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How the European recovery program (ERP) drove France's petroleum dependency, 1948–1975

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A B S T R A C T

The article investigates the roles of the European Recovery Program (ERP) and the Organization for European Economic Co-Operation (OEEC) in pushing France towards a pathway of petroleum dependency. The study is based on the energy transition and the Deep Transition frameworks, notably the analysis of specific collective actors. The analysis elaborates on the impact the OEEC Refinery Expansion Program had on (a) quality and quantity of petroleum product supply in France; (b) the French position within global crude oil and petroleum product trade; (c) the technological interrelatedness of the petroleum sector with agriculture, transport, and mobility. We show how different measures were designed to integrate sociotechnical systems, accelerate the transformation of energy systems and put the objective of Western Europe's "hidden integration" to work. The article concludes that complementing transition studies with historical and socio-metabolic perspectives can shed light on the origins of unsustainable pathways during the 20th century.

1. Introduction

The global extraction of resources and the ensuing CO_2 emissions have followed an exponential growth pattern since the mid-19th century and especially during the 20th century (Fischer-Kowalski et al., 2014; Krausmann and Fischer-Kowalski, 2013; Krausmann et al., 2008; Miller et al., 2019; Schaffartzik et al., 2021; IPCC, 2021). Fossil fuels were prominent enablers and drivers of this development.

In France, the transition from a primarily biomass-based to a fossil-fueled socio-economic metabolism had already started during the 19th century (Magalhães et al., 2019; Kuskova et al., 2008; Kander et al., 2015). Petroleum use took off during the interwar period but remained a niche market in the first half of the 20th century compared to coal. Yet, France had very limited coal resources. At the same time, the demand for petroleum products in the industries and mobility sector soared due to their universal applicability

List of abbreviations: BRP, Bureau de recherche de pétrole; CFP, Compagnie Française des pétroles; CFR, Compagnie Française de raffinage; DMC, Domestic material consumption; ECA, Economic Cooperation Administration; ERP, European Recovery Program; MFA, Material flow accounting; MSA, Mutual Security Agency; Mt, megaton; OECD, Organisation for Economic Cooperation and Development; OEEC, Organisation for European Economic Co-operation; REP, Refinery expansion program of the OEEC; TOC, Technical oil committee of the OEEC.

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(Milward, 2005: 212–213). The lack of domestic petroleum resources and refinery capacities forced France to import crude oil and petroleum products during the interwar years. The import dependency was characterized in the national balance sheet by a growing trade deficit with the USA (Milward, 1984). In the immediate post-World War II (WWII) years, France's ability to support itself with crude oil from domestic sources had further declined and the coal dispute with Germany aggravated the tight energy supply. Consequently, energy scarcity repeatedly paralyzed public life and industrial production. The coal dispute, which originated from French calls to separate the Ruhr region from Germany and place it under international control, was only settled by establishing a European Coal and Steel Community in 1951 (Lüders, 1988).

After 1947, the US poured nearly US $ 14 billion (about US $ 150 billion in 2017 prices) into 16 Western European countries under the framework of the European Recovery Program (ERP), commonly known as the Marshall Plan (Ritschl, 2008). The ERP marked the beginning of a dramatic change in the US-Western European relations that was described as "empire by invitation" and was partly responsible for the division of Europe into two hostile blocs. (Lundestad, 1986). It materialized as raw materials and machinery deliveries, technical assistance, propaganda and the permanent integration of experts in transnational organizations, such as the Organization for European Economic Cooperation (OEEC). Energy bottlenecks were one factor for delayed reconstruction. Thus, 12.6% of the overall ERP was utilized to import fuel, of which the majority (77.8%) was spend on petroleum (and products), while only 22.2% supported coal deliveries (Painter, 2009). The aid deliveries to France show a similar pattern: Next to loans for the biggest hydroelectric dam ever built until then (Donzère-Mondragon at the Rhone River), 60% of the fuel-funds were utilized to import crude petroleum and products, 40% remained for coal imports (Pritchard, 2004: 783; Gimbel, 1976; Milward, 1984; Economic Cooperation Administration (ECA), 1950). These deliveries allowed overcoming energy supply bottlenecks and improving living conditions, while creating the conditions for today's environmental sustainability challenges (Judt, 2005; Hobsbawm, 1995; Antal et al., 2020).

