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Synergies et persistances dans l'histoire des techniques de l'énergie

sous la direction de

Anaël Marrec



Centre François Viète
Nantes Université - Université de Bretagne Occidentale

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Wave Converters against Energy Systems? Le Minou's Ram and the Cattaneo Onco-Pump in the Frame of French Blue Coal Policy (1925-1945)

Anaël Marrec*

Abstract

This article develops two case studies of wave energy devices projects during the interwar period in France: Le Minou's ram (1925-1927) and the Cattaneo onco-pump (1925-1945). These historical examples meet two objectives, one historical and the other epistemological: they show the existence of mechanisms of persistence in the technological imaginary that orient the technical possibilities of the "thermo-industrial civilization" and they question the relevance and current use of the concept of "energy system" as a tool to analyze societies.

Keywords: history, energy, France, wave converters, energy system, imaginary, innovation.

Résumé

Cet article traite deux études de cas de projets houlomoteurs dans l'entre-deux-guerres en France : le Béliet du Minou (1925-1927) et l'onco-pompe Cattaneo (1925-1945). Ces exemples historiques répondent à deux objectifs, historique et épistémologique : ils montrent l'existence de mécanismes de persistance dans l'imaginaire technique qui orientent les possibles techniques de la société thermo-industrielle et questionnent la pertinence de la notion de système énergétique comme outil d'analyse des sociétés.

Mots-clés : histoire, énergie, France, houlomoteurs, système énergétique, imaginaire, innovation.

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THIS article develops two case studies of wave energy devices projects during the interwar period in France: Le Minou's ram¹ (1925-1927) and the Cattaneo ondo-pump² (1925-1945). These historical examples meet the objectives of the special issue "Synergies and Persistences in the History of Energy Technologies" on two levels, one epistemological (1) and the other historiographical (2): 1) They question the relevance and current use of the concept of "energy system" as a tool to analyze societies and changes in energy technologies; 2) They show the existence of mechanisms of persistence in the technological imaginary that guided the technical possibilities of the "thermo-industrial civilization",³ *i.e.* the assessment of the highest power by innovation actors, the possibility of delocalization from source to use and the constancy of the delivered energy.

To begin with, I will show how the history of renewable energies challenges the notion of energy system and I will introduce my conceptual framework. Then I will describe the French interwar marine energy policy in the frame of national hydroelectric development. Finally, I will expose in detail the two case studies based on archives from the Ministry of Public Works and technical publications.

Renewable Energies Challenging Energy Systems

The notion of energy system describes the overall set of energy resources and technologies used in a society.⁴ As a historical conceptual tool,

¹ "Bélier du Minou" in French, meaning literally "Kitty's Ram": "Le Minou" is the name of the place where the hydraulic ram described in this article was built. Like "ram" in English, "bélier" means "a male sheep" in French and "bélier hydraulique", the hydraulic ram, a device amplifying the pressure of a water flow for mechanic purposes (see below).

² "Ondo-pompe Cattaneo", from the name of its Italian inventor Francesco Cattaneo (see below).

³ Expression used by Alain Gras to underline the preponderant place of the thermal machine and its associated imaginary in the industrial civilization (Gras, 2003, p. 8).

⁴ Jean-Claude Debeir *et al* give a precise definition of this notion: an energy system is the "original combination of various converters" which are characterized by the use of specific energy sources and their interdependence, at the initiative and under the control of classes or social groups, which develop and control themselves (Debeir *et al*, 2013, p. 25)".

it is of great interest to understand global trends in the mobilization of energy sources as well as the economic and politic structures of societies.⁵ Like other holistic notions, its consideration as a universal feature tends to neglect specificities, namely the historical aspect of energy networks and the local dimensions of energy converters.⁶ Indeed, the existence of an energy system presupposes a necessarily privileged interaction between energy converters at any moment in history. However, there is nothing obvious about this assumption: energy technologies have not always been homogenized within networks, and they are intertwined with other dimensions than energy. The crossed history of energy networks and renewable energies in the industrial era challenges the relevance of considering energy converters as necessarily integrated within systems connecting energy technologies for the purpose of mobilizing energy.

Several scholars have analyzed “large technological systems” (Hughes, 1987), “technological macro-systems”⁷ (Gras, 1997) or “technological systems” (Hecht, 2014) as socio-technical networks linking technological objects and social organizations over very large territories. These were developed in the 19th century in industrialized countries, and unlike global energy systems that would exist without a preliminary plan, they were purposefully constructed by groups of stakeholders (State, engineers, and companies). The interactions that exist between the converters of these networks are as indisputable as they are unprecedented, as in the emblematic example of the electricity network. The development of energy systems has disrupted hitherto independent uses of energy. While new energy “sectors” have progressively connected energy uses to coal, gas, electricity and oil networks, most “traditional” energy converters using renewable energies, such as hydraulic (Benoit, 2020), tidal (Charlier and Ménenteau, 1997) and wind mills (Marrec, 2018) that disappeared progressively, were relatively

⁵ For example, it is used in studies on the long-term history of energy: for instance, Kander *et al* (2013, p. 8), speak about “energy systems” assuming that “every step, small or large, that a human takes, is part of an energy economy” (p. 1). Smil (2017) uses the terms “energy system” (p. 18) and “global energy system” (p. 383; p. 440) to refer to global human energy balances. Geneviève Massard Guilbaud (2018) refers precisely to Debeir *et al* (2013) and Sieferle (2001) to use this notion as a tool to understand energy transitions in human history.

⁶ One of these holistic notions is energy that was considered as a fundamental principle by European scientists and engineers in 19th- century Britain. Cara New Dagggett (2019) has shown the genealogy of energy and its political and cultural implications as a universal notion.

⁷ “Macro-système techniques”.

autonomous from each other.⁸ Their connections to local environments could be considered as stronger than to other energy converters. Meanwhile, the possibilities for developing the use of innovative renewable energy converters have been shaped by the evolution of the energy networks, with recurrent attempts to integrate these sources into the electrical grids. Indeed, since the end of the 19th century at least, renewable energies (wind, solar, tidal, wave, natural temperature gradients and geothermal) have been identified as inexhaustible and free, but intermittent and dispersed (Marrec, 2018). Engineers took the thermal machine as a model for energy converters, which enhanced control, high power, concentration, possibility of transport, and constancy (Gras, 2003). They considered the advantages of renewable energies as available resources, but also their drawbacks as unpredictable and difficult to “capture”. The developing electrical networks precisely offered the promise to integrate these phenomena as productive forces by accumulating and/or transporting them from one place to another. However, until the late 20th century, most of the attempts to reach this goal proved unsuccessful, and the only installations effectively used were far from the energy networks. Thus, were they part of the energy system? In which system were they (supposed to be) integrated?

