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The cohort effect in solar energy and nuclear power: unveiling collective agency in energy transitions

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ABSTRACT

How does the collective agency of multiple individual actors shape energy transitions? This paper engages with the many, varying careers of petroleum chemists, engineers and (geo)physicists who got involved in the development of alternative energy sources during the second half of the Twentieth century. In this period alternatives to oil, such as nuclear and solar power, were developed, often with the aid of many actors with roots in the already established oil regime. To preserve the agency of these many individual actors within the broader framework of energy transitions offered by the Multi-Level Perspective (MLP), this paper argues for the inclusion of (generational) cohort theory from the social sciences. Using cohort theory helps us better understand the agency the multi-facetted careers of the studied (oil) actors, often leading them through the revolving door between the political landscape, the existing oil regime, and the new technological niches of solar and nuclear energy.

1. Remarkable careers?

Transitions to sustainable energy systems involve a complex interplay between incumbent industries, emerging technologies, and individual actors navigating an ever-changing landscape. However, the individual actors are often difficult to pinpoint in more traditional transition frameworks. In these frameworks, emerging energy sources are presented as challengers to existing (fossil) energy regimes. Incumbent actors are then mainly described in their roles of developing strategies within (geo) political and societal frameworks to relate to the new competing energy sources, either facilitating or complicating the transformation. While this abstract representation of energy transition provides useful tools to interpret the strategies of incumbent actors, it becomes more complicated when zooming in on individual actors and their careers that move in and out of the various energy sources, as this article argues.

The career of Han Hoog, spanning from the oil industry to nuclear and renewable energy development, exemplifies this complexity. Starting as a chemical engineer in the oil industry at *Bataafsche Petroleum Maatschappij* (BPM), the Dutch branch of the Royal Shell Group, in 1934, he rose to director of Shell Petroleum N.V. and The Shell Petroleum Comp. Ltd. in 1967. That same year, Hoog also became director of a new nuclear subsidiary of Shell in the Netherlands, *Shell Kernenergie B.V.*, making him responsible for Shell's first steps in uranium enrichment and nuclear energy development. After retiring from Shell in 1971, he chaired the Dutch nuclear energy development center, the RCN. An organization he transformed into a nexus to promote alternative energy sources in the Netherlands, including wind and solar energy [1–3].

Han Hoog can be partly defined as part of the incumbent actor Royal Dutch Shell during the development of nuclear energy as a technological niche in the 1950s and 1960s. Even his first managerial position as chairman of *Shell Kernenergie B.V.* can still be regarded as part of a strategy employed by Shell to engage with the new technological niche of nuclear energy. However, it becomes more difficult to define Hoog's position in later stages of his career. As chairman of the RCN, established by the Dutch government, but still in an advising role for Shell, Hoog is more difficult to frame as a mere incumbent actor.

While Hoog's career trajectory may appear distinctive, it exemplifies a broader phenomenon of individual actors navigating multiple energy sectors. In this paper we put those individuals who navigated between the development of new energy niches, established energy regimes, and political landscapes that shaped ongoing energy transitions to the forefront. Specifically, this paper studies the collective agency of individuals during the energy transition of the mid-20th century, characterized by the rise of nuclear and solar power as alternatives to traditional fossil fuels. We argue that focusing on collective agency is

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key to the understanding how transition pathways unfold, how new energy technologies collide with existing regimes, and even why some potential transitions eventually did not yet fulfil all their promises. To study the collective agency of multiple actors, all connected to the established oil regime, this article integrates cohort theory with the Multi-Level Perspective framework (MLP).

Our analysis unfolds in two parts. The first is a theoretical discussion where we critically reflect on MLP's applicability to the case studies of nuclear of solar energyas energy transitions. Through the lens of cohort theory, we then examine the diverse backgrounds of actors who have traversed various levels during pivotal moments during these energy transitions. Commonalities in education, historical context, and shared experiences—including specific historical events and social pressures—are examined as interwoven threads fostering collective agency.

The second part considers two empirical case studies where a cohort approach enriches our understanding of two energy transitions within the MLP framework. First, we examine the development of nuclear energy for electricity generation from the 1950s to the mid-1980s, focusing on the Netherlands. Second, we turn to the emergence of an entrepreneurial cohort within the U.S. solar energy sector during the 1970s and 1980s. Despite their distinct contexts, these cases reveal cohorts that shaped oil industry engagement with alternative energy. In this way our paper not only contributes to better understanding of this engagement, an inquiry that has only recently occupied the attention of energy historians (see [4–8]) but also s highlights how individuals influenced the intersection of established energy interests and emerging technologies. This, however, offers a valuable complement to MLP and contributes to the literature on the importance of studying incumbent actors' agency [9].

2. Nuclear and solar within the MLP framework

The concept of "*transition*" is omnipresent in current energy history. In recent years, historians of energy have related their work to contemporary debates about energy transitions and examined past changes in energy provision from a variety of perspectives. Those changes include shifts between specific energy carriers or technologies, grand transitions between energy regimes, deep transitions, infrastructure transitions, and case studies of socio-technical transitions [10–12]. Analytical frameworks such as MLP, regularly use historical case studies to analyse a transition as a technological change over time. The 'change' is explored through interactions between three levels: the '*regime*' or meso level, the '*niche*' or micro level, and the '*landscape*' or macro level [11,12]. The 'regime' represents a fixed order of technologies and institutions characterized by incremental innovation. In contrast, 'niche innovations' is a space where radical innovations find applications in limited domains free from the selection environment of the regime. A structural landscape is an overarching collection of (geo) political developments, policies and organizations that can destabilize regimes and create opportunities for niches to emerge, when they slowly change over time [13]. Within the framework, transitions take place when niche developments/technologies breakthrough, start to penetrate, and eventually overtake the regime or when incumbents incrementally or radically shift their focus to adopt niche innovations and/or start looking at alternatives. By applying this framework, MLP helps to conceptualize transition pathways from new niche technologies to new regimes as a process of evolution over time. This becomes apparent when we apply the framework on historical case studies of nuclear and solar energy.

In the years preceding the end of the Second World War, atomic scientists and engineers worked on controlling and developing applications of the energy gained from the fission process on an ever-growing industrial scale. After the war, the search for more military and civilian applications of the nuclear fission, and fusion process accelerated rapidly with the launch of the first nuclear submarine (1951), the connection of the first nuclear power plant to the grid in Obninsk, Soviet Union (1954), and the Ford Company launching its model for their nuclear-powered automobile in 1958. Nuclear energy was predicted to "become too cheap to meter" and was expected to become competitive to oil in the coming future [14].

Although often framed as a "failed" or "stalled" transition for not fulfilling on its promises to overthrow the existing oil and coal regimes [15,16], nuclear power grew to produce 8 % of the world's energy needs in the mid-1980s. Because of its promises and the belief among many actors that nuclear power would eventually replace oil as the primary energy source, the development of nuclear energy has regularly been discussed in the context of an energy transition framework among MLP scholars - often focussed on national endeavours to establish a domestic nuclear industry. Within this approach, the development of nuclear technologies is framed as a transition from a niche – protected from direct competition with existing energy regimes and with mainly small-scale, often military, applications – to a full-fletched regime colliding with other energy sources such as coal and oil [17]. As various historians have argued, however, this development was shaped by oil actors from the very beginning. These actors were often directly employed by oil companies, but also regularly moved from the oil industry to (semi) governmental service and back to the oil regime [18,19].