This study investigates the role of the ERP in the transition of the energy system towards petroleum as a prerequisite for a rise in overall resource use after WWII. The paper focuses on the French national economy, considering transnational interdependencies by (a) scrutinizing trade linkages and (b) providing a historical and socio-metabolic reading of the ERPs relevance for the post-WWII transition. Firstly, the shift of energy systems from coal to petroleum is investigated by elaborating the interplay between the accumulation of the manufactured capital of energy systems (e.g., refineries, pipelines, end-user technologies) and their role in (re) structuring energy use and technology uptake in France. Secondly, this study shows that refineries and end-user technologies received considerable funding from the ERP that was coordinated by the OEEC, which kick-started a transition process that continued after the expiration of the ERP in 1952. Thirdly, we elaborate how geopolitics and past decisions created a trajectory of unsustainable resource and CO_2 intensive pattern of production and consumption. Based on this analysis, we also discuss the significance of historical case studies for the challenges of the upcoming transformation towards sustainable development.

The article is organized as follows: Section 2 presents the evolution of socio-economic metabolism in France from 1920 to 2010. The changes in France's socio-economic metabolism, its energy system, and the activities of the ERP and the OEEC as an important system entangler are described. Section 3 discusses the main results. Part 1 presents an analysis of the internal (upgrading refinery capacities) and external (restructuring petroleum and petroleum product trade) repositioning of the petro-based energy system. In part 2 of this section the impact of the ERP on the technical equipment of French refineries and the resulting changes in the petroleum product output is elaborated. The latter is presented as a precondition of technological interrelatedness of sociotechnical systems. Finally, in part four, the focus is on the interlinkages of the energy sector with two other key sectors: agriculture and transport/mobility. Section 4 discusses the impact of the ERP and the OEEC on the petroleum-based energy system. The article concludes with considerations of possible future research strategies that arrive from the presented results.

1.1. Conceptualizing transitions

A key concept of this study is the energy transition, defined as a shift from one state of an energy system to another, involving changes both in the quantity and the structure of energy used, including the main type of energy and the involved conversion technologies and energy applications (Grubler 2004; Smil 2010). While the definition implies that the basic energy types change, e.g., that biomass as main energy carrier is replaced by coal, energy transition research has shown that, on larger scales, energy transitions are rather characterized by "energy additions". While parts of established energy systems remain in place and are often even further expanded, they are superimposed by new energy types leading to a total growth of energy use (York and Bell, 2019; Grubler, 2012). Energy transition research is very diverse in terms of analytical foci, methodological approaches, and conceptual underpinnings (Johnston and McLeish, 2020: 3). Here we investigate energy transitions from a socio-metabolic perspective (Haberl et al., 2019) and link it to a Deep Transition approach (Schot and Kanger, 2018; van der Vleuten, 2019). Deep Transitions implies "a series of connected transitions in many sociotechnical systems [e.g., energy, mobility, food] towards" increased labor productivity, mechanization, reliance on fossil fuels, resource-intensity, energy-intensity, and reliance on global value chains (van der Vleuten, 2019).

The concept of social metabolism places energy transitions in the broader context of transitions in society's use of natural resources (Fischer-Kowalski and Rotmans, 2009). From a socio-metabolic perspective, societies depend on energy and material inputs from their environment to build up, maintain and reproduce their biophysical structures (people, livestock and manufactured capital), a process that results in wastes and emissions to the environment and is linked to many sustainability problems (Fischer-Kowalski and Weisz, 2016; Haberl et al., 2019). From such a perspective, food and feed, the energy sources of the biological metabolism of humans and livestock, are also an integral part of the energy system, in addition to the technical energy carriers usually considered. Shifts in the energy system of societies are considered central for changes in the overall metabolism and resource use (socio-metabolic transitions). Therefore, socio-metabolic transitions and energy transitions are nesting and interconnected processes (Krausmann and Fischer-Kowalski, 2013: Krausmann et al., 2017a; Schandl et al., 2002; Haberl et al., 2019; Pauliuk and Hertwich, 2015).