While highlighting a little-known episode in French hydroelectric history, the history of wave converters in the interwar period gives insights on these questions. The electrical grid then developed at a national scale, and there was an unsuccessful craze for the industrial use of wave energy in the framework of hydroelectric energy policy. Analyzing this historical dynamic shows how the conception and outcomes of wave energy converters were not only shaped by the development of the electricity grid and its stakeholders, but also by the local political and technical specificities of the places that the new converters were supposed to integrate, as well as the physical characteristics of waves and the ocean environment. Rather than a global energy system, I consider technological systems as heterogeneous sets of social actors, technological devices (including converters), infrastructures and natural entities (materials, phenomena and landscapes), purposely built and developed by groups of stakeholders in order to reach precise (though sometimes conflicting) goals. This approach follows Hughes (1993), Gras (1997) and Hecht (2014), but also envirotechnical academic literature that considers the co-construction of natural landscapes and in-

⁸ This does not mean that non-fossil energy resources were not integrated in productive systems: mechanical hydraulic energy (Benoit, 2020), animal (Jarrige & Kasdi, 2020) or wind energy (Terrier, 2020) played a central role in the industrialization of some European regions.

frastructures and the role of natural phenomena in the shaping of technologies (Pritchard, 2011). Indeed, both the materiality of the waves and their representations as a natural phenomenon and as an energy resource in the state engineer's imaginary was essential to the story of wave converters. According to this approach, the French electrical grid that developed from the end of the 19th century onwards can be considered as a technological system, first owned and developed by companies, and then progressively managed by the State. As a relatively homogeneous system devoted to energy production and consumption and mainly composed of energy converters, electrical networks can be regarded as an energy system.

This framework enables us to consider the historical specificities of energy systems and the local aspect of energy converters, but also to understand the outcomes of innovative energy converter projects. I will therefore describe the contrasted trajectories of two wave energy devices:

- 1) Le Minou's ram was designed and experimentally tested by state engineers closely linked to the national electrical policy. Primarily conceived as a part of the electrical system, it was evaluated between 1925 and 1929 and considered as a proof of the impossibility of using waves industrially.
- 2) The Cattaneo ondo-pump was implemented by Jules Richard, the director of Monaco's Oceanographic Museum. Aimed at pumping water into a turtle aquarium, it was integrated in the local ecosystem of the Museum.

Among the numerous interwar wave energy projects, these two examples provide interesting insights to understand the outcomes of the French marine energy policy. More generally, they allow us to rethink the relationship between converters and energy systems. Originally thought of as experimental small-scale machines for the production of electricity, they remain historical singularities and embody the failed integration of wave energy in the projected electrical system of the period. Nonetheless, one of them was a relative success as an operational device integrated in a local context.

“Blue Coal” within French Hydroelectric Development

At the end of the First World War, the French historical dependency on foreign coal was worsened by destructions and war needs, and while the importance of oil as a strategic resource had increased, the nation did not hold this resource in metropolitan or colonial territories. Therefore, the

⁹ “Houille bleue”.

French government implemented a policy oriented towards “national” energy supply, enhancing the development of hydroelectric power. In war times, state officials recognized the strategic role of this energy resource, also called “white coal”,¹⁰ and considered it a way to increase both energy supply and independence. With the law of October 16, 1919, hydroelectric power became a national resource under public domain: any location identified as a reserve of water power came within state jurisdiction, with allocation to companies through concessions whatever its other uses (navigation, fishing, industry, etc.) (Pritchard, p. 44-45). On January 10, 1919, a Scientific and Technical Committee for the Development of Hydropower was created within the Ministry of Public Works, whose goal was to organize and coordinate industrial studies and projects in this field (Cels, 1919). This energy policy also relied on the development of a nationwide electrical grid, based on the interconnection of local and regional networks and the construction of high voltage lines. It was supported by a series of laws facilitating the merging of production and distribution companies and standardizing prices (Varaschin, 2009). The electrical grid followed the state engineers’ cartographic view of electricity supply: while North and North-East France would feed the grid with black coal, the South-East and South-West would deliver white coal electricity (Bouneau, 1994). State engineers therefore constructed the French territory as a set of electricity reserves with local specificities that the grid would unify for the good of the nation.

In this picture, the north-western coast was particularly poorly supplied with energy, having neither black nor white coal, but it presented the specificity of a particularly high tidal range. That is why a “Blue Coal Commission”¹¹ was created within the Hydropower Committee in April 1919. It included some electrical companies’s engineers, but was mainly composed of state engineers and embodied their vision of public service. They were charged with studying and organizing the exploitation of marine energy sources, i.e. waves and tides, which were also included as national energy resources in the 1919 law (Marrec, 2018). Indeed, the success of mountain hydroelectric plants gave the state engineers confidence in their ability to harness other forms of hydroelectric power. Blue coal thus completed the French cartography of electrical resources, and gave the so-called “rainbow of coal” its blue ray.

The “rainbow of coal” (« arc-en-ciel des houilles ») expression was coined by Max-Albert Legrand, a doctor, inventor and “propagandist” of the blue coal development (Legrand, 1920a, b). He was partly responsible

¹⁰ “Houille blanche”.

¹¹ Commission de la Houille Bleue.

for the creation of the Blue Coal Commission (AN 1977 0313/46). It illustrates a wider cartographic vision of French energy resources by the stakeholders of renewable energies in the interwar period, who were not only state engineers in charge of the electricity grid development, but also engineers and inventors concerned with the national energy supply. These stakeholders envisaged a spatial complementarity between the energy resources of the metropolitan and colonial territories. After black coal and white coal at the end of the 19th century, followed by green coal (the energy of rivers and streams) at the beginning of the 20th century, came blue coal after WWI, but also yellow or gold coal (the sun), aimed at fertilizing and populating North African arid zones (Gandillon, 1925; Pasteur, 1942), and azure or colorless coal (the wind) for mechanical purposes in rural areas (Weiss, 1920) or to improve wind-driven sailing in the seas (Joëssel, 1922; Marrec, 2016).