The history of solar energy development could fit even more neatly into MLP framework. In the years after the Second World War, the solar industry transformed with Bell Laboratories' 1954 invention of the photovoltaic solar cell, capable of converting solar energy into electricity. This invention attracted attention from the U.S. Space program, which was looking into new ways to power their satellites. At first, solar energy was primarily used by NASA and the military market. At the same time, efforts to commercialize PV for civilian, terrestrial applications, were also carried out but on a much smaller scale. The initial governmental support, investments from universities and semiconductor companies quickly faded away due to the very high cost of as-yet immature solar technology, a very small 'niche' market, more prominent potential for cheap energy from nuclear fission, and the still low cost of fossil fuels [20–22].

The energy crisis created a window of opportunity for solar energy to break through, as disruptions in oil pricing and supply compelled Western governments and incumbent firms to reassess energy strategies. Response included drilling in remote areas or offshore [23,24], transitioning to alternative energy [25] and experimenting with renewables by subsidizing applied solar research programs, as exemplified by the efforts of Han Hoog and the RCN. Concurrently, many solar entrepreneurs, often with backgrounds as engineers with NASA or in the semiconductor industry, convinced, sometimes major, oil companies to invest in their solar start-ups and scale-ups [5]. These actors, both from within and outside the oil industry, operated within the technological niche, engaged with incumbent actors and landscape organizations such as semi-governmental programs. Whether directly employed or (in) directly financed by oil companies, these entrepreneurs shaped the development of solar technologies, laying the groundwork for the industry breakthrough during the early twenty-first century.

Although the two cases of the development of nuclear and solar are distinctly different in scale – both in time, geographies, and people and capital involved - the two examples both show how a transition framework such as MLP on the one hand offers useful tools to discuss the overarching transitions, but also lacks the vocabulary to talk about actors crossing the boundaries of niche, regime, and landscape.

MLP has been criticized regularly for falling short of explaining the interplay between various incumbents, or 'regime' actors, in establishing and supporting the niche technology. At its core, vocalizers of this criticism state that MLP is too descriptive and structural, pays too little attention to the agency of individual actors, and leaves little room for a broader analysis of power and politics [26–28]. Although proponents of MLP claim that the model accommodates actor agency by focusing on the "increasing structuration of activities in local practices" [29–32], they do recognize the criticism that certain types of agency, such as rational choice, power struggles or cultural discursive activities, is less developed [33]. This does not undermine the model but merely leaves room for incorporation of other theories or concepts within the context of MLP. Genus and Coles [34] therefore argue for the incorporation of more constructive approaches such as the Social Construction of Theory (SCOT), Constructive Technology Assessment (CTA) or the Actor Network Theory (ANT). Attempts to do so have been made in the studies of Grin et al. [35] developing the role of power struggles within MLP based on political science, Elzen et al. [36] on external normative concerns from Social Movement Theory, and Geels and Verhees [17] on the cultural dimensions of MLP, drawing on cultural sociology, discourse theory and Social Movement Theory (e.g. [37]). With this paper, however, we offer an additional way to integrate actor agency within the framework of MLP with the use of cohort theory.

3. Introducing (generational) cohort theory

The use of the concept 'generations', as an object of study to understand the structure of social and intellectual movements, can be traced to its roots in sociology and the work of Karl Mannheim on the so-called "problem of generation" [38]. According to Mannheim, a generation is like the class position of an individual in society. Although a generation does not constitute a 'concrete group' - its members do not need to have a mental or physical proximity, or any knowledge of each other - a generation can be defined by a common 'social location'. Mannheim further defines a generation as a group of "individuals (…) who share the same year of birth (…), a common location in the social and historical process and thereby limit them to a specific range of potential experience, predisposing them for a certain characteristic model of thought and experience, and a characteristic type of historically relevant action" [38]. In this way, Mannheim distinguishes two important elements to the term 'generation': a common location in historical time and a "distinct consciousness of that historical position (…) shaped by the events and experiences of that time" [39].

A great number of studies considering the concept of 'generations' has emerged in variety of fields since the work of Mannheim. These studies contributed to, and helped refine, the general debate about generations (see [40–43]), or juxtaposed different approaches to study social change [39,44]. While studying the role of generations in constituting social change, sociologists have made the claim that "for the sake of conceptual clarity, 'generation' should be used solely in its original and unambiguous meaning - as the temporal unit of kinship structure," [45] and that those born during specific time span are (birth) cohorts rather than generations. A cohort, then, describes a group of individual actors, born during a limited time span, that share a common and distinct social character shaped by shared experiences [46].

Unlike family generation, based on biological lineages, cohort generations are differentiated by the changing content of formal education, by peer-group socialization, and by idiosyncratic historical experience. In many cohort studies, this experience is birth, but can also include war, revolution, immigration, urbanization, or technological change. These shared experiences differentiate one generation from another [38,47,48], and leave far-reaching effects on beliefs and expectations, attitudes, and values [49]. Within the studies using the cohort approach each new cohort is a possible intermediary in a transformation process, a vehicle providing the possibility for social change to occur. Social change then is defined as a transition in culture, social norms or social behaviour, which only can happen through changes undergone by individuals due to aging or period effector, or through the succession of cohorts [45,50,51]. Since then, this concept of 'cohorts' is used by various scholars in political science, sociology, art history, and even the history of oil elites.

Douglas Yates [18], in his study of the French oil industry in the twentieth century (2009), focuses on cohorts of prominent actors in the oil sector. These prominent actors are selected because, at some point during their career, they became the CEO, or *président*, at one of the major French oil companies at their time, like Compagnie Française Petroleum (CFP, later TOTAL), Elf Aquitaine, or the oil service firm Schlumberger. Based on a selection of characteristics - year of birth, Alma Mater, membership of one of the Grand Corps, region of origin, main base of operation, and military service in either the First or Second World War – Yates distinguishes three broadly defined cohorts of "patrons of the French national oil companies".

First a cohort rooted within the concept of an oil firm as "Family Firms" with oil managers mainly being part of rich dynasties that 'ruled' the French oil industry during the first decades of the twentieth century, with examples of Le Bel family and Conrad and Marcel Schlumberger. After the Second World War, the modal French petroleum president was an engineer, good in mathematics, and physics and who had graduated in the top ten of his class from the prestigious *Ecole Polytechnique*. From there, he continued his studies at the *Ecole des Mines* that prepared him, via some field assignments in the oil or mining sectors, for a position as state engineer in the powerful technical-administrative *Corps des Mines*. There he quickly gained an influential position within the Ministry of Industry, the minister's cabinet, and ultimately at one of the National oil companies. The final cohort is formed by managers with backgrounds in the *École Nationale d'Administration*, a prestigious national school focused not on engineering and geophysics, but on finance, economics, and management. This new cohort of managers took the helm during the 1970s and 1980s, leading the French oil industry into a new period of privatisation [18].