Socio-ecological approaches and the concept of Deep Transition are both suitable to analyze systemic transformations of societies. However, both perspectives face conceptual difficulties related to the integration of an actor perspective into the analysis due to their focus on large timeframes, global interconnectedness, and on structural change (Fischer-Kowalski and Rotmans, 2009; Newell and Cousins, 2015; Breetz, 2017; van der Vleuten, 2019: 23). As the incorporation of the ERPs role into the analysis of France's energy system requires an adequate understanding of the role of collective actors at the macro level, the study aims to bring the socio-metabolic approach and the Deep Transitions framework into conversation. The latter concept is rooted in the social and economic sciences applied to technological systems (Perez, 2010; Schot and Kanger, 2018, 2019). It allows analyzing the making of "socio-technical, transnational, and cross-system entanglements" (van der Vleuten, 2019: 24).

The assemblage of interlinkages between different sociotechnical systems is governed and guided by specific collective actors (van der Vleuten, 2019). The concept of system entanglers is used to integrate the role of the OEEC as collective actors that actively interlinked various sociotechnical systems and created the conditions for locking societies into structures requiring a high demand of petroleum products. As the use of petroleum products is an essential precondition for both mobilizing mineral resources and for industrializing agriculture, technological interrelatedness in sociotechnical systems is directly linked to far reaching changes in the socio-economic metabolism (Krausmann and Fischer-Kowalski, 2013). Based on a synopsis of the Deep Transition and the socio-metabolic framework, the paper specifically aims to answer the following research questions:

- How did the ERP shape the trajectory of the petro-based energy system in France and paved the way towards petroleum dependency?
- Which role did system entanglers (e.g., the OEEC) play in the diffusion of petro-based technologies and how did this affect the overall socio-economic metabolism in France?

1.2. Material and methods

For a biophysical perspective on the French economy, the study by (Magalhães et al., 2019) is highly relevant. The authors applied economy-wide material flow accounting (ew-MFA) to investigate long term changes in the scale and composition of the French metabolism (European Commission. Statistical Office of the European Union, 2018). This study provided us with detailed data on the extraction and trade with all materials (biomass, fossil energy carriers, ores and metals, non-metallic minerals) from 1830 to 2015. Trade data for petroleum (products) was supplemented by more detailed information on origin and sales areas from the "Direction générale des Douanes". Statistics on refineries' production come from the "Comité Professionnel du Pétrole". These data were used to calculate domestic energy and material consumption from 1920 to 2010 and to quantify the bilateral trade with crude oil and petroleum products. To quantify energy flows, the data from the material flow database were converted to Joules by applying gross calorific values sourced from Schandl et al. (2002). To investigate sectoral changes data on agricultural machinery and fuel consumption from a publication on the agricultural transition in France from 1882 to 2013 were integrated (Harchaoui and Chatzimpiros, 2019). Data on the production and stock of motor vehicles was sourced from Mitchell (2003).

To shed light on the role of the ERP, the OEEC and the French administration, archival research in the National Archives/College Park, MD was conducted, collecting information on refineries, counterpart investments, and their geostrategic relevance. Records from the Economic Cooperation Administration (ECA), the Mutual Security Agency (MSA), and the OEEC were analyzed. Table 1 gives an overview on the main topics, indicators and sources as utilized in this study.

Table 1
Overview on main indicators, their definitions and data sources used in this study.