Despite the similarities of blue coal and white coal, the engineers of the Blue Coal Commission were well aware of the specificity of this source of hydraulic energy. Concerning tides, they generally endorsed the views of Georges Boisnier (an engineer from the Ponts et chaussées office¹² of the Ille-et-Vilaine department in Brittany), who had himself drawn up a project for a tide-based hydroelectric plant in the estuary of river Rance. In a memorandum which was a basis for the Commission's studies, Boisnier emphasized that the only reason for exploiting blue coal was the lack of any better resource: the low height of fall and intermittence of tides were two "original defects" which made them similar "to solar heat, to the heat of thermal springs, to the force of the wind". Thus, it was a "degraded energy" which "[would I] only be used in the absence of better sources" (Boisnier, 1921). However, tides had the advantage of being predictable and unaffected by droughts.

In comparison, wave energy was little encouraged within the blue coal policy. Indeed, the Commission was mainly composed of state engineers familiar with dam building and hydroelectric technologies.¹³ They planned the exploitation of tides under a special form: using large accumulation basins for electricity production. There are three reasons for this preference: (1) economic-technical, (2) historic-cultural and (3) environmental-geographical, namely

¹² The state corps responsible for "bridges and highways", but also railways, canals, rivers, hydraulic building and energy.

¹³ It was composed of state engineers working in fields related to hydraulic energy, dam building, marine engineering and hydrography, but also electrical companies' engineers (Marrec, 2018).

(1) The desire to obtain a power that is both significant and as continuous as possible, in order to produce basic electrical power that could be distributed to several customers within the framework of the electrical network development.

(2) The familiarity of the technique, since white coal was likewise used thanks to regulating accumulation basins for the production of electricity. As was pointed out by Eugène Fichot, Chief Hydrographic Engineer of the Navy and member of the Commission, the use of tides “is, in short, the application to the tides of the process commonly and successfully used to capture the energy of rivers” (Fichot, 1923).

(3) The Breton coasts were very well adapted to this type of installation, whereas they lacked black and white coal. They are very indented and with their high tidal range, it is possible to build dams forming wide reservoirs at a low cost.

This explains on the one hand why the engineers of the Blue Coal Commission did not consider other types of tidal installations, and, on the other, why they put aside wave energy. Indeed, waves have very different physical characteristics and they had never been used for industrial production. Accumulation in basins is difficult to apply because waves present erratic and diffuse power. And yet, the engineers of the Blue Coal Commission still took waves into consideration, because they received multiple proposals from inventors and foresaw the possibility of weaker but also less expensive installations that new electrical companies could take over.¹⁴ Le Minou’s ram was born in this context.

Le Minou’s Ram: The Failed Integration of Wave Energy into the Electrical System (1925-1929)

At the beginning of the 1920s, the Blue Coal Commission engineers were not yet completely categorical about the possibilities and interest of an “industrial” use of wave energy. Stimulated by the national blue coal dynamic and eager to participate in the development of electrical networks, new private groups in French metropolitan and North African territories carried out experiments and asked the Commission for financial support (Marrec, 2018). Consequently, the state engineers decided to examine the problem, and entrusted a study to their colleagues of the Finistère’s Maritime Service in Brest. There, the Ponts et chaussées state engineer André Coyne (1891-1960) facilitated and organized these experiments from 1925

¹⁴ AN 1977 0313/46, René de la Brosse, “Utilisation de l’énergie de la mer. Rapport de la Commission”, 1919/12/10.

to 1929, before distinguishing himself in the civil engineering community as a famous designer of hydraulic dams.

Coyne was commissioned to evaluate a process patented in the United States:¹⁵ it consisted in pumping sea water into a high reservoir by exploiting the horizontal movement of the swell, and using the potential energy of the water thus stored by discharging it on an adapted converter. It was based on the principle of the hydraulic ram, still commonly used in some water distribution installations and sold by a few manufacturers (see Figure 1¹⁶). A water flow enters a perpendicular pipe (10) and compresses air in a chamber (17, right-hand element), which in turn pushes the water thus trapped towards a reservoir above via a vertical pipe (18), and then expands before starting a new cycle. A funnel at the entry of the pipe orients the incidental waves (9).

Coyne chose to install the ram at the foot of Le Minou's lighthouse in the Brest bay. It is indeed "frequently battered by the swell of the open sea", and the tip of Le Petit Minou where it is located presents one of those "many natural funnels where the sea breaks" (Coyne, 1939, p. 85). The configuration of the site and its exposure to the sea were also well known due to the building of the lighthouse. The installation began in 1925 thanks to a Blue Coal Commission subsidy that was renewed every year. Le Minou's first ram¹⁷ was gradually constructed and made up of a hydraulic ram entirely designed by Coyne,¹⁸ a pipe and a funnel obtained by modifying a break in the rock with masonry work. In 1926, Coyne and Lambert, a state civil works engineer,¹⁹ began a series of measurements with the support of Maritime Service technicians. They evaluated the stored force by measuring the pressure of the air compression chamber. In 1927, Coyne had the satisfaction of recording a constantly significant pressure in the chamber, and deduced that "the use of the hydraulic ram at sea makes it possible to multiply the pressure of the waves by a very high coefficient and to master the enormous masses of water that the sea brings into play at low pressure, un-

¹⁵ This process was patented in 1921 by an American inventor, Lybrand Smith.

¹⁶ Smith, Lybrand Palmer (1921), « Water elevating device », Patent n°1.412.424, 1921/02. Available on Espacenet.

¹⁷ As Coyne names it in a 1936 conference given at the Société hydrotechnique de France (Coyne, 1939).

¹⁸ "The dimensions of the hydraulic rams supplied commercially were too small" for the tests undertaken (Coyne, 1939a, p. 85).

¹⁹ "ingénieur des Travaux publics de l'État".

der a relatively high potential and a fairly small volume”;²⁰ according to him, “the first result sought [was] achieved”²¹ (Coyne, 1939a, p. 88). Two other devices succeeded, with increasingly bigger entry diameter and pipe dimensions. The last one was equipped with a 4-meter-long and 2-meter-large pipe (B) and an air compression chamber (A) (Figure 2).²² At this stage, Coyne changed the concept of Smith’s patent by using compressed air instead of elevated water for energy storage: what was originally a measuring means became the conversion tool.

