Innovation Dynamics in the Development of Nuclear Energy and Electric Vehicles in France

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***Abstract*— Technological change is shaped by a confluence of processes that are governed by socio-political, economic, and regulatory factors within a region. In this paper we describe the transformation of the electricity generation system in France and the emerging changes in the transportation sector in the country. We trace the impact of national energy security policy in France after the 1973 oil crisis that catalyzed a shift from dependence on fossil fuel to nuclear power, and then examine the continuing impacts of that legacy that are now emerging through development and deployment of electric vehicles in the country. We examine the two cases of nuclear power and electric vehicles in France using processes of innovation, and discuss the interaction of these processes that formed reinforcing loops to advance these technologies in the country and highlight the role of sustained policy in initiating and driving the reinforcing cycles. We also discuss the issue of new emerging linkages between the electric power generation and transportation sectors that were traditionally decoupled due to use of different fuel sources. We expand the notion of path dependence, and discuss how established technologies in one sector can shape future technological trajectory in other sectors.**

Keywords*— innovation processes; nuclear energy; electric vehicles ; technological trajectory.

I. Introduction

Technological change is shaped by a confluence of processes that are governed by socio-political, economic, and regulatory factors within a region. An understanding of these processes and factors can provide important strategic insights that can help inform policy as well as private enterprise. Over past decades, researchers have extensively worked on this topic, and there is a vast amount of literature on technology innovation [1], technological transitions [2], and industrial transformation [3]. In recent years, this area has gained particular salience for policy makers who want to enable a transition to renewble energy and other sustainable technologies [4][5]. The question of how to diffuse new technologies has been explored [6], and the question of why certain technologies remain embedded (or locked-in) despite evidence of sub-optimal performance on economic, environmental, and safety dimensions has been investigated [7].

A number of frameworks have been proposed for understanding and analyzing technological change and technology adoption from economic [8], engineering [9], and socio-political [10] perspectives. A widely accepted notion, based on socio-economic arguments, is that in systems where there are increasing returns, chance events and not innate technological superiroty of a technology, can determine large-scale adoption in the long-term. In this paper, we present a narrative of technology change in the power generation sector in France drawing concepts from the above mentioned literature. We discuss how the oil crises of 1973 catalyzed strong policy action for energy independence and national energy security that led to a transformation from imported fossil fuel based electricity generation to nuclear power. We systematically analyze the transition by using a discrete set of processes proposed by Hekkert et al. [4][5]. We use this set of processes, called ‘functions of innovation’, to map how their interaction formed reinforcing cycles leading to large-scale adoption of nuclear power in the country. We also show how these interactions were initiated and sustained through state policy. We then apply this approach to the case of electric vehicles in France, and discuss existing policy and its implication on potential future trajectories of the technology in the country.

II. Functions in Technology Innovation Systems

Hekkert *et al.* have discussed technological innovation systems (TIS), comprising of actors, technology, institutions, and networks, that influence the speed and direction of a technological change in a specific technological area [5]. They also propose seven functions (or processes) that collectively (and in various combinations) either impede or facilitate the overall success (*i.e.* large-scale diffusion) of a technology. The functions are: F1. Goal Formulation, F2. Knowledge development, F3. Knowledge exchange, F4. Entrepreneurial action, F5. Market formation, F6. Resource mobilization and F7. Legitimacy creation. In our work, we change the terminology for F4, and refer to it as Goal formulation and for F2 as Knowledge creation. Furthermore, we also change the numbering convention proposed in [5]. Table 1 explains the functions that we use in our study.

TABLE I. Functions in Innovation Systems (based on [6].)

System Functions	Description
F1: Goal formulation	Announcement of policy goals, or expectations that converge to generate a specific momentum towards change in a particular direction (e.g. the case of renewable energy systems).
F2:Knowledge creation	Research and development activities that generate new knowledge. Examples include R&D projects in public and private sectors.
F3: Knowledge diffusion	Knowledge exchange through conferences, workshops, platforms, and publications between government, competitors, and markets.
F4:Entrepreneurial action	Activities that convert new knowledge into concrete action that takes advantage of business opportunities. Examples include new firms, or development of new projects, or production facilities in existing firms etc.
F5: Market formation	Creation of a market of the new technology. This maybe assisted through policy action (using tax-breaks), or with other competitive advantage provided by the new technology.
F6: Resource mobilization	Human and financial (investments, subsidies) resources provided by actors in the system to run all the innovation activities.
F7: Legitimacy creation	Creating advocacy coalitions (e.g. lobby of actors) to improve technical, institutional, and financial conditions for the particular technology. This is needed to counteract resistance to change so that the new technology can become part of an incumbent regime or even overthrow it altogether.