Because of the common features, a cohort offers a network in which ideas about future developments can be realized and a transition – in this case the industrialization of the national oil sector in France and the later privatisation - is shaped in relation to previous and succeeding cohorts. Individual actors from the same cohort can thereby play different roles in the development of a niche technology, the execution of transition pathways undertaken by corporate incumbent interests, and the shaping of landscape features, like governmental policies and the design of the privatisation wave during the 1980s. By doing so, cohort theory provides a way to integrate actor agency within MLP. MLP can be used to localize a technology transition as a change during a specific period. In our cases: the diversification of oil actors into nuclear energy between the 1940s and 1950s (the moment nuclear energy emerged as an industry) and the end of this diversification during the 1980s and early 1990s, and the development of solar energy during the late 1970s.

In this way, MLP offers tools to define the 'change' the individual actors constitute in our case studies. By using the concept of a cohort as a "surrogate index for the common experiences of many people in each category" [45], we can observe and study the agency of individual actors without losing sight of the overarching transition. In other words, cohort offers a structure through which the agency is exhibited. That structure of common education, shared experience, common historical location, same goals, and visions for the future mobilizes individuals' knowledge of schemas and resources [52] and create a (collective) agency able to carry out the change. The scope of that agency can vary depending on social systems in which a collective cohort agency unfolds, as we will see in our case studies. For instance, solar entrepreneurs were driving force behind terrestrial solar application in the context of the U.S., whereas many (former) Shell employees shaped the development of a Dutch nuclear industry (Fig. 1; Table 1).

4. The revolving door between Royal Dutch Shell and the Dutch nuclear industry

The history of Western nuclear energy development is steeped in the involvement of actors with a strong connection to the oil industry. Already during the first decades of the twentieth century, oil geophysicists used their knowledge of radioactivity to locate petroleum and radioactive minerals in used boreholes, leading to various scientists being trained in atomic physics to start working for oil service

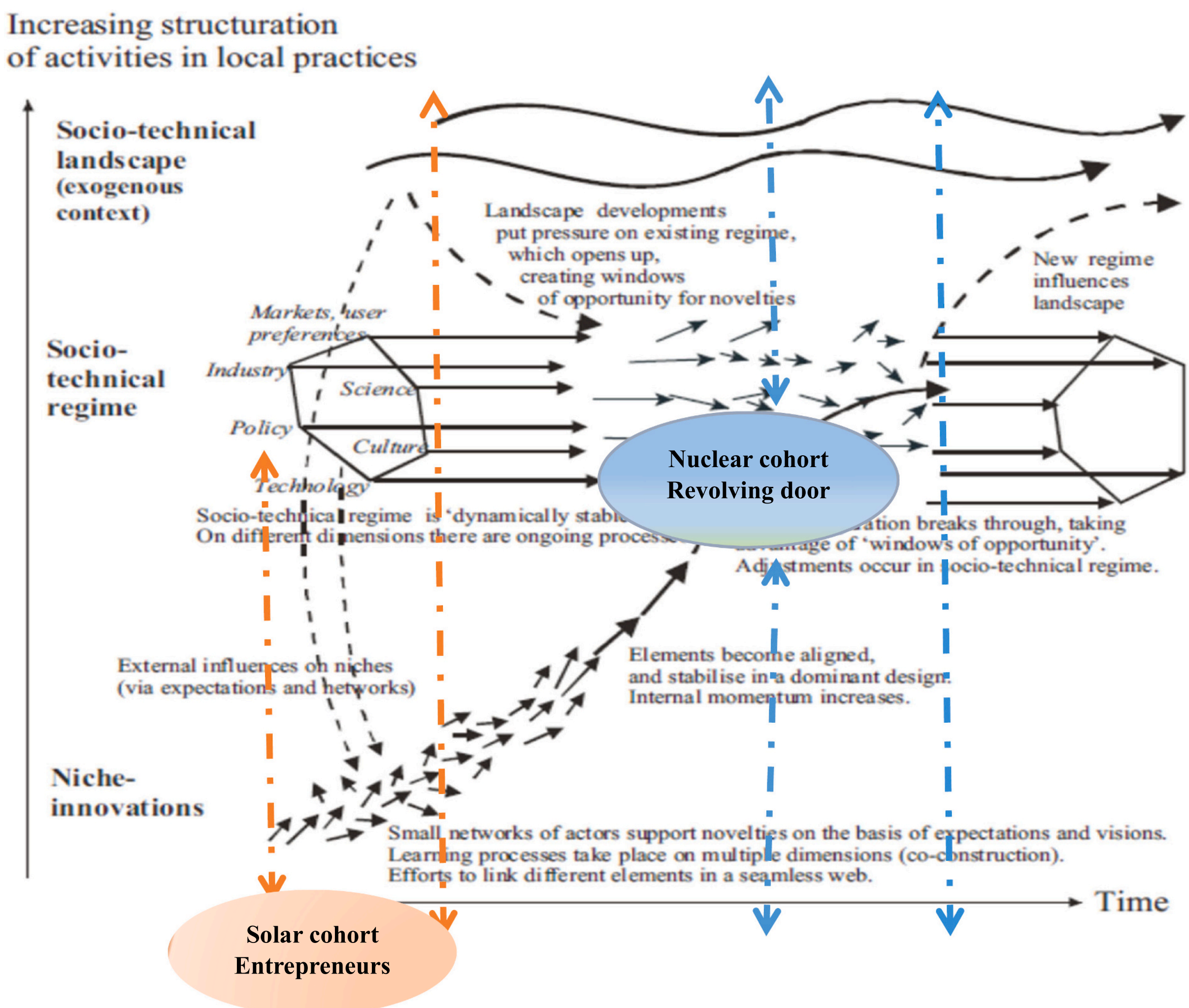

Fig. 1. Source: Original MLP illustration from F.W. Geels, The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions. 1(1) (2011), 24–40, is modified to illustrate cohorts' formation and its influence.

companies like Schlumberger, Lane Wells Company, and Tulsa Oil Company [53–55]. During the Second World War, oil engineers, chemists, and geophysicists worked on different projects within the Manhattan Project to further harness nuclear fission processes, find uranium, and develop the atomic bomb. After the war, oil geophysicists and geologists became involved in advisory committees to atomic energy authorities all over the world and were often called upon to aid in the search for uranium and establishing nuclear industries. Actors who often had had a long career within the oil industry moved into positions within governmental agencies or nuclear industrial projects where they influenced the development of the nuclear niche and shaped landscape features like the debates on resource scarcity, future energy production, and safety regulations [19,56].

The Dutch case offers a relevant example of a national nuclear energy transition that was shaped by actors with a background in one of the internationally active oil majors, Royal Dutch Shell. The example shows that, like Yates's cohort study of French oil engineers, also in other countries individual oil actors played outsize roles in shaping energy transitions while also being part of a network that shared their oil background, academic careers, and idiosyncratic events. Frank Geels and Bram Verhees [17] framed the development of nuclear energy in the Netherlands as an "innovation journey" within the MLP framework. In their case study, the authors distinguish two distinct periods in the development of the Dutch nuclear industry: an early period (1945–1970) in which Dutch scientists convinced policymakers to focus on civilian applications of nuclear energy and the establishment of an early Dutch atomic industry with its own nuclear reactors and uranium enrichment, and an ensuing period (1970–1986) in which nuclear energy in the Netherlands was increasingly criticized and developments slowed down or were phased out. However, this case study does not explain who these scientists and policy makers were and how they were able to establish this civilian nuclear industry. Applying cohort theory within an MLP framework to this specific case shows that the involvement of oil actors from Shell played a major role in the initial development of nuclear power by creating a network of individual actors who shared a common background.