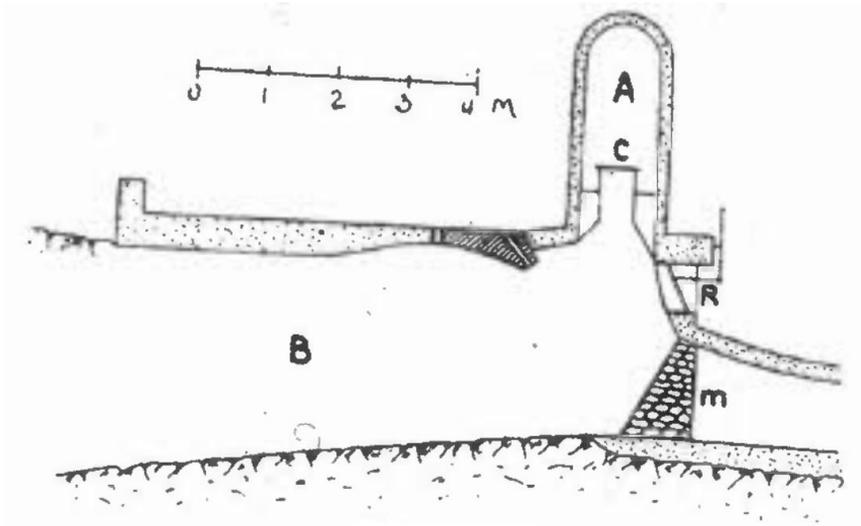


Figure 1 - Cross-section of Le Minou’s ram (1929) (Coyne, 1939b, p. 141)

When he left the Brest Maritime Service for the Building Service of the Haute Dordogne in 1928, Coyne charged his successor, Paul Pétry, with taking over the direction of the experiments according to a program he had set. The 1929 device offered satisfactory results: despite an abnormally

²⁰ “l’emploi à la mer du bélier hydraulique permet de multiplier, par un coefficient fort important, la pression des lames et de rendre maniables, sous un potentiel relativement élevé et un volume assez restreint, les énormes masses d’eau que la mer met en jeu à faible pression”.

²¹ “le premier résultat cherché [est] atteint”.

²² Coyne André (1939b), “La captation de la houle”, *Revue générale de l’hydraulique*, [Conference for the Société hydrotechnique de France (4 June 1936)], 04/1939, p. 141-148, Available at the Bibliothèque nationale de France.

small swell, measurements yielded between five and ten horsepower, corresponding to Coyne's predictions. Pétry continued the experiments to improve the efficiency of the process. But one night in November 1929, during a high tide, a violent storm stopped the 4-year studies on Le Minou's ram: "the sea pushed with unprecedented violence tore off the rock, lifted the two air tanks in one piece and threw them under the rocks of the lighthouse", some fifty meters away.

"This is how Le Minou's ram died",²³ Coyne recounts (Coyne, 1939, p. 142). The same night, "the wall of the quay at Lampaul in Ouessant was demolished, [...] considerable damage was caused to the constructions at Sein, and [...] a dock in the Brest bay was partially demolished." However, the recorded wind was not exceptional for a storm wind (30 m/s) and it was indeed the ram itself that was able to give such a force to the impulse of the sea: "a very frank water hammer that we will unfortunately never be able to record", as Lambert assessed.²⁴

For both Lambert and Pétry, the conclusion was fatal, as their respective reports to the Blue Coal Commission show: according to the former, "this damage proves that the sea is a fickle, capricious energy and that its capture is a problem for which the data are too variable to be practically resolved". According to the latter, "capturing the swell by means of a hydraulic ram would always be of poor industrial efficiency, because the disproportion is too great between the power of the average swell and that of the maximum possible swell, requiring considerable equipment for a very low average energy"; so, the Smith patent was "not likely to be applied industrially". The two engineers thus decided to stop the experiments on Le Minou's ram, and Pétry asked for the cancellation of the Blue Coal Commission subsidy that had already been allocated to them. In comparison, Coyne expressed a rather optimistic view in his report to the Commission: he only admitted to being "momentarily" defeated. According to him, the accident could probably have been avoided, and it was the imprudence of successively enlarging the device's dimensions "without consequently reinforcing the ram's attachment to the rock" that caused its demolition. Therefore, further experiments would certainly have made it possible to obtain acceptable efficiency. Indeed, on coastlines with natural creeks or caves that are better exposed than Le Minou's tip, the swell would have been larger and more regular, and the installation costs lower. The Ouessant coast, for example, would have been suitable, but Coyne's preferred location was Mo-

²³ "Ainsi mourut de sa belle mort le bélier du Minou".

²⁴ AN 1977 0614/6, Lambert, "Rapport à propos de la destruction du bélier du Minou", 1929/11/30.

rocco, where the tidal range is also lower. By limiting oneself to low efficiency and simple equipment, “one [ould] hope to achieve an acceptable cost price”.

Despite Coyne’s optimism, the negative opinion of Lambert and Pétry prompted the 1930’s Blue Coal Commission to stop supporting wave energy projects. Wave converters definitely appeared to be small-power machines, and at this experimental stage, they did not produce electricity but compressed air. All these parameters were opposite to the national energy policy, which encouraged above all high-power electricity production. Moreover, considering the geographical and administrative aspects, the two regions designated by Coyne were Brittany, where the tides were explicitly favored by the Commission, and Morocco, a territory that the metropolitan Ministry of Public Works did not feel concerned about.

In 1936, several years after the experiments had ended, Coyne related them in a conference to his colleagues of the Société hydrotechnique de France (Coyne, 1939). Seeing as the national dynamic in favor of blue coal had largely weakened, he almost apologized for a “youthful sin”, and asked “electricians” not to worry: “the time has not come to inject on the market masses of kilowatt-hours supplied by the ocean” (Coyne, 1939b, p.78). This contrasts with the enthusiasm and sometimes epic tone of his previous account, in which Coyne portrayed a passionate quest to capture a capricious and powerful natural force.²⁵ Having become famous as a designer of large hydroelectric dams, on a completely different scale from Le Minou’s ram experiments, Coyne depicted them as “of little importance” (Coyne, 1939b, p. 148). Nevertheless, in 1939, in a period of renewed interest in marine energies, he decided to publish these results in the *Revue générale de l’hydraulique*, a journal dedicated to the hydraulic engineering community. This article is a rich testimony, not only because it gives a detailed description of Coyne’s experiments and conclusions, but also as an illustration of the changing national dynamics around marine energies in the interwar period: from Coyne’s mitigated conclusions in 1929, to the enthusiastic 1936 conference that he somehow never assumed conference, until the publication meant to “serve the researchers that, one day, would take this path” (Coyne, 1939, p. 78).

²⁵ For example, when he describes the enlargement of the ram’s dimensions: “The sea, channelled through the entrance corridor, reached the entrance of the funnel and broke thunderously inside. At times it sounded like a real explosion. The swell thus trapped sought to escape on all sides, flowing back towards the open sea through the entrance corridor, and gushing through the air vents in strident jets, the noise of which could be heard more than a kilometre around.” (Coyne, 1939b, p. 142).