These seven processes or functions need to be present in a system of technology innovation, and the particular interaction and combination of these functions shapes the long-term outcome for the new technology. In some cases, these functions interact to produce a cycle of growth and expansion in which the new technology secures wide adoption. In other cases, these functions may interact to create a cycle of destruction in which the new innovation is unable to take hold and diffuse at a large-scale.

A systematic mapping of these functions, and their particular interactions for a given technology can allow for understanding how past technologies were successfully established, and also help inform future strategies for deploying new technologies. This study is motivated within this context, and in this paper we present detailed narratives of nuclear energy and electric vehicles in France and map the development and deployment of those technologies using the seven functions of innovation described above.

III. Power Generation System in France

Our narrative draws from a historical account of the development of nuclear power in France as reported in [11]. Before 1946, the electricity system in France comprised of a large number of private firms that provided production, transmission, distribution and other services. The system had emerged without any central planning or control, and at the start of the Second World War, there were 200 companies engaged in production, 100 in transmission, and 1150 in distribution in the country. At the end of the war, the law makers decided to consolidate the industry to improve efficiency and speed up reconstruction efforts. In 1946, the national assembly unanimously voted to nationalize both the electricity and gas sectors in France. For the electricity sector, Electricité de France (EDF) was formed as a state-owned company that was charged to build up the electricity generation capacity for the country.

Pierre Simon, the first director general of EDF, and a former director of hydroelectric energy at the Ministry of Public Works, directed the company to focus on construction of hydro-electric systems. In the 1940s and 50s the focus was mostly on expansion of hydro-power, and in the period between 1949 and 1957 forty eight new hydroelectric facilities were brought into service. In 1960, the hydro power plants generated 37.1 GWh of electricity that constituted 71.5% of EDFs total production at that time. The fossil fuel powered systems contributed to the remaining mix with 18% generation from coal-fired thermal stations and 3% from oil burning stations.

As demand for electricity continued to grow with increasing economic development in the country, other sources of energy were soon needed. Starting in the 1960s, a shift towards oil burning stations began to occur. At the time, oil was a cheap fuel and oil-powered plants offered the flexibility of meeting diurnally fluctuating electricity demands. Over the next decade the electricity generation mix changed, and by 1973 oil-fired power stations provided 43% and hydroelectric stations 32% of generation capacity in the country. In a 13 year period, the share of electricity generated from oil-burning power plants increased from 3% to 43% and assumed a critical role in energy production in France.

A. *The Era of Nuclear Power*

The French military nuclear weapons program had spawned off a civil nuclear project in the 1940s. General de Gaulle established the Atomic Energy Commissariat (CEA) in October 1945 that continued research on nuclear technology. The development of this technology had steadily progressed over the years, and by 1957 a small 68 MW nuclear power station project in the Loire Valley had been started. This power station, using technology developed by the CEA, was commissioned in 1962, and was slowly expanded in stages over the years. With increasing experience and continued technological development (wherein heavy water reactors and pressurized water reactors were introduced), nuclear powered electric plants had come to form a small niche within the power sector and produced 14 GWh or 8% of EDFs total output in 1973.

In the 1973 oil crisis, the price of oil quadrupled, and the economics of the oil-based energy generation system changed dramatically. The nuclear option, previously considered too expensive seemed much more attractive. Furthermore, the risks of being reliant on imported commodities became prominent. A mix of economic as well as public sentiments of national independence and self-reliance came together to influence a significant shift in the trajectory of energy technology in the country.

In March 1974, the French prime minister, Pierre Messmer, made a major speech and outlined the case for nuclear energy for the country by pointing out that the country has no oil resources, less coal than England and Germany, and much less gas than Holland. For France, only the nuclear option could provide energy independence. This became known as the Messmer plan, and called for creating 13 GW of nuclear power plant capacity over the next two years. In 1974, work on three nuclear plants was started, and by 1979 nuclear energy accounted for 20% of EDF's total output. This share further grew to 49% in 1983 and 75% in 1990. The total capacity in 1990 of EDF's nuclear power generation stood at 54 GW and was greater than the combined nuclear power capacity of the UK, West Germany, Spain, and Sweden. In 2012, the total capacity of nuclear power generation in France has reached 63 GW. The net production of electrical energy coming from nuclear plants accounted to 404.9 TWh, representing ~75% of total electricity generation (541 TWh) (See Figure 1).

