche. The low price of hydroelectricity blocked wind development. Initially, Hydro-Québec promoted the idea that wind must compete with the average cost of hydro. The utility also stated its disinterest in diversifying from its core expertise in hydro. However, other regime elements enabled wind development. IREQ created an organizational niche for research into new energy sources. The “social pact” rule of having geographically uniform electric rates and quality of service, created an imbalance between cost and revenue in isolated communities that spurred interest in wind-diesel systems. Finally, the organizational connection between the government and Hydro-Québec and the historic role of the utility in promoting economic development created a conceptual space for wind energy.

6.2. Nurturing

Nurturing is a largely internal process focused on the structural evolution of the niche. Once protection was secured, the case demonstrated the gradual strengthening of the niche. Expectations and visions of building a wind energy industry solidified within the Gaspé region, and its citizens, municipal leaders, and industries became advocates for wind development. While local opposition to renewable energy projects exists in Québec (see Jegen, 2008), the interest in regional development created *yes in my backyard* (YIMBY) pressures, which contrasts with experiences in other jurisdictions, such as Ontario (Stokes, 2013; Hill and Ferguson-Martin, 2010). The research on wind-diesel applications in isolated grids strengthened IREQ's expertise in wind energy in cold climates and demonstrated the potential to integrate high levels of wind into a power system. This raised researcher expertise and expectations about the ability to integrate wind in the main grid, and acted as a prototype for visions associated with smart grid and community-based balancing of multiple sources of energy supply and demand (Saulnier, 2013). The Nordais project and the first 1000 MW RFP introduced foundational experiments that provided information about wind energy development, especially wind energy prices that were socially acceptable and economically viable. After the first two RFPs, municipalities and First Nations and other actors representing a “soft path” energy vision advocated for greater inclusion and received a carve-out for community-based energy. This strengthened the actor coalition in favor of wind and demonstrates social learning related to different ownership models.

The case revealed few overlaps with the hydroelectric regime that directly blocked or enabled nurturing processes. The blocking influence of the regime is best categorized as selection pressure preventing shielding. IREQ contributed to knowledge development and exchange, but we can describe these activities as proceeded from IREQ acting as a shielding organization.

6.3. Empowering

Empowering relates to how niches interact with the regime. A key transition point whereby the niche confronted the regime occurred during the debate over the Suroît natural gas plant. Wind was thereafter incorporated as an add-on technology. This event exhibits elements of a *fit and conform* pattern, whereby the niche fits within the established regime and a *stretch and transform* pattern, where the niche induces changes to the regime. A fit and conform pattern is present since the hydroelectric regime needed to find a cost competitive complementary technology to manage the problem of short-term energy shortages. However, the case also reflects stretch and transform because a social mobilization strategy was involved in the choice of wind over natural gas.

The Suroît event straddles these two concepts because political debate was less concerned with the wholesale displacement of the regime than the type of complementary technology to associate with it. Furthermore, within the political debate, actors highlighted different complementary elements of the regime. Hydro-Québec followed utility manager expectations regarding the value of gas in a deregulated environment. The utility sought a centralized and dispatchable power plant to fit within existing system operation routines. Opponents argued that hydro should be coupled with another clean energy technology, and linked leadership in wind energy to Hydro-Québec's history of technological innovation. They emphasized the conception of sustainable development and the hydroelectric regime's organizational capabilities. Researchers within IREQ openly opposed HQ's natural gas orientation. Smith and Raven's comment that niche empowerment often involves “strategically re-telling the past to make new sense of the present”, is particularly relevant. In this case, the hydroelectric regime provided historically conditioned assets along organizational and institutional dimensions that enabled wind development. The debate had as much to do with the conception of the hydroelectric regime, as advocacy for the wind niche.