The ram's remains are still visible behind the lighthouse today, almost a century after its destruction (see Figure 2). It is very likely that the majority of walkers enjoying the beautiful view offered by the Brest bay do not pay attention to this worm-eaten cylinder, nor, at its foot, to this pipe melted into the rock, and, finally, to the particular shape of the surrounding rocks. Probably even rarer are those who know that this strange object was once intended to convert the energy of the swell into power.



Figure 2 - The remains of Le Minou's ram, December 2016 (Picture by Anaël Marrec)

From this case study, the following conclusions can be drawn: on the one hand, the Blue Coal Commission's reluctance to use wave and swell energy was fed by the results of Le Minou's ram experiments. The economic benefits were obviously not the most important factor to explain their position, but it was rather their technical imagination as State engineers, responsible for great national technological developments, which led them to favor large power sources, and more precisely large electrical power sources. The technical imagination evoked by Coyne is also characteristic, since he wants to "imprison the moving and capricious energy of the swell" (Coyne, 1939b, p. 142). Given that he considered the waves to be the "only source of industrial energy" of the sea (Coyne, 1939a, p. 79), Coyne's personal interest in the issue was essential until he was replaced by Pétry, who

appears to have been less interested in the subject. Coyne, famous among hydropower historians, began his career in this field with the less noble form of blue coal, before moving on to the most ambitious white coal installations. Finally, it is worth noting that the economic crisis of the 1930s, that slowed and stopped the Blue Coal Commission activities, was not the reason for the cessation of the experiments: a subsidy was available, but it was refused because of a lack of faith in wave energy technologies. The half-opened possibility of using the waves industrially by integrating them into the French electrical network was closed for a long time.

Cattaneo Ondo-Pump: Local Integration within Monaco's Oceanographic Museum Ecosystem

In the 1920s, Jules Richard (1863-1945), a French oceanographer and the director of the Oceanographic Museum of Monaco, tackled the problem of the use of waves and succeeded in installing an operational wave converter. His work relates to Le Minou's ram project in its ambition to contribute to the electrification of coastal areas. It nonetheless differs from it and is an interesting case in itself for several reasons. Firstly, it is the only blue coal project that came to fruition in the wake of the French interwar dynamic in favor of blue coal exploitation. Secondly, Richard remained relatively away from the Blue Coal Commission, because he had the financial means to have his private laboratory, and was much more connected to international scientific networks. Finally, Richard was not an engineer, and his claimed belonging to the scientific community of oceanographers was central to his work on wave energy. This also explains the variety of converter forms that he took into consideration.

In 1900, Prince Albert I created the Oceanographic Museum of Monaco and nominated Richard as director. Through the creation of the Museum in Monaco and its attached Oceanographic Institute in Paris in 1906, Prince Albert sought to take an active part in the international emergence of oceanography as a scientific discipline (Deacon, 1997, p. 90-91).²⁶ The Museum's vocation was thus to become a central place for scientific research but also for the popularization of knowledge. Richard, who played

²⁶ This Monegasque project clearly relied on French strategic arrangements: on the one hand, the Museum depended on the Oceanographic Institute (of Monaco but based in Paris), whose board of directors was comprised of French and Monegasque personalities; on the other hand, Richard was French and published extensively in French journals; he was also involved in French public projects for the exploitation of solar energy.

a crucial role in the Museum until his death, considered oceanography as an interdisciplinary science that should also serve industrial purposes (Richard, 1907). Thus, he considered that “the use of the energy of the sea” was “entirely within the remit of the Oceanographic Institute” (Richard, 1931). Richard, who was primarily a biologist, therefore undertook research on wave energy as a way to establish the Oceanographic Museum as a leading institution thanks to a topical problem.

Familiar with machines that measured wave energy, Richard planned to adapt the operation of one of these, the Stevenson dynamometer, to the use of energy production. But he finally chose to focus on two other machine processes presented in the international scientific and technical press: the Savonius rotor and the Cattaneo ondo-pump.

The Savonius rotor, named after its Finnish inventor Sigurd Savonius, had the particularity of using a fluid dynamics phenomenon: the Magnus effect. According to it, “[i]f a cylinder rotates in a current of air, a force appears, tending to move the cylinder perpendicularly to the direction of the wind” (Sancery, 1925, p. 296). Savonius was not the only one who wanted to take advantage of the Magnus effect thanks to an aero-engine. It was also the case of the German engineer Anton Flettner, known worldwide for having developed the “Flettner rotors” used for the partial propulsion of a ship thanks to the wind (and Magnus effect) (Marrec, 2018). In addition to pumping water and generating electricity, Savonius had also tested the propulsion of a ship using his rotor. Savonius’ rotor was made of two half-cylinders, constituting two blades, laterally offset from each other. Wind pressure and the Magnus effect exert force on each of these cylinders. Because of its shape, the device always rotates in the same direction regardless of the wind direction (see Figure 3).²⁷

Having read this article, Richard intended to explore this possibility for the water supply of the Museum’s aquariums. He argued that “[t]he use of waves can in many cases be more advantageous than the use of wind”, because “[t]here can be waves, even very strong ones, at the seaside, when there is no wind” (Richard, 1931).

²⁷ Sancery Raymond (1925), “Pour utiliser l’énergie du vent : voici une solution nouvelle”, *La Science et la vie*, vol. 130 (April), p. 297-302. Available in the Bibliothèque nationale de France.