The large scale of development however, left the country with an over-capacity by the mid 1980s, and by 1988 the nuclear power plants were running at a load factor of 61% (as compared to 92% in Finland or 84% in Switzerland). Thus the goal of self-reliance and independence was fulfilled, but to an extent that exceeded domestic needs. With the excess capacity, EDF explored export opportunities, and within a few years France was exporting significant amounts of power to neighboring European countries (see Figure 2).

During the yearly years of nuclear power development, some public groups opposed the technology with street protests and demonstrations. Such activities of resistance and opposition were highly insulated and stifled with police action [11]. Over time, the public support for nuclear power plants grew owing to new job opportunities. Current report [12] shows that the nuclear industrial sector in France has created 410,000 jobs in the country, and in the future (2009-2030), the sector would be able to create between 70,000 and 115,000 additional jobs. In addition to EDF, AREVA and CEA have been major stakeholders in research, development, and innovation in nuclear energy technology in France. In 2012, CEA had a budget of € 4.7 billion with 10 research centers and bout 16,000 technicians, engineers and researchers [13].

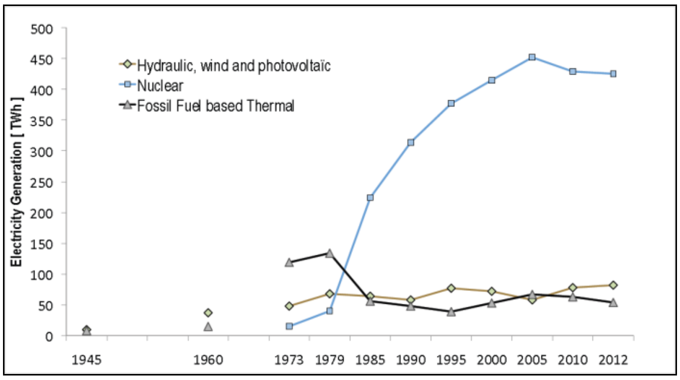

Fig. 1. Electricity generation [TWh] by fuel type in France from 1945 to 2012 (Source: [11][14][15])

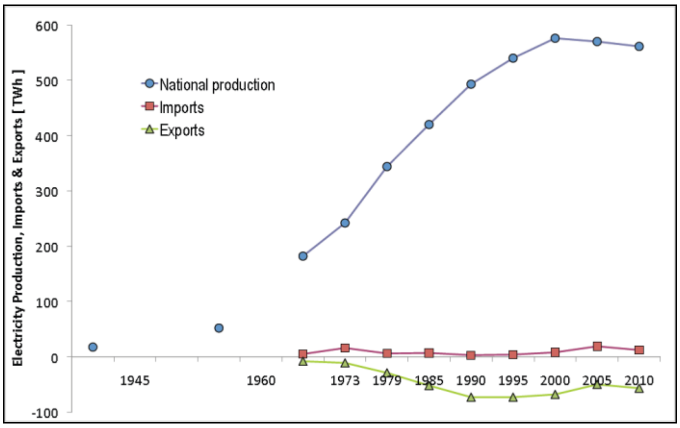

Fig. 2. Electricity import, export, and national production (TWh) in France from 1945 to 2012 (Source: [11][14][15])

In addition to exporting the electricity, the extensive know-how and expertise that had developed in France of building nuclear power systems was also brought in service to coutries. EDF began selling its products and expertise to countries in Africa and started a series of projects in China.

B. Dynamics of Nuclear Energy System in France

Based on the historical case of nuclear energy in France described above, we mapped the dynamics in a causal loop diagram using the seven functions of innovation (see Figure 3).