Topics and key indicators	Units	Main sources
Domestic Material Consumption (DMC) Domestic Energy Consumption (DEC)	Metric tons/yr for DMC, Joules/yr for DEC	Own calculations based on Magalhães et al., 2019; UNEP 2009; IEA, 2019.
Physical Trade Balance (PTB) of Crude Oil and Refined Products 1920–1975	Metric tons/yr	Own calculations based on Magalhães et al. (2019); Direction générale des Douanes ; Comité Professionnel du Pétrole
Agricultural Machinery and fuel consumption, 1920–1998	Items and metric tons/ yr	Harchaoui and Chatzimpiros (2019). Energy, nitrogen and farm surplus transitions in agriculture from historical data modeling. France, 1882–2013. Journal of Industrial Ecology.
Petroleum refinery expansion in the OEEC countries	US $/yr, metric tons/ yr, barrel/yr	OEEC 1951, Second report on Co-ordination of Oil Refinery Expansion in the OEEC Countries.
ERP funding and total costs of key industrial projects in France (incl. refineries)	US $/yr	MSA 1953, European Industrial Projects, Statistics and Report Division, Industry Division
Economic aspects of ECA operations in France (incl. counterpart Funds)	US $ and metric tons/yr	ECA 1950, Country Data Book France
Motor vehicles (production and number of vehicles in use)	Items, Items/yr	Mitchell (2003): International Historical Statistics. Europe 1750–2000: 550,735. 5th ed. Hampshire, New York: Palgrave Macmillan.
Technical and economic information about French refineries	US $, metric tons, barrel/yr	NARA, RG 469, 2022, Records of the Agency for International Development and its Predecessor Agencies, Records Relating to Oil Refinery Projects 1949–52, France, Box 1–4