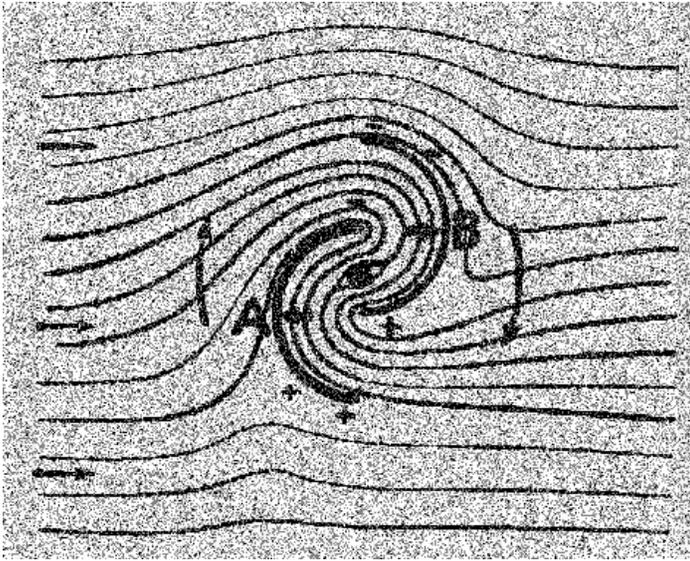
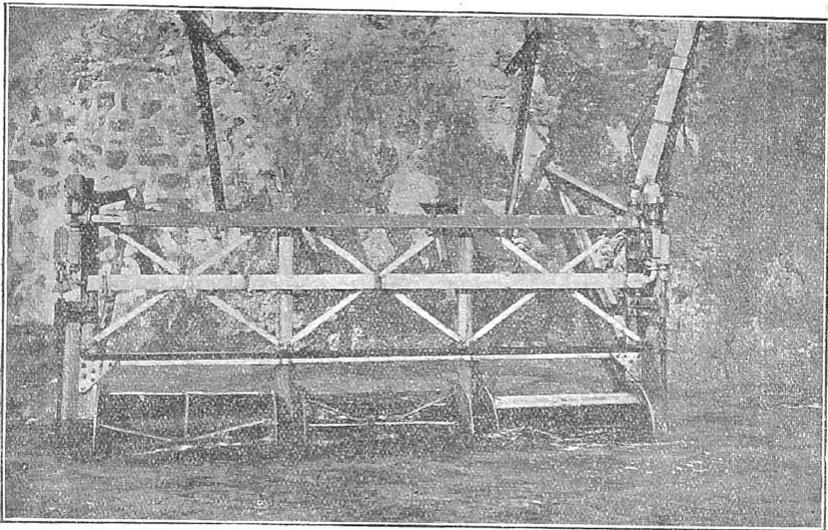


Figure 3 - Savonius rotor's principle (Sancery, 1925, p. 296)



*Figure 4 - Savonius rotor tested at the Monaco Oceanographic Museum (Aug 30-May 31)
(Richard, 1931, p. 8)*

He pointed out that the use of wave energy was an interesting solution for seas without tides, such as the Mediterranean. Discussions with Sancery — the author of the article — convinced him that this process was “very suitable for using the energy of the waves that break on the rocks at the foot of Monaco’s Oceanographic Museum” (Richard, 1931, p. 1-2).

Between 1929 and 1931, Richard built and tested two prototypes of Savonius rotor pumps. Savonius provided him with the design charts for a machine adapted to the Museum’s site and to a 35-meter water elevation. The largest of them, built between 1929 and 1930, was equipped with three 1.20-meter-long and 0.8-meter-wide steel rotors arranged on a horizontal shaft. Sealed in rocks by a steel structure, it was put in place between August 1930 and May 1931 (see Figure 4). After a couple of experiments, it was partly destroyed and heavily corroded, and was therefore removed the same year.

Richard concluded from these tests that “the performance is [...] very poor on rocky shores”. This was because the water rose in a very irregular manner due to the highly variable direction and strength of the waves that were reflected off the multiple rock faces, while the rotor only worked with water coming in certain directions. But, like Coyne’s hydraulic ram, it would have been suitable for coastlines without tides and rocks. For the Oceanographic Museum, Richard thus turned to another type of wave pump: the Cattaneo ondo-pump.

In June 1931, Richard received a visit from Francesco Cattaneo, an Italian inventor who had read about his work and wanted to see the Savonius rotor. He had himself installed an experimental station for marine energy technologies in Voltri, a few dozen kilometers east of Monaco, where he tested six different devices using the tides, the waves and the sea currents. A model of his “ondo-pump” had been in operation since 1917 and produced electrical energy. The Cattaneo ondo-pump that interested Richard was what Cattaneo called the “ondo-pump-float”.

It was a pump using the vertical movement of the swell to drive a float working as a piston (see Figure 5). The cylindrical float (EF) was installed in a well whose middle was at mean sea level and whose bottom communicated with the sea (Richard, 1933b). The level of the well oscillated according to the vertical movements of the sea waves. When a wave rushed in, the float, guided by vertical rods, rose with the pistons; then, as the level dropped, the weight of the float drove it down with the pistons that pushed the water into the upper tanks through the two pipes. The float then fell down to start a new cycle.

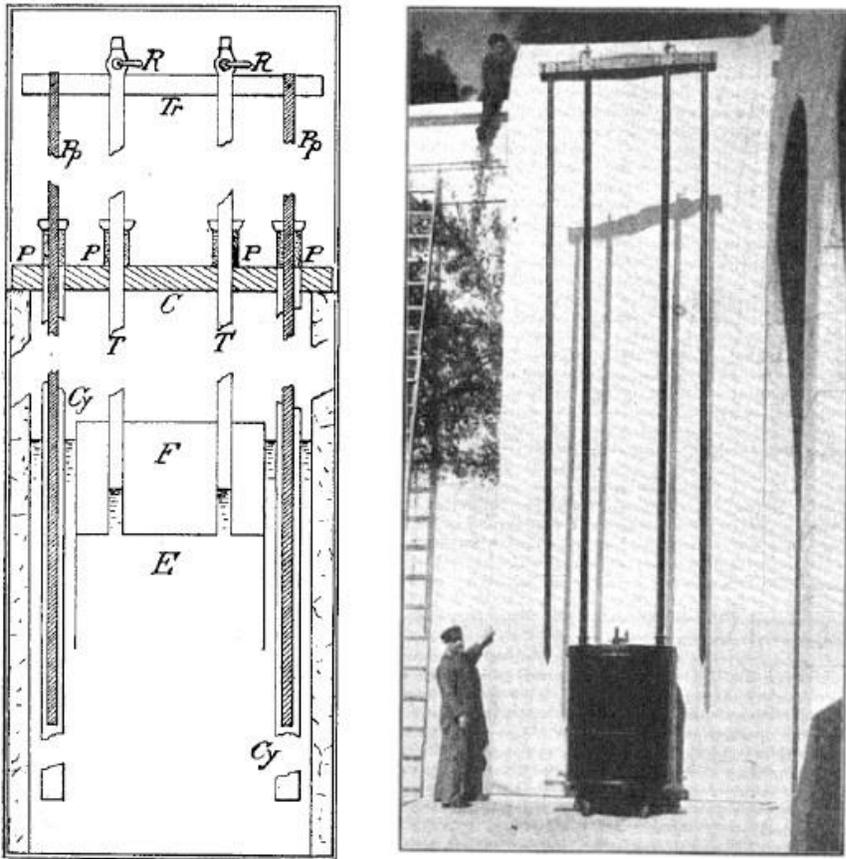


Figure 5 - Section and picture of the Oceanographic Museum's Cattaneo Ondo-pump installed in 1930-1931 (Richard, 1933a, p. 529-530)

Convinced by the 12-year-long electricity production of Cattaneo's plant, Richard believed that the ondo-pump could be adapted for the use he planned. He organized the installation of two successive devices between December 1931 and March 1933. The final device was composed of a 1-meter-across and 1.20-meter-high copper float, installed in a 6-meter well dug into the rock (Figure 5). The installation made it possible to raise between 500 and 2500 litres of water per hour, which was perfectly in line with Richard's expectations, without using any electricity. After Richard's death in 1945, the pump was still supplying water to the aquarium (Durand-Viel, 1946, p. 6).