For this case study, we have focused on actors that were involved within the (semi)governmental institutions coordinating Dutch nuclear industrial developments, specifically at the Reactor Center of the Netherlands (RCN). Based on the network studies of the interlocks between companies, institutions, and the government, nuclear historian Gerrit Zijlstra identified the Dutch nuclear industry as an interlocked network of seventy-five organizations, divided over seventeen groups and four sectors. The sectors distinguished by Zijlstra were (1) industry with two groups of companies and a group of joint ventures; (2) the electricity sector; (3) semi-government with three groups of research institutions and four groups of advisory boards; and (4) government with ministries, government departments, and a standing committee in

Table 1
Cohort contribution to MLP, Examples from Solar energy and Nuclear power (Source: own depiction).

	Cohort theory Contribution	Example from Solar Case Entrepreneurs	Example from Nuclear Case Revolving door
Niche	Identifies key actors within the niche, their shared characteristics (expertise, motivation, historical location), which drive niche development.	Solar entrepreneurs with space program experience leveraging their expertise to develop terrestrial PV technology and markets.	Scientists and engineers with a shared background working for Shell, transitioned into the nuclear sector, applying their expertise in physics, chemistry, and geology to nuclear projects
Regime	Identifies key actors (incumbents) in the regime, explains how cohorts (based on their shared values, beliefs, strategies, and contribution) challenge, reinforce and/or work together with existing regimes.	The cohort challenging existing energy paradigms and/or working closely the incumbents (e.g. creating solar industry market).	The Shell cohort as part of the incumbents (e.g. through their positions and connection to (oil) industry) shaped the development of the nuclear sector in the Netherlands.
Landscape	Showcase how cohorts respond to landscape pressures and vice versa (e.g., economic shifts, policy changes, geopolitics) based on their shared experiences, opportunities, and how these responses shape the transition process.	The solar cohort responding to the oil crisis by developing innovative solutions. Landscape tries to accommodate new solar market (e.g. policy).	Demonstrates how a cohort can bridge the gap between a niche (nuclear research) and the existing regime (government and industry), ultimately influencing policy and technological development.

parliament. The center of this network was located at the semi-government institutions, with RCN being the thickest node with connections to seventeen organizations, including ministries, scientific advisory councils, research centers, and six industrial parties (including Shell and multiple nuclear industrial companies). These connections were manifested by the different parties being represented in the board and advisory committees of RCN, representing the various companies and institutions [57,58].

Although Zijlstra and institutional historians of RCN, acknowledged that around 1972 Shell played an influential role in this nuclear network by delegating board members and being a shareholder in many of the Dutch nuclear companies that were represented at RCN [58], these studies miss the shared Shell background of even more of the board members at RCN. A biographical cohort study to the preceding careers of the managers illuminated some additional information about this network: many of these board members, also already before 1972, had started their careers at Shell *before* moving to other nuclear industrial or policy positions. In this way they created a network of (former) Shell employees that shaped the establishment of a Dutch nuclear industry. The already introduced Han Hoog could be regarded as an archetype of the oil actors engaging with nuclear developments. At the Royal Dutch Shell, multiple scientists and engineers experienced a similar career as Han Hoog, shaping the development of nuclear energy from a technological niche, with specific, often military applications, to a technology that was expected to compete with the oil regime within the Netherlands.

Several of the scientists who had joined Shell before, or during, the Second World War became employed in the emerging nuclear science and industry in the Netherlands from the second half of the 1940s to the early 1960s. Mathematical physicist Henri Brinkman, after studying quantum mechanics, joined the Dutch branch of Shell in the 1930s to work on the viscosity of liquids. In 1949 however, he quit at Shell to start working on behalf of the semi-governmental Netherlands Organization for Applied Scientific Research (TNO) from 1958 onward to establish the Dutch nuclear fusion research centre [59]. Edmund Boon had joined Shell as an engineer in 1938 but in 1949 became a professor of chemical tools and control engineering at Delft University of Technology. A position he used to get involved in the construction of nuclear reactors and become a nuclear energy consultant for the Dutch government. Already before the Second World War and before he started working for Shell during the German occupation of the Netherlands, Hendrik Antony Kramers was already an internationally renowned physicist. After the war, Kramers continued working on his ideas on gaseous diffusion, the theory of which was applied in the Dutch research projects on uranium enrichment [60].

Shell scientists not only ended up in Dutch research on nuclear energy through a position in academia. Also, industrial positions were dominated by former Shell employees. Geologist Heinrich Schürmann had been responsible for the training of new geophysicists at Shell before he assisted the Dutch government as a consultant in a search for uranium deposits in the Dutch colonies of Surinam and New Guinea [61,62]. Robbert van Erpers Royaards studied electrical engineering at the University of Applied Sciences in Delft before joining Shell as a seismologist. In 1963, he shifted his career to become project manager of the nuclear power plant to be built in Dodewaard, of which he would eventually become the director and board member of RCN from 1973 onward [63].

Maarten Bogaardt, too, started his career with Shell after finishing his studies in chemistry and physics before the Second World War. From 1957 onward, he was seconded by Shell to RCN, where he helped establish a Dutch nuclear industry and focused specifically on building a nuclear ship reactor. In 1959, Bogaardt became a permanent employee of RCN. He played a major role in setting up the Dutch uranium enrichment project (now URENCO) and the first nuclear reactors before becoming chairman of RCN, a predecessor of Han Hoog [1]. Like Bogaardt, Hendrik Slotboom would play an important role in developing the Dutch enrichment project. Until 1963, physicist Slotboom had been the director of Shell's research laboratory in Amsterdam. From 1963, however, Slotboom became chairman of TNO and a member of the Central Council for Nuclear Energy, an advisory body to the Dutch government, where he would chair the committee that assessed that, with the help of Shell's Dutch nuclear subsidiary managed by Han Hoog, the Dutch uranium enrichment project should be industrialized [2].

Although all these actors were born in different places in the Netherlands and had strongly individualized characters, it is still possible to classify them according to their backgrounds and to recognize patterns within the diverse careers: most of them were men, and almost all of them had finished academic education in geoscience, chemical engineering, or (atomic) physics at the Utrecht, Leiden, or Groningen University or the University of Applied Sciences in Delft. After finishing their studies, they went to work for the Royal Dutch Shell in the 1920s and 1930s where they became responsible for establishing geoscientific research, chemical analysis of petroleum products, or big petroleum-engineering projects. From the Second World War onward, they became increasingly involved in establishing atomic research projects and a Dutch nuclear industry. Based on their knowledge on finding radioactive minerals, chemical analysis, and their basic background in atomic physics, they worked together as advisers, scientists, and managers in various nuclear projects. Some of them started working for government agencies, semi-governmental organizations, or industrial parties, while others stayed at Shell and helped their company diversify into nuclear energy from 1967 onward. In this way, these actors constituted a cohort: a generation of scientist engineers, trained in early nuclear and geophysics, that made use of idiosyncratic historical experiences, such as the introduction of nuclear fission, to steer their careers from the oil industry to alternative energy and shaped – through their collective agency – the Dutch nuclear energy transition as described by Geels and Verhees [17].