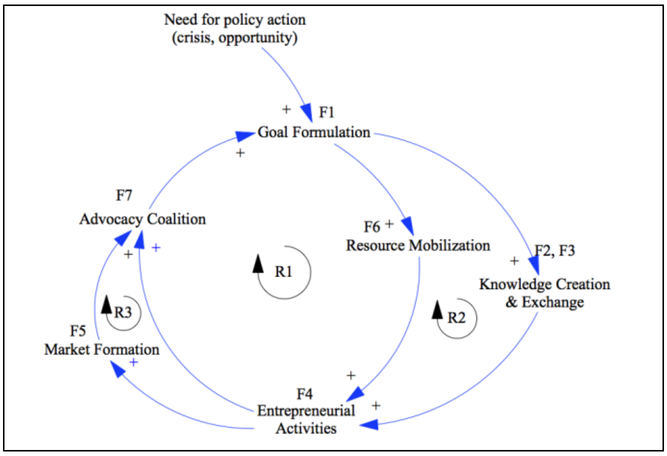

Fig. 3. Development and Expansion of Nuclear Energy in France

Figure 3 shows that the exogenous stimulus for change came with the oil crises. The shock to the domestic energy system catalyzed a policy response (F1), and the Messmer plan (of nuclear energy) sets the dynamics in motion. The policy mobilizes monetary and human resources (F6) to quickly establish a nuclear energy base. A number of power plant projects are started (F4) that quickly build up capacity, and any opposition is thwarted due to advocacy for national independence and energy self-reliance (F7). The early successes in stifling any opposition leads to sustained policy (F1) and the reinforcing loop – R1 takes hold. As the initial plants are brought to service and consumers are provided with electricity, a market is formed (F5) that further strengthens the advocacy power for the technology (F7). This dynamic is depicted by loop R3. Additionally, with continued state support (F1), the government-owned power utility engages in R&D (F2 and F3) for advancing technology and expertise in nuclear power generation (shown in loop R2) that favorably helps in further expanding nuclear power capcity (F4) in the country. And with increasing number of power plants distributed throughout the country, a large number of jobs are created for those regions that strengthens public support and advocacy for the established system (F7) and puts pressure on the state to maintain the favorable and supportive policies for nuclear power (F1).

In summary, a series of reinforcing (or virtuous) cycles come into play to enable a rapid and vast expansion of nuclear power plants in France. The rate of expansion of nuclear capacity however slowed over time as domestic demands were met with the installed base. The growth in nuclear power capacity was thus checked when market demand no longer justified new domestic installations, and a series of balancing cycles – that inhibit further growth and maintain a saturation level for the technology – came into action. We limit our analysis in this paper up to the technology adoption stage, and in future work will describe the set of processes that led to saturation and growth inhibtion.

IV. Electric Vehicle Technology Development in France

An Electric Vehicle (EV) is a vehicle using only electric energy for its propulsion. EVs emerged in the late 19th century, but could not gain wide spread adoption as compared to internal combustion engine vehicles. In the following paragraphs, we give an overview of the history of the development of EVs in France, drawing mainly from the report presented in [16].

However, it is worth to say that the oil shock not only initiated significant transformation in power generation, but also stimulated changes in energy consumption trends in France (see figures 8, 9, 10 in the appendix). In 1973, transportation accounted for ~21% of crude oil consumption in the country [17]. Thus, in order to reduce the crude oil consumption by transport, in parallel with a massive and rapid electrification of railways, an Inter-Ministries Group for Electric Vehicles was set up in 1973 to coordinate development of EVs. Efforts for electrification of road vehicles, however, proceeded slowly due to lack of maturity in the technologies. The efforts continued, and by the 1980s, cooperative efforts grew to include major European operators (EDF -France, RWE -Germany and Electricity Council -England) to promote EVs. The national activities were connected with other European efforts such as the COST program that aimed to study the impact of EVs in the transportation systems and to identify gaps and R&D needs in the sector. In the 1990s, the French government created a new set of opportunities by providing policy and R&D support for advancing battery technologies and increasing the travel range of electric vehicles. A program of research and innovation on transport (PREDIT) was established to accelerate the introduction of new, energy efficient, and clean energy vehicles and transport systems. Many projects were launched to support the creation of new categories of users, incentivize acquisition, and to create enabling infrastructures. The objective was to initiate a large market by promoting acceptance by users and preparing the physical and organizational infrastructure. Several French regions participated in different programs for this purpose, and all major automakers proposed concept cars. In 1995, the government coordinated agreements with Peugeot, Renault and EDF, to organize development of necessary infrastructure. Overall, the results remained modest and wide spread adoption did not come about, largely due to high costs, technical performance, and other difficulties related to the absence of adequate infrastructure. The programs did, however, allow for large-scale demonstration tests that significantly helped in advancing the technological knowledge in the field and allowed manufacturers to gain a better understanding of driving habits and preferences of users in the country.