Despite Richard's efforts to publicize the successes of his experiment and to promote the process, the Museum's pump remains a historical

singularity, being the only French “blue coal” converter in application in the interwar period. Indeed, when it came into operation, the national dynamic in favor of blue coal development had weakened, and the Blue Coal Commission had stopped taking waves into consideration. It is therefore a partial failure considering the ambitions expressed by Richard, and more broadly by the stakeholders of the “blue coal” policy. Indeed, it involved the direct use of wave energy, without the need for electricity, for a very precise, low-power, non-industrial use. However, such a device, which found its place on the margins of the network, can be considered as a success in many ways. According to Richard, the ondo-pump fulfilled several of the Museum’s missions. From the point of view of industrial applications, he concluded that it “could be installed at a multitude of locations on the Mediterranean littoral” (Richard, 1933b, p. 14-17). In this tide-free sea it could produce large amounts of electrical power. Richard’s considerations here provide a cartographic view different to that drawn by the state engineers: a regional and transnational blue coal territory. Moreover, the Museum set an example and made visible the positive practical results of this invention. In addition, the ondo-pump served directly to the Museum’s operations, on the one hand by bringing healthier water into the aquariums, because it was sourced from deeper into the sea, and on the other hand by minimizing the use of increasingly expensive electricity. Finally, it fulfilled an esthetic and promotional function: by means of mirrors in the turtle aquarium, the pump was voluntarily made visible to museum’s visitors, who thus could see the institution’s involvement in the current challenges facing oceanography, embodied in a technological solution.

Conclusion

From these two case studies, one can learn that the relative failure of both wave converters projects is due to a series of factors. The main ones are not operational, but inherent to the nature of waves and geography of the coast, as well as the imaginary and techno-political power of the state engineers involved in the electricity grid’s development. The abandonment of Le Minou’s ram experiments led to the interruption of the French ministry of Public Works’ studies about waves, and it hindered the national development of wave energy utilisation. This partly explains why the Cattaneo ondo-pump was not replicated on the French territory. Two conclusions emerge regarding the integration of converters in energy systems and the inertia of imagination regarding energy.

(1) The two wave-based devices were first thought of as integrated in the electrical system. From this point of view, both projects were failures:

Le Minou's ram was swept by the winds, considered as a proof of the impossibility to use waves industrially, then forgotten on the Breton coast. The ondo-pump has remained a historical singularity, without replication. Both illustrate how the deployment of energy systems has shaped the use of converters. The state engineers' cartographic thinking that structured the dynamic of blue coal development in France favored wave exploitation projects but paradoxically hindered their implementation. Indeed, wave converters did not find a place in the electrical network because of the physical and geographical characteristics of waves and the difficulties of converting them like usual hydraulic energy. The Cattaneo ondo-pump, however, was integrated in the singular context of the Oceanographic Museum, as a functional, esthetic, and promotional object. Richard's imagination did not restrict this device to an exclusively energetic function; it was much more a part of the Museum's ecosystem than an element of any energy system.

(2) The imaginary of the thermal machine was crucial in the project of integrating waves into the electrical network. While the possibility of harnessing waves into a transportable and powerful energy form stimulated the wave energy projects, the converters were still too far from the thermal machine model and led to the abandonment of Le Minou's ram experiments even with favorable results. However, the thermal machine model was not completely determining in the design of wave converters. While the state engineers of the Blue Coal Commission considered only one form of converters for the tides (retention basins associated with electric turbines), the wave-based devices experimented during the interwar period had various technical forms. The one Richard chose for the Oceanographic Museum was adapted to the singular context of this institution. Two main reasons explain this abundance of forms: the technical imaginary was free because there were no historical antecedents to the use of waves (conversely to mountain waterfalls, rivers, tides and wind), and their physical characteristics were very different from those of the other energy sources in use. With the further development of the electricity grid, this double logic of profusion of technical forms and competition with other converters better adapted to the system has been affirmed in wave energy exploitation projects until today (Roche *et al.*, 2018).

Both projects underline the importance of considering the historical specificity of energy systems and the local specificities of energy converters. Since wave energy has still not been industrially exploited, thinking about converters outside the energy system appears not only as a way to put them into use, but also as a possibility to grasp them in all their dimensions: social, cultural, political and environmental. Questioning the univer-

sality of energy systems raises societal questions in a time of energy transition. Since the 1990s, the integration of renewable energies (particularly the wind and sun) in power grids has constituted a break in their history, because it fulfils the old dream of capturing these intermittent sources of energy, embodied by the thermal machine model. Before that, the majority of renewable energy converters were not connected to the grid. This observation has a political significance, given that the “smart grids” model which concretizes the marriage of electric and digital networks appears to be an essential vector of the energy transition desired by governments and major energy companies. Just like criticism of the energy transition warns us against erroneous images of the past that project an equally “ghostly” future (Fressoz, 2021), criticism of the energy system calls for thinking converters of the past outside energy systems, in order to identify possible alternative energy sources.

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References

Archives : French National Archives at Pierrefitte-sur-Seine

AN 1977 0313/46, Service des phares et balises, “Commission de la houille bleue”.

AN 1977 0614/6, Direction de l’électricité, “Technique Vents et marées”.

Primary sources

BOISNIER Georges (1921), “Utilisation de l’énergie des marées”, *Annales des Ponts et chaussées. III. Mémoires et documents*, p. 297-396.

CELS Jules (1919), “Le Comité d’électricité”, *La Houille blanche*, n° 2 (March-April), p. 63-66.

COYNE André (1939a), “La captation de la houle”, *Revue générale de l’hydraulique*, Conference for the Société hydrotechnique de France (4 June 1936), March, p. 78-89.