5. The emergence of a solar photovoltaic entrepreneurial cohort

When one takes a brief look at the Celebratory book on the century of solar [64] it becomes clear that solar energy development has long history with numerous contributors. Thus, the history of solar energy extends far beyond the specific entrepreneurial cohort examined in this study. While research on this specific group is scarce, existing studies [65–68] point to its unique significance for several reasons. First, already in the 1960s, the US experienced a significant shift towards an entrepreneurial mindset. This “entrepreneurial turn” not only impacted business but also influenced scientists, encouraging them to explore new approaches and seek opportunities beyond established academic structures (see [69–71]).

Second, their proactive pursuit of partnerships with established oil companies bridged the divide between the established fossil fuel regime and the emerging solar niche. Third, the capital-intensive nature of PV technology needed strategic alliances, further shaping their trajectory. These entrepreneurs actively sought cooperation with oil companies, recognizing their financial resources and existing infrastructure as crucial for scaling up PV technology. These dynamics highlight the agency of solar entrepreneurial cohort in leveraging opportunities to shape the technological development and market expansion of US solar PV. This study focuses specifically on the cohort of entrepreneurs who emerged in the 1970s, laying the foundation for the American terrestrial solar PV industry.

The American terrestrial solar PV industry was founded in the 1970s by a handful of solar entrepreneurs stemming from both academia and industry, with the latter often linked to the oil sector. These pioneers played a crucial role in laying the groundwork for solar PV development and commercialization, making their stories particularly relevant to understanding the industry’s trajectory. One such pioneer was an academic entrepreneur Karl Böer, the distinguished professor at the University of Delaware and founder of the Institute of Energy Conversion, who passionately advocated for the terrestrial applications of solar cells, particularly thin-film and CdS technologies. His creation of Solar One, an experimental house built in 1973, served as a highly visible demonstration of solar technology’s practical potential, attracting significant attention, including that of Shell Oil. Böer’s entrepreneurial drive led him to establish Solar Energy Systems, Inc. in 1973. However, soon SES needed financial backing, and Böer initiated discussions with Shell. The oil giant first invested $3 million in 1973, to support the pilot line and applied research for SES [72]. Already in 1975 Shell acquired a majority stake in SES, eventually transforming it into a wholly owned subsidiary. This acquisition exemplifies the oil industry’s early interest and investment in solar PV technology, a topic that very recently attracted more attention from historians [5].

Industry entrepreneurs, however, consisted of a small group of science and engineering professionals, primarily engaged in manufacturing solar cells for the space program. This entrepreneurial quartet – or how academic and later founder of SunPower [67] Richard Swanson called them, “intrepid entrepreneurs” – were instrumental in paving the way for solar entrepreneurship, which ultimately fostered the growth of the industry. The quartet consisted of Elliot Berman, Joseph Lindmayer, Peter Varadi, and Bill Yerkes. They were founders of three influential companies within the solar industry, all supported by financial backing from the oil industry. These individuals were entrepreneurs who made “gutsy calls”, taking significant risks with their careers, families and homes, to develop the new solar technologies [66]. According to Varadi, they all believed that the future of terrestrial PV must be built slowly and patiently. “We believed that one has to find a market and make the product for that market. This is the first brick, after that the second is to enlarge the production and this has to be done globally. And this was a crucial element (…)” [68].

The first among them to attract oil funding was Elliot Berman, an industrial chemist with a degree in organic chemistry from Boston University. After his work on early computers, carbonless paper, and photochromic material at National Cash Register (NCR) he moved to optics company Itek, US defense contractor making cameras for spy satellites [22,67]. While in Itek, he got interested in solar cells and their potential for the terrestrial market. In pursuit of this idea, he left Itek and founded Solar Power Corporation (SPC) in 1968. In a search for a partner, he approached Exxon, under which patronage Berman had enough resources to design a significantly less costly solar cell [60]. When Berman left SPC in 1975 to go back to Boston University, the company became fully owned by Exxon [68]. Berman, following his brief return to academics, rejoined the solar industry as a chief scientist of the newly formed research department of Arco Solar, the solar subsidiary of yet another oil company, Atlantic Richfield [66].

Bill Yerkes provides another example of a solar entrepreneur connected to Arco Solar. As Stanford graduate with a mechanical engineering degree, Yerkes started his career at Chrysler and Boeing. At Boeing he contributed to solar array production for the Apollo 11 moon mission. Following the mission’s success, Yerkes sought to bring solar PV technology to Earth by continuing his career as vice president and general manager at Spectrolab, a space solar cell manufacturer [73]. Recognizing the potential for terrestrial application, in 1973–74, Yerkes initiated a terrestrial PV cell and module production line at Spectrolab. Despite this initiative, the company was reluctant to invest heavily in expanding this new venture and Yerkes ventured out to start his own company, the Solar Technology International (STI) [68]. Financial challenges, however, prompted Yerkes to sell STI in 1977 to Atlantic Richfield, which subsequently renamed STI into Arco Solar. Yerkes then assumed the role of general manager and later of Arco’s Solar president, spearheading the formation of the Arco Solar team [67]. During this phase, his former Spectrolab colleague, Charlie Gay, a Ph.D. chemist specializing in designing components for solar power systems, joined Yerkes as the head of the Research and Development (R&D) department. When Arco sold the solar business to Siemens in 1990, Gay was appointed president of Solar ARCO and then the first chief executive of Siemens Solar [74].

The other two of the entrepreneurial quartet were Hungarian immigrants Peter Varadi and Joseph Lindmayer, the cofounders of Solarex. Peter Varadi with a Ph.D. in physiochemistry, became the head of the chemistry laboratory of COMSAT, a communication satellite corporation in Maryland, in 1968. There he had his first exposure to PV, which COMSAT used to power its satellites, and met his colleague and a fellow countryman, Joseph Lindmayer. Lindmayer was an electrical engineer and head of the physics department, as well as a good friend of Yerkes. Soon Varadi and Lindmayer became more than just colleagues who shared a strong interest in terrestrial application for PV cells. On the New Year’s Eve 1972, they decided to leave their positions at COMSAT and to start their own company, Solarex.[1] The company was rather successful, but supporting its rapid expansion became challenging. Solarex was eventually acquired by Amoco (Standard Oil of Indiana), which had been one of the company’s shareholders since 1979 [66–68].

Another group of solar entrepreneurs emerged from the electronics and semiconductor industry. The semiconductor industry was among the early promoters of the solar cells, with companies such as Hoffman Electronics, which supported solar cells for space application. Other companies like TYCO and Texas Instruments in the U.S. also began exploring research on terrestrial solar applications [75] Abraham Mlavsky is one example of a solar entrepreneur from these industries. With a Ph.D. in physical chemistry, Mlavsky began his career as a research scientist at General Electric, before transitioning to a role as a semiconductor scientist at Transition Corporation in Massachusetts. As Chief Operating Officer at TYCO [76], he pioneered the developed of the

[1] Solarex became operational in August 1973.

process for producing a continuous thin ribbon of silicon, suitable for conversion into solar cells, and integration into modules [61]. Initially, NASA expressed interest in this innovation, but their engagement was short-lived. In 1974, TYCO joined forces with Mobil to further develop silicon solar cells [22,77].