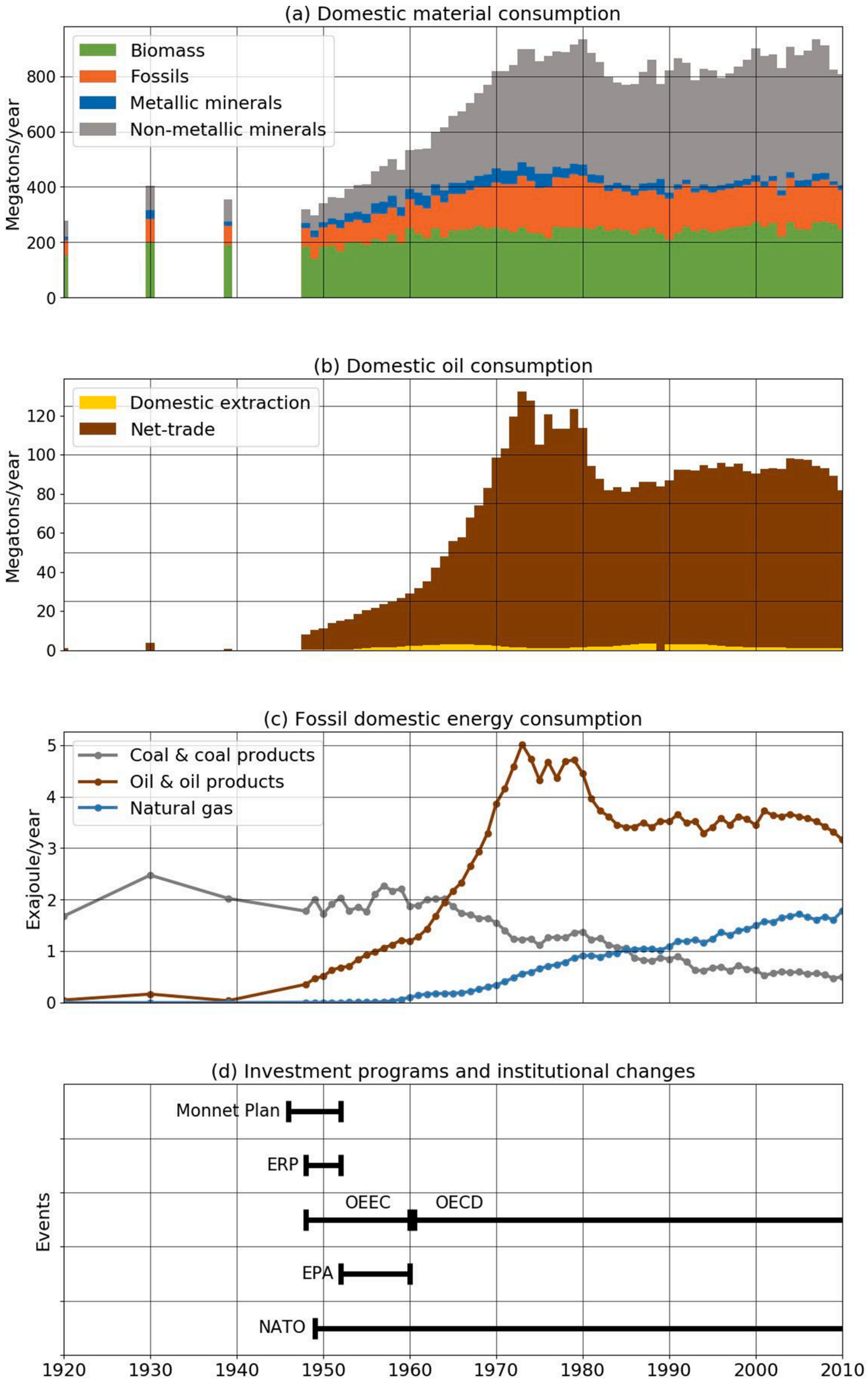

Fig. 1. Development of France's socio-economic metabolism and the most relevant investment programs and transnational organizations: Annual data for the years 1920–2010 on (a) French domestic material consumption by main material groups. Note that biomass here includes all biomass (food, feed, raw material or energy carrier), (b) French domestic petroleum consumption, (c) French fossil domestic energy consumption and (d) global and national socio-economic events. Data for (a-c) was derived from (Magalhães et al., 2019).

2. Transitions of the French socio-economic metabolism

This section presents the course of socio-metabolic developments from a material and energy perspective and highlights key collective actors (system entanglers) and policies governing the transition between 1948 and 1975.

Fig. 1a shows the shift from a biomass-based economy towards the dominance of fossil fuels and mineral materials. Within only three decades, domestic material consumption (DMC, defined as domestic extraction plus imports minus exports) tripled to roughly 900 Mt/yr in the 1970s which increased the average material use per capita of population from 7.2 to 17.2 t/cap/yr between 1949 and 1973.

Fig. 1a also indicates that fossil and mineral materials had not simply replaced biomass as key raw material and energy source. The absolute amount of biomass used (as food, feed, raw material or energy carrier) actually increased from 150.4 Mt/yr in 1920 to 248.9 Mt in 1960. Only its relative importance dwindled, with the share of biomass in DMC declining from 50% in the 1920s to 22% in the late 1970s, a level at which it remained until present. However, the transition to petroleum products affected the production and use of biomass in many ways. On the one hand, fertilizers and agrochemicals based on fossil fuels helped to boost crop yields. Between 1920 and 1980, cereal harvest roughly doubled from 16.4 Mt/yr in 1920 to 30.9 Mt/yr and oil crops skyrocketed from 0.04 Mt/yr to 34.1 Mt/yr. Fruits (1.5 Mt/yr to 17.2 Mt/yr) and sugar crops (3.5 Mt/yr to 34.1 Mt/yr) roughly decupled from 1920 to 1980. On the other hand, fossil fuels substituted for draft animals and fuel wood and made large amounts of land and biomass available for other applications (Section 3.3). Fuel wood, for example, declined from 12.3 Mt/yr in 1920 to only 0.7 Mt/yr in 1975 while in the same period the use of wood to produce timber and paper increased from 0.6 to 20.9 Mt/yr; overall the use of wood increased by 67% in that period. The multiplication of crop production and the reduction of draft animals, for example, allowed to devote more crops to feed livestock and fueled the dietary transition (Harchaoui and Chatzimpiros, 2018; Krausmann, 2004).

The growth of DMC came to an abrupt halt in the 1970s when material consumption stabilized at a high level. This trajectory of post-WWII acceleration of resource use and a relative stabilization (or slow-down), following the oil price shocks in 1973 and 1979, seems typical for the metabolic transitions in many industrialized countries (Wiedenhofer et al., 2013; Krausmann et al., 2017b).

Fig. 1b zooms into the fraction of fossil materials and shows the DMC of petroleum resources. After WWII, the DMC of petroleum rose sharply from a very low level in the first half of the 20th century to a peak in 1973 at 132.1 Mt/yr, and stabilized at around 80 to 95 Mt/yr since the mid-1980s. These dynamics match that of mineral materials (Fig. 1a).

Fig. 1c shows the development of consumption of technical energy from fossil fuels in France in energy units. Coal remained France's most crucial energy source until 1964/65 (Nouschi, 2001; Magalhães et al., 2019). Petroleum played a subordinate role but overtook coal during the 1960s and remained dominant until the 1970s, when France began to massively expand nuclear energy production under the "Messmer Plan" (1974) (Hecht, 2004).