- COYNE André (1939b), “La captation de la houle”, *Revue générale de l'hydraulique*, Conference for the Société hydrotechnique de France (4 June 1936), April, p. 141-148.
- DURAND-VIEL, Georges (1946), “Notice nécrologique sur le Docteur Jules Richard”, *Bulletin de l'Institut océanographique de Monaco*, n° 892, p. 5-6.
- FICHOT Eugène (1923), *Les marées et leur utilisation industrielle*, Paris, Gauthier-Villars.
- GANDILLON Pierre (1925), “La ‘houille d’or’”, *Comptes rendus de l'Association Française pour l'Avancement des Sciences*, 4th session, p. 171.
- JOËSSEL Raymond (1922), “Navires à hélices aériennes pouvant progresser contre le vent”, Caen, Imprimerie Olivier, extracted from *Bulletin des élèves de l'École nationale supérieure des Mines*, October-November 1922.
- LEGRAND Max-Albert (1920a), “La fin de la vie chère”, *La Revue mondiale*, vol. 134, Year 31, n° 1 (January), p. 72-76.
- LEGRAND Max-Albert (1920b), “La fin de la vie chère”, *La Revue mondiale*, vol. 84, Year 134, n° 3 (February), p. 341-346.
- PASTEUR Félix (1942), “L'utilisation pratique de la chaleur solaire”, *Le Génie civil*, n° 3087 (June), p. 169-173.
- RICHARD Jules (1907), *L'Océanographie*, Paris, Vuibert et Nony.
- RICHARD Jules (1931), “Sur l'utilisation du dynamomètre de Stevenson pour l'utilisation des vagues de la mer”, *Bulletin de l'Institut océanographique de Monaco*, vol. 583, p. 1-12.
- RICHARD Jules (1933a), « L'utilisation des mouvements de la mer. L'ondo-pompe de Cattaneo », *La Nature*, n° 2907 (June), p. 529-533.
- RICHARD Jules (1933b), “Sur l'utilisation des mouvements de la mer par l'ondo-pompe de F. Cattaneo à Voltri”, *Bulletin de l'Institut océanographique de Monaco*, n° 625 (June), p. 1-20.
- SANCERY Raymond (1925), “Pour utiliser l'énergie du vent : voici une solution nouvelle”, *La Science et la vie*, vol. 130 (April), p. 297-302.
- WEISS Eugène (1919), “Progrès dans l'utilisation des moteurs à vent”, *La Nature*, vol. 2415 (July), p. 39-43.

Secondary sources

- BENOIT Serge (2020), *D'eau et de feu, forges et énergie hydraulique. XVIII^e-XX^e siècles. Une histoire singulière de l'industrialisation française*, Rennes, Presses universitaires de Rennes.
- BOUNEAU Christophe (1994), “Le transport d'énergie et l'interconnexion”, in Henri LEVY-LEBOYER & Maurice MORSEL (eds), *Histoire générale de l'électricité en France, Tome deuxième. L'interconnexion et le marché*, Paris, Fayard, p. 777-800.

- CHARLIER Roger H. & MENENTEAU Loïc (1997), “The Saga of Tide Mills”, *Renewable and Sustainable Energy Review*, vol. 1, n° 3, p. 171-207.
- DEACON Margaret (1997), *Scientists and the Sea, 1650-1900: A Study of Marine Science*, Alershot, Brookfield, Ashgate.
- DEBEIR Jean Claude, DELEAGE Jean Paul & HEMERY Daniel (2013), *Une histoire de l'énergie. Les servitudes de la puissance*, Paris, Flammarion.
- FRESSOZ Jean Baptiste (2021), “Pour une histoire des symbioses énergétiques”, *Annales des Mines, Responsabilité et environnement*, vol. 101, p. 7-11.
- GRAS Alain (1997), *Les Macro-systèmes techniques*, Paris, Presses universitaires de France.
- GRAS Alain (2003), *Fragilité de la puissance. Se libérer de l'emprise technologique*, Paris, Fayard.
- HECHT Gabrielle (2014), *Le Rayonnement de la France. Énergie nucléaire et identité nationale après la seconde guerre mondiale*, Paris, Éditions Amsterdam.
- HUGHES Thomas P. (1993), *Networks of Power: Electrification in Western Society*, Baltimore, John Hopkins University Press.
- JARRIGE François & KASDI Mohamed (2020), “‘Moteurs animés’ des filatures”, in François JARRIGE & Alexis VRIGNON (eds), *Face à la puissance. Une histoire des énergies alternatives à l'âge industriel*, Paris, La Découverte, p. 71-83.
- KANDER Astrid, WARDE Paul & MALAMINA Paolo (2013), *Power to the People, Energy in Europe over the Five Last Centuries*, Princeton/Oxford, Princeton University Press.
- MARREC Anaël (2018), *Histoire des énergies renouvelables en France, 1880-1990*, Thèse de doctorat, Université de Nantes.
- MARREC Anaël (2016), “Politiques des forces naturelles et imaginaires de l'énergie dans l'entre-deux-guerres”, *Pour Mémoire*, n° 18, p. 83-92.
- MASSARD-GUILBAUD Geneviève (2018), “From the History of Sources and Sectors to the History of Systems and Transitions: How the History of Energy Has Been Written in France and Beyond”, *Journal of Energy History/Revue d'Histoire de l'Énergie*, n° 1, energyhistory.eu/en/node/88
- NEW DAGGETT Cara (2019), *The Birth of Energy. Fossil Fuels, Thermodynamics and the Politics of Work*, Durham/London, Duke University Press.
- PRITCHAR Sara B. (2011), *Confluence. The Nature of Technology and the Remaking of the Rhone*, Cambridge/London, Harvard University Press.
- ROCHE Sylvain, CLEMENT Alain, BABARIT Aurélien & BOUNEAU, Christophe (2019), “Transformer les vagues en énergie: utopie ou réalité ?”, *Artefact*, vol. 9, p. 239-265.
- SIEFERLE Rolf Peter (2001), *The Subterranean Forest Energy Systems and the Industrial Revolution*, Cambridge, The White Horse Press.

SMIL Vaclav (2017), *Energy and Civilization. A History*, Cambridge/London, The MIT Press.

TERRIER Didier (2020), “Moulins à vent à huile”, in François JARRIGE & Alexis VRIGNON (eds), *Face à la puissance. Une histoire des énergies alternatives à l'âge industriel*, Paris, La Découverte, p. 57-70.