A bit of a 'lone wolf' among industry entrepreneurs is Stanford Ovshinsky. Lacking formal education, he was a self-taught material scientist who did not follow the traditional paths of space/electronics or academia. Nevertheless, he possessed a keen entrepreneurial spirit and a remarkable ability to secure funding for his various ventures. Ovshinsky was a founder of Energy Conversion Devices (EDC), initially focusing on producing solid-state switches. However, during the first oil crisis, he got interested in solar energy, claiming that so-called Ovshinsky effect utilized in his switches could make a significant impact on solar cells [78]. Like any other entrepreneurs mentioned in this paper, he faced financial difficulties. Despite this, he successfully attracted investments from two oil companies. In 1979, he secured a deal with Atlantic Richfield for his silicon cell production project. When this funding waned in 1983, he obtained new investment from Standard Oil of Ohio.

The story of this solar entrepreneur cohort is more than just a collection of individual careers, but a story that reveals a distinctive and exceptional community. United by expertise in engineering or scientific fields like chemistry and physics and often drawing on experience from sectors like the space industry, this cohort embodies a strong network among solar pioneers. While Stanford Ovshinsky stands out as somewhat unique figure, challenging traditional educational norms yet contributing innovative perspectives and entrepreneurial drive, the cohort's strength is not just in academic qualifications but in a shared intrinsic motivation: a passion for the practical application of solar cells on Earth. This driving force and their perseverance propelled them beyond the boundaries of traditional sectors, as many found themselves immersed in the space program or, to a lesser extent, the electronics/semiconductor industry. This shared journey, shaped by both individual ingenuity and collective purpose, underscores the importance of considering the solar entrepreneurs as a cohort.

The bond among this group goes beyond the professional sphere, and in some instances, was rooted in deep friendship as exemplified with Varadi, Lindmayer and Yerkes. Shaped by the historical context of the oil crisis and resource scarcity discourse, the various cohort members found themselves at the forefront of a knowledge transfer during a pivotal moment. The surge in government and (oil) incumbents' investments in solar energy became the catalyst for their entrance into the solar energy transition. Even though this bold step came with the cost of facing significant financial challenges, they showed resilience and adaptability. Their indomitable spirit embodies a strong level of agency that marked a generation committed to leading the energy transition towards a more renewable future.

6. Discussion

Our analysis of the development of nuclear and solar power reveals that the collective agency of individuals navigating between new technological niches, incumbent oil companies, and the political landscape played a significant role in shaping these transitions. Both former Shell employees, through influencing nuclear policy in the Netherlands, and solar entrepreneurs, through their innovation and building the solar market, played key roles in shaping the energy landscape. The former shaped the trajectory of nuclear power, while the latter transformed the perception of solar energy from niche to a viable alternative.

As these case studies show, applying cohort theory offers a useful additional tool for analysing the similarities in the backgrounds of the various actors. In the nuclear case, it shows the longer intertwinement of Shell and the Dutch nuclear industry, even before Shell itself entered the nuclear business, in this way further establishing the network that was able to establish a civilian nuclear industry. For solar energy, many individuals were involved in developing and refining solar, pushing the boundaries of what was possible and making solar power more efficient and cost-effective. In this way, the cohort created a market for solar energy products and services and shifted the public discourse around the energy sources. Especially in the solar case, the changes established by this cohort were incremental rather than transformative. The incumbent fossil fuel regime remained dominant, and the widespread adoption of solar energy faced significant challenges. However, their collective agency played a crucial role in laying the foundation for the future growth of the solar industry and the broader transition towards renewable energy.

Cohort theory, as exemplified in our case studies, focuses on the agency of historical actors shaping these transitions. By studying the shared experiences of individuals who develop new technological niches and energy regimes, we can better understand how transition pathways to alternative energy sources are shaped. Combining cohort theory with MLP helps discuss the collective agency of various individual actors who crossed the boundaries between micro, meso and macro levels. This challenges the simplistic dichotomy often presented in transition frameworks between incumbents and niche actors. Instead, it foregrounds the complex interplay between individual agency and structural forces in shaping energy transitions, offering insights into the diffusion of knowledge and expertise across different energy sectors that influences the pace and direction of technological change.

This framework opens up several avenues for further exploration. Further research could explore cohort formation in different time periods. Our preliminary research suggests that this approach could be applied to earlier or subsequent cohorts in both case studies. For instance, while solar entrepreneurs were focused on improving technology, forming the industry, and building the market, a previous cohort, including figures like John Yellot, Farrington Daniels, Maria Telkes etc., focused on rising awareness on solar energy applicably though building solar homes and appliances (such as solar ovens), but also building the (international) solar network through establishing Association for Applied Solar Energy (AFASE) in the 1950s and lobbing for policy changes.

This approach also contributes to the existing literature on interlocks in business history, offering a new perspective on how these connections are formed and how they influence technological transitions. Several business historians have tried to understand transitions in corporate societal engagement, the emergence of political ideologies such as neoliberalism, or (nuclear) energy transitions by studying how companies, semi-governmental and research institutions, and the banking sector were interlocked during the 1960s and 1970s and increasingly fractured during the 1980s [79–81]. As this paper shows, cohort theory offers an additional lens to better understand the formation of these interlocks by focusing on the shared backgrounds of individual actors shaping these developments. Especially in the nuclear case study, it became clear how intertwined Shell, and the Dutch nuclear industry already were, even before Shell entered the nuclear business.

Of course, cohort theory is still an abstraction of historical reality. There are many points of deviation between individual actors. We acknowledge that individual motivations are complex and that other factors, such as policy changes, economic incentives, and technological advancements, also contributed to these transitions. Points that a predominant focus on the common features does not always show. The examples of Han Hoog, Henri Brinkman, and Hans Kramers show that both engineers and physicists transitioned between Shell and the Dutch nuclear industry. In the case of the solar cohort, Ovshinsky did not have a formal education or prior experience working on the solar cells like it was the case with Berman and Yerkes. We, therefore, explicitly, do not want to argue that using cohort theory offers a clear-cut explanation as to *why* all these individual (oil) actors got involved in nuclear or solar energy. What we do want to argue, however, is that using the concept of a 'cohort' certainly highlights the how - how shared experiences, educational backgrounds and historical context facilitated collective action and thus shaped the direction of energy transitions.

By integrating cohort theory with MLP, this research offers a valuable framework for understanding the dynamics of energy transitions beyond the specific cases of nuclear and solar power. This combined approach can be applied to analyse other technological shifts, providing insights into the role of individual and collective agency, and inter-organizational networks in shaping innovation and societal change. Ultimately, energy transitions are also a human story. By recognizing the power of collective agency and the importance of understanding individual experiences and actions, the transition to more sustainable energy systems could be better understood.