The surge in petroleum consumption has been shown to be an essential factor underlying the overall socio-metabolic transition (Krausmann and Fischer-Kowalski, 2013). The rise of petroleum as key energy resource fueling economic growth after WWII contributed to mass production and consumption, including cars and plastics, an upswing of the construction sector and large-scale infrastructure development, the expansion of passenger and commodity transport, as well as driving land and labor productivity in agriculture and the dietary transition. Together, these developments not only irreversibly altered France's metabolism but also point to a series of entangled sociotechnical and cross-system transitions (Huber, 2013; Cahen-Fourot and Magalhães, 2020).

Fig. 1c reveals that the energy transition was an addition and expansion of energy sources in which the use of coal declined only slowly. It pushed sociotechnical systems towards a resource intensive development path. In doing so, the French biophysical economy after WWII repeated a transition path, which the USA had begun to follow after the Great Depression of the 1930s (Gierlinger and Krausmann, 2012; McNeill and Engelke, 2016; Steffen et al., 2011).

To understand this shift to petroleum, political and economic factors have to be considered (Yergin, 1991; Painter, 1984, 2009, 2012; Mitchell, 2011; Steil, 2018). David Painter argued that ERP-funded crude oil and petroleum product deliveries relieved US-Dollar reserves into the participating national economies. Additionally, the ERP facilitated long-term changes through infrastructure investments. Fig. 1d depicts the most pivotal investment programs and international organizations. The ERP lasted from 1948 to 1952. France received aid deliveries worth US $ 2.7 billion (in prices of 1952) of which 18% were provided in the context of coal-aid (Painter, 2009; Holter, 1985). The focus was on mining infrastructure (67%). The remaining 33% was used to import coal from the USA (71.2%), and Western Europe (29.8%) with the UK and Germany taking the lead (ECA, 1950). Petro-aid amounted to US $ 420.9 Mio or 15.6% of total ERP funds for France, and included petroleum deliveries (nearly 90%), refinery expansion, transport infrastructure and oil drilling in France and the colonies.

In addition, France accumulated US $ 1.85 billion in ERP-counterpart funds that were distributed under the Monnet Plan to mechanize agriculture, improve road networks, the electricity, natural gas, and power sector, as well as mining (Barjot and Dreyfus, 2011: 133–136; Brunet, 2018; Lynch, 2006). Here, too, the great importance of the ERP in the reorientation of French production systems becomes apparent. Alan Milward argues that the French government would not have been able to implement the Monnet Plan without the ERP (Milward, 1984: 109).

Fig. 1d shows a timeline of the organizations founded to coordinate the ERP and Western Europe's reconstruction (Schot and Kanger, 2018: 1045). The OEEC is particularly important for our analysis, as it emerged as a pivotal system entangler. Its foundation resulted from a British-French initiative to coordinate national reconstruction programs. Its headquarters moved to Paris in 1949, and Frenchmen held the position of the secretary-general until 1961. Robert Marjolin (1948–1955) was economic advisor under Charles de Gaulle and later Secretary of State for French Reconstruction before his transfer to the OEEC (Schmelzer, 2016: 64). When Marjolin left the OEEC, he became a consultant to General Motors and Shell Oil (Schulz-Forberg, 2019: 689). His-successor, Rene Sergent (1956–1961), had worked as Deputy Secretary-General of NATO (1952–1955) before he became secretary-general of the OEEC

(Schmelzer, 2016: 64). Although, the analytical focus of this study is on the institutional level, these individuals testify the close ties of the OEEC to the political administration in France as well as the military-industrial and the petroleum product-combustion engine complex.