Debates over wind vs. hydro costs highlight different empowerment actor strategies. Jegen and Audet (2011) attribute the argument that large-scale, Hydro-Québec owned wind could be cost competitive to a “nationalist coalition”, emphasizing public ownership as a regime characteristic. However the “soft path” coalition, prioritizing community development over lowest cost, made more headway. The actor strategies highlight attempts to fit within different aspects of the regime and to stretch it in separate ways.

Institutional and technical changes to the regime were made after the wind energy target was established, triggering interesting complementary dynamics. New engineering problems activated research expertise within IREQ, related to simulation and analysis of weather patterns. The experience with the balancing contract demonstrated the potential for hydro to fully smooth wind generation, and triggered a learning process that examined how to manage the costs and benefits of wind variability. Yet, these dynamics do not seem to correspond to either the fit and conform

or stretch and transform patterns, as we will discuss further in the next section.

7. Theoretical and policy implications of transitions within a two-world regime

Fit and conform vs. stretch and transform might present a useful spectrum to describe actor strategies, but these concepts seem misplaced as descriptors of niche-regime industrial dynamics, especially when a regime is based on a two-world technology. These concepts present the regime as a monolithic whole, without disaggregating regime characteristics with different blocking or enabling relationships with new technologies. The Québec case shows that some regime characteristics helped complement niche development. Although, technological complementarity did not naturally occur as the regime reproduced itself: niche shielding, nurturing, political struggles, and technical and institutional tensions related to incorporating wind energy played an important role.

In the two-world case where complementary relationships are sought, Dahmen's (1989) conception of a "development block" could be more appropriate. Dahmén emphasized the potential for technological complementarity, while outlining that various types of imbalances were integral to placing transformative pressure on existing economic structures, and eventually empowering the innovative capabilities of all technologies within the development block. The case demonstrated the importance that technical imbalances played in activating IREQ's research capabilities in wind integration, and the role of political tensions, particularly the controversy over Suroît, in fostering the social understanding that Québec's electric regime should be based on clean energy. The manner in which some regime characteristics (IREQ and the expectation that Hydro-Québec promote regional economic development) enabled shielding of wind niches can also find a place within the development block concept's recognition that complementary and unbalanced economic structures can be part of the same process.

The recent debates on wind energy and the existence of an electricity surplus introduces new imbalances that could unleash either positive or negative transformation pressure. Canceling Québec's wind energy activities would create negative transformation pressure. Dahmén outlines how positive transformation could occur if actors seek new markets and new technological combinations. This has implications for future transition pathways that could empower complementary clean energy development.[15] A "supergrid" pathway whereby extensive transmission interconnections and centralized system operations are used to incorporate more variable renewable energy would provide a market for wind-hydro production and hydro balancing services, and could also draw on Québec's expertise in simulation, weather monitoring, and long-distance transmission. Also, a future with "mass electrification" of transportation, heating, and industrial systems could empower a wind-hydro development block by activating a need for "clean" electricity, innovation in system operations, and matching of winter and overnight electricity loads with wind generation, backed up by hydro's flexible generation capabilities.

Whether or not these futures come to fruition depends on landscape factors, as well as elements within Québec's control. For instance, Québec could advocate for an east–west supergrid within the Canadian federation and/or north–south grid linkages with the US Northeast and Midwest. It can also promote a domestic policy of electrification. To maximize the potential for hydro to complement new renewables, Québec's electricity regime would need to develop an interest in the provision of technical and organizational services related to renewables integration, rather than simply seeking to export hydroelectricity. This would see Hydro-Québec emphasizing its research strengths and moving closer to becoming an integrator of energy services, as discussed in conceptions of "new utility business models" (Lehr, 2013).