CRediT authorship contribution statement

J. Stanković: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Michiel Bron:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] C. Andriesse, De Republiek der Kerngeleerden, Bergen: BetaText, 2000.
[2] J. Kistemaker, De geschiedenis van het Nederlandse Ultracentrifuge Project: hoe een nieuwe industrieontstond, FOM-Instituut voor Atoom-en Molecuulfysica, Amsterdam, 1993.
[3] G.P.J. Verbong, E.H.M. Berkers, M. Taanman, Op weg naar de markt: de geschiedenis van ECN, 1976–2001, Energie Centrum Nederland, Petten, 2005.
[4] C.C.M. Mody, Surveying the landscape: the oil industry and alternative energy the 1970s, in: E. Conway, W.B. Carlson (Eds.), Electrical Conquest: New Approaches to the History of Electrification, Springer, 2024, pp. 51–79.
[5] J. Stanković, History of oil and solar relationships: makeups and breakups, Journal of Energy History 12 (1) (2024) 1–21, https://doi.org/10.3917/jehrhe.012.0128.
[6] C.C.M. Mody, Taking the marks to the market: the oil industry and the entrepreneurial turn, in: M.D. Gordin, W.P. McCray (Eds.), Greedy Science: Creating Knowledge, Making Money, and Being Famous in the 1980s, Johns Hopkins, 2025, pp. 19–44.
[7] O. Melsted, Geoscience spillover: Gunnar Böðvarsson and the adoption of petroleum technologies in Iceland's geothermal industry, 1940s–1970s, History and Technology 40 (3) (2024) 218–249, https://doi.org/10.1080/07341512.2024.2408055.
[8] M. Bron, Oil's nuclear frames: the oil industry shaping the environment with "innovative" nuclear technologies since the long 1970s, Journal of Energy History 12 (1) (2024) 1g–15. https://stm.cairn.info/journal-of-energy-history-2024-1-page-1g?lang=en.
[9] P. Späth, H. Rohracher, A. Von Radecki, Incumbent actors as niche agents: the German car industry and the taming of the "Stuttgart E-mobility region", Sustainability 8 (3) (2016) 252, https://doi.org/10.3390/su8030252.
[10] A. Cherp, V. Vinichenko, J. Jewell, M. Suzuki, M. Antal, Comparing electricity transitions: a historical analysis of nuclear, wind and solar power in Germany and Japan, Energy Policy 101 (2017) 612–628, https://doi.org/10.1016/j.enpol.2016.10.044.
[11] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Research Policy 31 (8–9) (2002) 1257–1274, https://doi.org/10.1016/S0048-7333(02)00062-8.
[12] F. Geels, Co-evolution of technology and society: the transition in water supply and personal hygienein the Netherlands (1850–1930)—a case study in multi-level perspective, Technol. Soc. 27 (3) (2005) 363–397, https://doi.org/10.1016/j.techsoc.2005.04.008.
[13] A. Smith, J. Voß, J. Grin, Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges, Research Policy 39 (4) (2010) 435–448, https://doi.org/10.1016/j.respol.2010.01.023.
[14] M. Melosi, Atomic Age America, Routledge, New York, 2013.
[15] S. Gross, A. Needham, New Energies: A History of Energy Transitions in Europe and North America, University of Pittsburgh Press, Pittsburgh, 2023.
[16] R. Lifset, Nuclear power in America: the story of a failed energy transition, Environ. Hist. 24 (2019) 525–531.
[17] F.W. Geels, B. Verhees, Cultural legitimacy and framing struggles in innovation journeys: a cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986), Technol. Forecast. Soc. Chang. 78 (6) (2011) 910–930, https://doi.org/10.1016/j.techfore.2010.12.004.
[18] D. Yates, The French Oil Industry and the Corps Des Mines in Africa, Africa World Press, 2009.
[19] M. Bron, The Petro-Atom: A Century of Ubiquitous Oil Involvement in Nuclear Energy, PhD Dissertation, Maastricht University, 2025.
[20] H. Etzkowitz, Solar versus nuclear energy: autonomous or dependent technology? Soc. Probl. 31 (4) (1984) 417–434.
[21] R.D. Lifset, A new understanding of the American energy crisis of the 1970s, Hist. Soc. Res. 39 (4) (2014) 22–42, https://doi.org/10.12759/hsr.39.2014.4.22-42.
[22] G. Jones, L. Bouamane, Power From Sunshine: A Business History of Solar Energy, in: Harvard Business School Working Paper Series, 2012, pp. 12–105. https://dash.harvard.edu/handle/1/9056763?show=full.
[23] T. Priest, Tyler Priest, The dilemmas of oil empire, J. Am. Hist. 99 (1) (2012) 236–251, https://doi.org/10.1093/jahist/jas065.
[24] T. Mitchell, Carbon Democracy: Political Power in the Age of Oil, Verso, London, 2011.
[25] P. Sabin, Crisis and continuity in U.S. oil politics, 1965–1980, Journal of American History 99 (1) (2012) 177–186, https://doi.org/10.1093/jahist/jas086.
[26] H. Ahlborg, Towards a conceptualization of power in energy transitions, Environmental Innovation and Societal Transition 25 (2017) 122–141, https://doi.org/10.1016/j.eist.2017.01.004.
[27] K. Aroújo, The emerging field of energy transitions: progress, challenges, and opportunities, Energy Research and Social Science 1 (2014) 112–121, https://doi.org/10.1016/j.erss.2014.03.002.
[28] A. Smith, A.C. Striling, F.G.H. Berkhout, The governance of sustainable socio-technical transitions:the allure of the multi-level perspective and its challenges, Res. Policy 34 (10) (2005) 1491–1510, https://doi.org/10.1016/j.respol.2005.07.005.
[29] F.W. Geels, From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory, Research Policy 33 (6–7) (2004) 897–920, https://doi.org/10.1016/j.respol.2004.01.015.
[30] F.W. Geels, The multi-level perspective on sustainability transitions: response to seven criticisms, Environ. Innov. Soc. Trans. 1 (1) (2011) 24–40, https://doi.org/10.1016/j.eist.2011.02.002.
[31] F.W. Geels, J. Schot, Typology of sociotechnical transition pathways, Research Policy 36 (3) (2007) 399–417, https://doi.org/10.1016/j.respol.2007.01.003.
[32] F.W. Geels, J.S. Schot, The dynamics of transitions: a socio-technical perspective, in: J. Grin, J. Rotmans, J. Schot, F.W. Geels, D. Loorbach (Eds.), Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change, Routlege, New York, 2011, pp. 9–87.
[33] B. Turnheim, F.W. Geels, Incumbent actors, guided search paths, and landmark projects in in infra-system transitions: re-thinking Strategic Niche Management with a case study of French tramway diffusion (1971–2016), Research Policy 48 (6) (2019) 1412–1428, https://doi.org/10.1016/j.respol.2019.02.002.
[34] A. Genus, A. Coles, Rethinking the multi-level perspective of technological transitions, Research Policy 37 (9) (2008) 1436–1445, https://doi.org/10.1016/j.respol.2008.05.006.
[35] J. Grin, J. Rotmans, J. Schot, F.W. Geels, D. Loorbach (Eds.), Transitions to Sustainable Development:New Directions in the Study of Long Term Transformative Change, Routledge, New York, 2011.
[36] B. Elzen, F. Geels, C. Leeuwis, B. van Mierlo, Normative contestation in transitions 'in the making': animal welfare concerns and system innovation in pig husbandry, Research Policy 40 (2) (2011) 263–275, https://doi.org/10.1016/j.respol.2010.09.018.
[37] G. Prayag, L. Ozanne, R. Martin-Neuninger, P. Fieger, Integrating MLP and 'after ANT' to understand perceptions and responses of regime actors to Airbnb, Curr. Issue Tour. 25 (19) (2020) 3150–3167. Available at: https://doi.org/10.1080/13683500.2020.1768226.
[38] K. Mannheim, The problem of generations, in: P. Kecskemeti (Ed.), Essays in the Sociology of Knowledge, Routledge & Kegan Paul, Boston, 1952, pp. 167–168 (Original work published 1927).
[39] C. Gilleard, Cohorts and generations in the study of social change, Soc. Theory Health 2 (2004), https://doi.org/10.1057/palgrave.sth.8700023.
[40] A. Bontekoning, The evolutionary power of new generations: generations as key players in the evolution of social systems, Psychol. Res. 1 (4) (2011) 287–301.
[41] W. Strauss, N. Howe, Generations: The History of America's Future 1584 to 2069, WilliamMorrow, New York, 1991.
[42] H. Schuman, J. Scott, Generations and collective memories, Am. Sociol. Rev. 54 (3) (1989) 359–381, https://doi.org/10.2307/2095611.
[43] P. Bourdieu, Sociology in Question, Sage, London, 1993.
[44] D.F. Alwin, R.J. McCammon, Generations, cohorts and social change, in: J. T. Mortimer, M.J. Shanahan (Eds.), Handbook of the Life Course, Handbooks of Sociology and Social Research, Springer, Boston, MA, 2003.
[45] N. Ryder, The cohort as a concept in the study of social change, Am. Sociol. Rev. 30 (6) (1965) 843–861, https://doi.org/10.2307/2090964.
[46] K. Mannheim, The problem of generations, Psychoanal. Rev. 57 (3) (1970) 378–404.
[47] C. Jurkiewicz, R. Brown, Generational comparison of public employee motivation, Review of Public Personnel Administration 18 (4) (1988) 18–37, https://doi.org/10.1177/0734371X9801800403.
[48] B. Kupperschmidt, Multigeneration employees: strategies for effective management, The healthcare manager 19 (1) (2000) 65–76.
[49] R. Inglehart, P. Norris, Rising Tide: Gender Equality and Cultural Change Around the World, Cambridge University Press, New York, 2003.