In the last decade, a number of program and public initiatives – stemming from broader policies on climate change mitigation – were enacted that lent new support to EV development. The National Plan of Action against climate change and its operational implementation through the National Program to Improving Energy Efficiency were formulated in 2000. This was followed by the ratification of the Kyoto Protocol in 2002. During this period, oil prices started to increase again after a long period of relatively low prices. In addition, in 2000, transportation accounted for ~64,7% of refined oil consumption in the country [17]. The high fuel costs created renewed interest and a new urgency for adopting electric vehicles. In 2003, Prime Minister Raffarin launched a plan for `*Véhicule Propre et Econome*` with a two-year budget of € 40 million for R&D aimed for large-scale industrial production of innovative, clean vehicles. In 2008, the `*Grenelle de l`Environnement*` Forum provided another injection of resources through the set up of a new financial fund for accelerating research and development of electric buses, heavy vehicles, and small urban vehicles. The government also committed €250 million in soft loans, by extending a subsidy of € 5,000 for purchasing electric vehicles and coordinating public purchase orders of electric vehicles [18]. A recent stated goal of the government is to bring together the resources of major French car manufacturers and several industry groups to meet the challenge of sustainable mobility in the country [19]. It also aims to help create jobs in the sector, with estimates ranging from 15,000 to 30,000 new jobs in electric cars, and electric and hybrid trucks production by 2030 [20].

A. Dynamics of Electric Vehicle Innovation

We use the same methodological approach as we used for the nuclear energy case analysis, and draw from the historical narrative described above for EV development in France, to map the seven processes of innovation and their interactions in a causal loop diagram.

The 1973 oil crisis served as the external stimulus for change in France, and the state undertook major policy initiatives for energy independence and energy security that included provisions for transforming the oil-dependent transportation sector in the country (F1). Resources were used (F6) for a rapid electrification of the railways (F4) and with energy independence as an important strategic goal there was strong support and advocacy for change (F7) that sustained policy action (F1). These dynamics formed loop R1 shown in the diagram in Figure 4. The government also created research programs to develop knowledge and technical know-how in electric road vehicles (F2), and these efforts were enhanced with wider cooperation with other European partners and major national actors in car manufacturing and energy production (F3). The knowledge generation and exchange efforts, however, continued to cycle through (loop R2) with increasing entrepreneurial activities (undertaken by Renault and EDF etc.) (F4), and advocacy for clean energy (F7) that maintained state support (F1) but did not lead to significant market creation. This dynamic is captured by loop R3. EV technology has so far not been able to move on to the last successful stages of innovation, *i.e.* of large-scale production and deployment (unlike the nuclear energy case) in France. The recent incentives and resources that have been mobilized by the government (in the form of subsidies and loans) (F6), however, may shift the dynamics where the resources allow for sufficient entrepreneurial development (F4) such that successful markets are created (F5). This will produce stronger advocacy (and counteraction to the resistance to change from the established regime of internal combustion engine vehicles) (F7) enabling and furthering state support (F1). Increasing entrepreneurial activities (F4) leading to market creation (F5) in turn will mobilize further resources in the private sector (F6) that creates loop R5. These dynamics of loops R4 and R5 may, thus set in motion strong positive reinforcing cycles that change the mix of ground transportation propulsion technology in the near future in France.

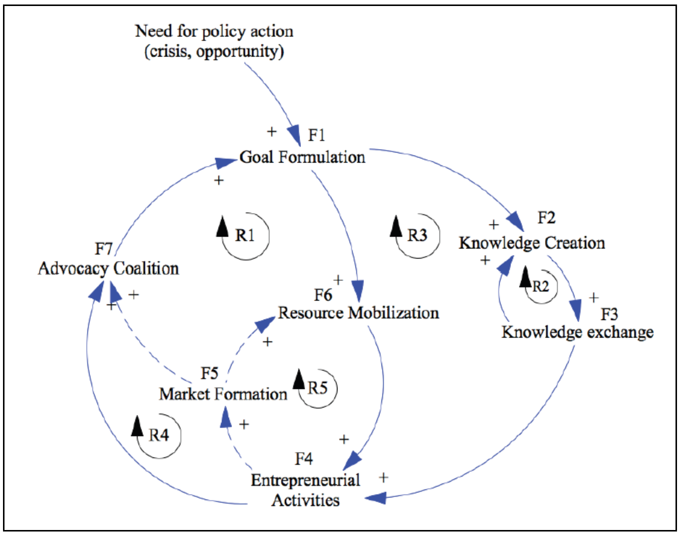

Fig. 4. Current innovation processes in EVs Technology vs Potential future processes needed for large-scale deployment of EVs in France.