The role of political struggle in the case demonstrates that the extent to which Québec citizens and policymakers see wind energy remaining as an important technology depends on the narratives and institutional rules that actors construct about the nature of the regime itself. If Québec actors understand hydro primarily as an export commodity, a provider of low prices for consumers delivered via its heritage investments, and a "cash cow" for the government, wind energy could fall out of favor. If instead, actors emphasize the role of Québec's electricity regime in electro-technology innovations, economic development, energy independence, and environmental sustainability, a vision could be developed aimed at using hydro as an enabling technology for wind and other renewable energies. The analytical task in studying niche-regime interactions in a two-world case is to identify the particular regime characteristics that could enable new technologies and to activate them, while reforming institutional characteristics that could create blockages.

Since supergrid and mass electrification structures cannot be immediately installed, Québec's wind and new renewable energy promotion policies are presented with a near-term challenge of maintaining developmental momentum in the wind sector. If these visions are established as worthy goals, some protection for wind, and potentially other emerging sustainable energy technologies, could be maintained. A reduction of wind innovation activities could prevent the establishment of a renewable energy development block and would remove transformative pressure that can unleash the complementary capabilities of hydroelectricity. The policy objective of encouraging transformative pressure to promote these long-term visions would need to be explicit to avoid capture by political actors primarily interested in maintaining protection to guard current technical and organizational frameworks. For a significant interim period, policy might prioritize learning and institution building over the volume of megawatts installed. Activities to promote the activation of innovative capabilities could include community-based projects to expand actor coalitions and social learning, experiments with electric vehicle-wind coupling, research on wind and water weather patterns in the context of a changing climate, exploitation of the opportunities that remain in wind-diesel combinations in isolated grids,[16] and experimentation with emerging non-wind renewables.

While this case was particular to Québec, identifying pathways to maximize the transition potential of two-world technologies in other jurisdictions could be a fruitful research avenue. The case highlighted technological complementarities that could exist in other hydro-based jurisdictions. The discussion on future pathways noted that Québec's wind-hydro development block could expand towards new technologies and geographies. Supergrid or mass electrification configurations could be implemented via a larger Canadian electrification strategy, with hydro as the backbone. The case demonstrated that experience with wind diffusion within a hydro-intensive jurisdiction strengthened the development block by building political constituencies, societal visions, and technical expertise. This paper did not explore wind-hydro complementarity in hydro importing regions. Given the potential for hydro to both complement and compete with new

[15] Note here the useful translation of transition pathways to electricity scenarios by Verbong and Geels (2010).

[16] By 2013, two pilot projects have been approved by the Régie.

technologies, it would be important to analyze the potential influence of hydro imports on domestic niche technologies, and to consider policies to promote complementary development blocks.

8. Conclusion

This paper explored wind niche and hydroelectric regime interactions. The regime was based on a two-world technology, with the potential to enable the development of the niche. Technical complements between wind and hydro exist, but were set in motion by actors able to exploit different characteristics of the hydroelectric regime to shield the niche from selection pressure.

Conceptual elements of the multi-level perspective were useful since wind required protection from regime selection pressure, and the wind niche was able to exploit windows of opportunity within the regime. Smith and Raven's (2012) elaboration of niche development processes provided worthwhile analytical concepts, but the notion of "empowering" somewhat awkwardly fit the case since it de-emphasized the innovation potential of some complementary regime elements. The goal for sustainability transitions in the case of a two-world regime is not the wholesale displacement of the regime, but an activation of its transformative potential. The case demonstrated that complementary characteristics of the regime could be activated through political struggle and debate over the nature of the regime itself, the maintenance of niches, and the nurturing of those niches.

Dahmén's conception of the development block provided insights on technological complementarity, while also emphasizing the role of social and technical tensions to foster innovation. The concept highlights the value of shielding and nurturing renewable energy niches with a goal towards creating transformative pressure to activate the complementary potential of related technological regimes. Future transition pathways that allow the wind-hydro development block to evolve will need to expand to incorporate new technologies and geographies. A supergrid or mass electrification future could not only empower the technical potential for clean electricity production, but also the Québec electricity regime's organizational and institutional assets. In particular, the research capabilities found within IREQ and the potential to foster a social vision based on technological innovation in clean energy.

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