[50] G. Firebaugh, Where does social change come from? Estimating the relative contributions of individualchange and population turnover, Population Research and Policy Review 11 (1992) 1–20.
[51] N.D. Glenn, Distinguishing age, period, and cohort effects, in: J.T. Mortimer, M. J. Shanahan (Eds.), Handbook of the Life Course, Handbooks of Sociology and Social Research, Springer, Boston, MA, 2003.
[52] W.H. Sewell, Logics of History: Social Theory and Social Transformation, University of Chicago Press, Chicago, 2005.
[53] M. Bron, The uranium club: big oil's involvement in uranium mining and the formation of infamous uranium cartel, Hist. Soc. Res. 49 (1) (2024), https://doi.org/10.12759/hsr.49.2024.03.
[54] S. Turchetti, The Pontecorvo Affair: A Cold War Defection and Nuclear Physics, University of Chicago Press, 2012.
[55] A. Allaud, M. Martin, Schlumberger: The History of a Technique, John Wiley & Sons, Inc., New York, 1977.
[56] C.C.M. Mody, M. Bron, Scientific Instruments and/as Oil Spillovers: The Case of Oil Involvement in the Manhattan Project, Nuncius, 2025. Forthcoming.
[57] G. Hecht, The Radiance of France: Nuclear Power and National Identity after World War II, Editions La Decouverte, Paris, 2009.
[58] G.J. Zijlstra, Networks in public policy: nuclear energy in the Netherlands, Soc. Networks 1 (1978/79) 359–389.
[59] H.W. Broer, H.S.V. Snoor, Mathematisch fysicus H.C. Brinkman, Nederlands Tijdschrift voor Natuurkunde, 2011, pp. 31–32.
[60] M. Dresden, H.A. Kramers, Between Tradition and Revolution, Springer, New York, 1987.
[61] Nota: Instelling Commissie voor onderzoek aanwezigheid splijtbare materialen in Nederlands-Nieuw-Guinea en Suriname, Dutch National Archives. Archives Directorate of Nuclear Energy of the Ministry of Economic Affairs, 1956, 2.06.101.735.
[62] J. Dozy, Obituary H.M.E. Schürmann (1891–1979), Geol. Mijnb. 58 (3) (1979) 289–290.
[63] F. Eijgenraam, Robbert van Erpers Royaards: Vasthoudende voorvechter van kernenergie, NRC Handelsblad, 1988.
[64] ISES, The Century of Solar-Stories and Vision, Available at: https://www.swc50.org/celebratory-booklet.
[65] J. Perlin, From Space to Earth: The Story of Solar Electricity, Harvard University Press, Cambridge, Mass, 2002.
[66] B. Johnstone, Switching to Solar: What We Can Learn from Germany's Success in Harnessing Clean Energy, Amherst, Prometheus Books, N.Y, 2011. Available at: http://archive.org/details/switchingtosolar0000john.
[67] R.P. Wolfe, The Solar Generation: Childhood and Adolescence of Terrestrial Photovoltaics, IEEE Press Willey, New Jersey, 2018.
[68] P. Varadi, Sun Above Horizon, Meteoric Rise of the Solar Industry, Jenny Stanford Publishing, 2014.
[69] E. Popp Berman, Creating the Market University: How Academic Science Became an Economic Engine, Princeton University Press, 2012.
[70] Wisnioski, Engineers for Change: Competing Visions of Technology in 1960s America, The MIT PRess, Cambridge MA, 2012.
[71] A. Nordmann, H. Radder, G. Schiemann (Eds.), Science Transformed? Debating Claims of an Epochal Break, University of Pittsburgh Press, 2011.
[72] W. Palz, Power for the World: The Emergence of Electricity from the Sun, Pan Stanford, Singapore, 2011.
[73] N. Elias, Solar Energy Maverick, Stanford Magazine, 2014. https://stanfordmag.org/contents/solar-energy-maverick (accessed 2024 Mar. 27).
[74] The Solar Journey, Episode #016 w/Charles Gay, YouTube, 2022. https://www.youtube.com/watch?v=LwzEJiZ7YSo.
[75] C.C.M. Mody, The Squares: US Physical and Engineering Scientists in the Long 1970s, MIT Press, 2022.
[76] Praabook, Abraham Isaac Mlavsky, Biography. https://prabook.com/web/abraham_isaac.mlavsky/33112#google_vignetteWorld (Accessed 2024 Mar. 27).
[77] R. Reece, The Sun Betrayed, Black Rose Books, 1979.
[78] L. Hoddeson, P. Garret, The Man who saw tomorrow, in: The Life and Inventions of Stanford R. Ovshinksy, MIT press, 2018.
[79] M.S. Mizruchi, The Fracturing of the American Corporate Elite, Harvard University Press, Cambridge, Mass, 2023.
[80] M. Hertsgaard, Nuclear Inc.: The Men and Money behind Nuclear Energy, Pantheon Books, New York, 1983.
[81] W.K. Carroll, Canada's carbon-capital elite: a tangled web of corporate power, Can. J. Sociol. 42 (3) (2017) 225–260.