In 2010, Renault, the automotive company estimated a global market share of 10% for EVs over the next ten years. It has commercially launched four types of EVs targeted for customers who do not drive long distances. This is applicable for the majority of drivers in Europe, where 87% of drivers travel less than 60 km daily [21]. Additionally, the power company, EDF, has announced that it will provide customers with electricity up to five times cheaper per kilometer traveled than gasoline or diesel [22]. Furthermore, there are now charging systems in shopping centers, parking, public buildings, etc. in the country. On the market side, 13,954 individuals and light commercial electric vehicles were registered in France in 2013. Sales increased by nearly 50% compared to 9314 registrations recorded in 2012 [23][23]. Public orders were encouraged by the French Government, and for example, Renault will provide more than 10,000 EVs to the French mail company (La Poste) [23]. Furthermore, a number of partnerships are being established between automakers, electricity utilities and parking companies [22][23] etc. Figure 5 shows the market share and number of registered individual EVs in France.

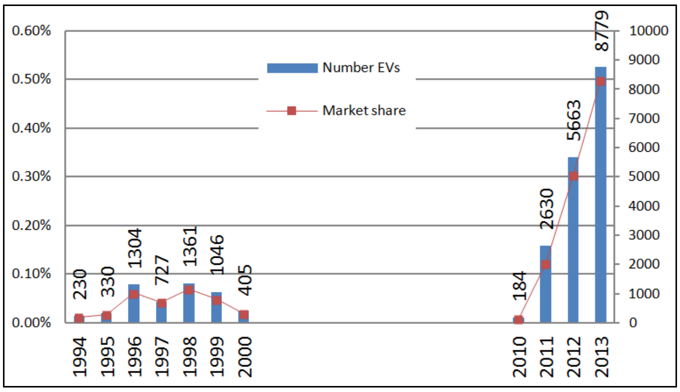

Fig. 5. Number of registered new individual electric vehicles and market share in France (Source [16][17][24]).

For the first generation of EVs (with low production volumes), the acquisition price would be higher than for an internal combustion engine (ICE) vehicle of the same category due mainly to the battery price. However, the total cost of ownership would be less expensive mainly due to the price of electric energy and cheap maintenance as shown in Figure 6. Indeed, despite a relatively high taxation of electricity in France, the prices are relatively cheap compared to the rest of Europe due to its large development of nuclear and hydropower (see Figure 7.)

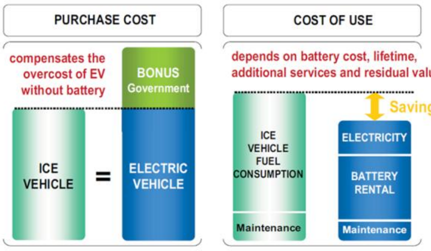

Fig. 6. Total cost of ownership - Difference between EV and ICEV [21]

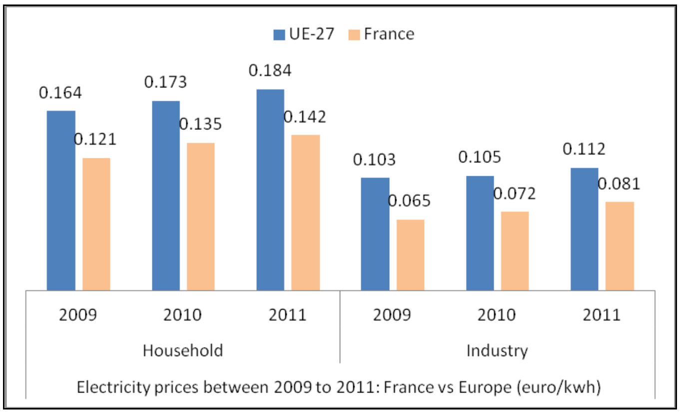

Fig. 7. Electricity prices between 2009 to 2011: France vs Europe (euro/kwh) (Source [25][23])

The new complex economic equation and business model related to EVs could evolve in the future given the potential of their introduction in the market. The economy of scale and the evolution of technology could impact the evolution of these costs in the future. The business models become more complex given that the prices of energy may drastically change during the day, and that some value is attached to the ability to level energy demands on the energy network (see for example [26] about "Vehicle to grid" interactions). That would increase the electricity and transportation nexus.

In an interesting parallel with the nuclear energy case, we also find that technology diffusion of electric vehicles is also crossing international boundaries. The Reanult-Nissan Alliance signed a Memorandum of Understanding (MoU) in 2010, for the promotion and deployment of EVs in Ankara, Turkey. Another MoU has been signed with the Municipality of the City of Córdoba in Argentina, etc.

V. Discussion

The historical development of nuclear energy in France and its comparison with the now evolving transition in transportation offers an interesting case for studying technological change. We find in the case of nuclear energy, that the observation made by Arthur in [8] is pertinent that "under increasing returns, competition between objects - in this case technologies - takes on an evolutionary character, with a 'founder effect' mechanism akin to that in genetics. 'History' becomes important." He notes that the dynamical processes that select winners from a pool of competing technologies are impossible to predict due to interactions of economic forces and random historical events.

The two cases that are discussed here are linked at the outset in history through dependence on oil and policy action that stemmed from the oil crises of 1973. We find that the adoption rate of the two technologies, however, was very different. Nuclear energy was quickly and decisively deployed at a large-scale in the country, whereas EVs did not have the same wide spread diffusion (expect in niche areas). Investigating the factors that led to these different outcomes can provide useful lessons.

One possible explanation maybe that at the time of the crisis (that created a window of opportunity for enacting change), nuclear power generation technology had matured to a level such that it already occupied a small niche market in the power sector (of 8%) in France. The technical knowledge, as well as state enterprise (through EDF) already existed that could quickly and decisively shift the system at a large scale. This fits within the proposed theory offered in [9] that suggests that a technological subsitution occurs if at the time of sudden disruptions (such as shocks, crises) there is a niche technology that occupies a share of 5% or more in the market. The niche technology can then quickly diffuse and replace the incumbent technology. In the case of EVs, while railways could quickly change due to sufficient technology maturity, the technology for other modes of ground transportation (buses and cars) was not sufficiently developed to allow for quick large-scale substitution. The impetus for large-scale change waned with time as the shock of the crisis wore off, and EV innovation was stuck in the knowledge creation, exchange, and limited entrepreneurial activities loop. State support remained – but its magnitude fluctuated over the decades with the long-term trends of the price of oil. The awareness of global warming and large increases in price of oil a few years ago have brought renewed support for deploying EVs – but that support has not matched the urgency and strength of impulse for change as was brought about in 1973 with the oil crisis.

In the two cases, it is interesting to note the significant role of policy in initiating and shaping the outcome of the two technologies. In France, the government not only formulated policy, but also operationalized it through state-owned techincal enterprises. The roles of EDF and Renault (partly owned by the government) are prominent in advancing the innovations and deployment. Additionally, a number of state-owned research labs and organizations (such as CEA) worked under the central policies that brought about change in the power sector and are now increasingly influencing the transportation sector. As a number of countries seek to escape the ‘carbon lock-in’, these cases offer a perspective on the role of long-term policy in building new industrial paradigms.

In analyzing the two cases, it is also interesting to note the critical issue of electricity costs that are likely to play an important role in adoption of electric cars in the country. With EDF providing electricity for charging EVs, the total cost of ownership of EVs becomes attractive to customers in France. The large nuclear power base that allows for cheap and abundant electricity suppplies in France, puts EVs in a much more advantageous position (especially if oil prices remain relatively high) as compared to many other countries in the world. The legacy of nuclear power is thus likely going to play an influential role in the future success of EVs in the country.

Based on the discussion presented above, we postulate the notion of cross-sector path dependence due to inter-connections between traditionally different technology domains. Path dependence refers to the pattern of behavior of a system in which initial conditions and unpredictable events in the early stages, decisively determine its ultimate fate [6]. Initially, a number of outcomes are equally possible, but random events shift the trajectory in a particular direction and a series of positive reinforcing loops lock the system into a particular course from which it cannot turn back. There is a vast amount of literature on this behavior of complex, socio-technical systems, with often cited examples ranging from the QWERTY keyboard layout [8] to gauge of railroads in the US [6]. We extend this idea, and note that as new technologies are creating inter-linkages across traditionally separate domains, it is likely that incumbent technologies in one sector (that became entrenched through path dependence) will shape future trajectories of technology in other sectors. In other words, historical chance events bring about lock-in of a particular technology in a sector, which in turn influences the trajectory of technologies in other inter-connected sectors.

VI. Conclusions and Future Work

In this paper we map the historical development of nuclear power systems and electric vehciles in France. We develop a qualitative analytical approach by employing concepts from literature on innovation, technology adoption, and technological change, and map the virtuous cycles of growth using a set of seven process of technology innovation. This work is a departure from the linear models of innovation, and attempts to identify the interactions of processes of innovation that led to different outcomes for adoption of nuclear energy and EVs in France. Unlike the disconnected system of innovation described by Vannevar Bush (where he suggested that the government should contribute in basic research and the industry will apply it to practical problems [27]), in the two cases we presented in this paper, we describe iterative and incremental cyclic loops to represent the process of innovation. We also discuss the notion of cross-sector path dependence that may grow in importance as system inter-linkages increase [28]. An improved understanding of this behavior maybe necessary to predict diffusion of new technologies.

We will expand this work in the future to include the important consideration of economic aspects. We have not evaluted the optimality of the policies and processes for the French economy in this paper – that was outside the scope of this study. We only attempted to systematically map the forces and processes that have shaped the trajectory of the two technologies. In future work, we will investigate the critical issues of costs and financial resources provided by the state to initiate and sustain the development and deployment of these technologies. Furthermore, we will apply our method to study the case of EV development in Japan (given the impacts of Fukushima), and the US (considering the shale gas context) in order to make comparative assessments. Also, it will be interesting to study the ongoing energy transition in Germany where policy makers have proposed a complete phase out of nuclear energy by 2022 [29]. Using the different cases, we will attempt to draw out general archtypes of interactions of the process of innovation in order to elicit lessons for policy and strategy for technology development and diffusion.

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APPENDIX

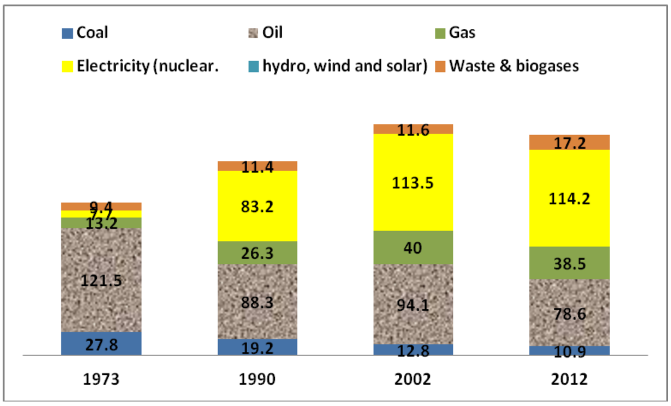


Fig. 8. Primary energy consumption by source in toe (tonne of oil equivalent) (source [17])

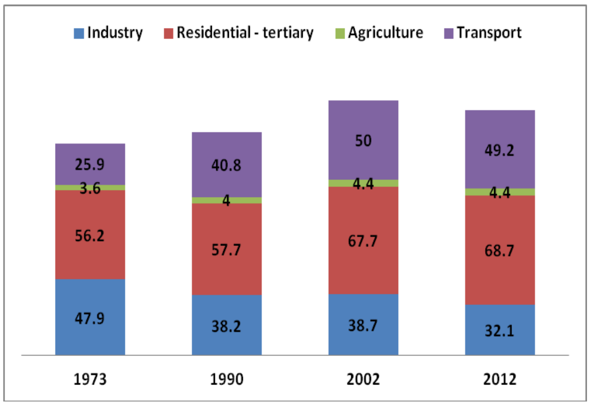
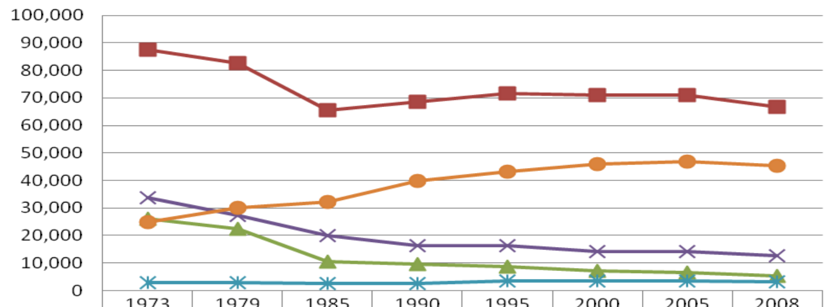


Fig. 9. Final energy consumption by sector in toe (tonne of oil equivalent) (source [17])



	1973	1979	1985	1990	1995	2000	2005	2008
Total	87,420	82,728	65,525	68,439	71,677	71,057	71,101	66,765
Industry	25,966	22,515	10,654	9,469	8,614	7,262	6,479	5,390
Residential - tertiary	33,655	27,186	20,079	16,328	16,288	14,316	14,316	12,532
Agriculture	2,845	2,920	2,659	2,690	3,421	3,452	3,414	3,344
Transport	24,954	30,107	32,133	39,952	43,354	46,027	46,892	45,499

Fig. 10. Final energy consumption of refined oil by sector (in thousand tonne) (source [17])