France, the UK, and the USA dominated the OEEC. Unlike the UK, however, France was less reluctant to respond to the US invitation to become part of its petro-based empire (Schmelzer, 2016: 40; Lundestad, 1986). Albeit not a full member, the US played an important role in the OEEC. A remarkable example for this was Paul Hoffmann's (leader of the ERP agency Economic Cooperation Agency) threat to stop the entire aid-action, when American ideas of economic integration by trade liberalizations were about to fail (Holter, 1985). In the following years, intra-European trade rose by 272% between 1948 and 1956 (Woodward, 2009). In 1961, the USA and Canada joined as full members. At the same time, the OEEC became the Organization for Economic Cooperation and Development (OECD), and turned from an agent of reconstruction, productivity pushes, and trade liberalizations to an advocate, planner, and coordinator of Western European economic growth as well as warden of the West vis-à-vis the communist bloc and the Global South (Schmelzer, 2016: 54).

Although the OEEC lacked supranational power, the organization developed mechanisms to guide national developments into the desired direction. The OEEC/OECD applied a procedure in which national reconstruction plans and development goals were mutually reviewed in committees, which resulted in a "continuous adjustment of national policies […]" (Schmelzer, 2016: 63–64). This made the OEEC the primary interface for national data exchange. The most critical lever of that procedure was that "committees routinely engaged in a process of 'confrontation,' […] in which the performance of each member country was scrutinized and monitored by the 'peers'" (ibid.). This ensured a "common value system" among Western European bureaucrats with the petroleum product-based mechanization at the very core of economic growth (Graf, 2014: 42; Mitchell, 2011).

Fig. 1d also depicts NATO and the European Productivity Agency (EPA), both of which collaborated closely with the OEEC. The OEEC "provided bureau, and permanent staff for NATO […] and both organizations shared data and expertise" (Schmelzer, 2016: 43). Marjolin even worked in NATO's headquarter from time to time. NATO also planned and built the first transnational crude oil pipeline, which was financed mainly from French funds and supplied French refineries funded under the ERP (Poppe, 2015: 240). The EPA played a somewhat different role. Its establishment derived from the idea that Western European political stability could only be achieved through a productivity push. The EPA received considerable funding from the OEEC and organized productivity tours for about 20,000 Western European workers and specialists between 1953 and 1961 (Boel, 2003; Leimgruber and Schmelzer, 2017: 31; Silberman et al., 1996; Giorcelli, 2019). Five thousand technicians, trade unionists, and managers came from France alone (Judt, 2005: 93).

3. Rewiring the French energy system

The actual core of the OEEC/OECD was formed by 13 (vertical) technical and several (horizontal) economic committees, in which the transition of the post-World War II transition was coordinated through the entanglement of sociotechnical systems. Vertical committees were formed to govern energy and material flows through modernizing the necessary infrastructure of mobility, transport, extraction, and industrial production (Leimgruber and Schmelzer, 2017: 31; Schmelzer, 2015). Within these committees, technicians, civil servants, national administrations, and industrialists, entangled differing sociotechnical systems to accelerate the flow of raw materials, energy carriers, capital and knowledge (Schmelzer, 2016: 59; Biebuyck, 2019: 20). Due to their rather technical and low politics character, their work met only little political resistance.

The Technical Oil Committee (TOC) was of overriding importance. It negotiated ERP petro-aid with the ECA. By doing so, the first OEEC-wide official crude oil and petroleum product database was put together that allowed to debate present and envisioned future manifestations of an integrated Western European oil-based energy system (Morgan, 2012). This paved the way for governance modes aiming at the entanglement of discrete sociotechnical systems. When raw materials became scarce during the Korean War in the early 1950s, the TOC and the Technical Committees for Machinery and Steel devised and coordinated a program which fostered the transition from coal to petroleum in the steel and machinery industry while increasing the output of steel products to facilitate refinery expansion (Hutton, 1974: 235). In 1956, the Suez crisis led to shortages of crude oil supplies to Western Europe. In response, the TOC interlinked several Technical Committees to elaborate on fuel diversification in terms of crude oil origin as well as the implementation of new burner technologies for underutilized petroleum-based products (OEEC, 1958: 28). In both cases, the entanglement of diverse sociotechnical systems created co-benefits that translated into growing economic output and energy consumption (Graf, 2014: 55). In 1961, the OECD deepened precautionary planning in the oil sector. In 1974, in the wake of the first oil crises, energy agendas were delegated to the newly founded International Energy Agency, a subsidiary of OECD, which built on the oil committees' expertise, personnel, and databases (Ibid: 62; Schmelzer, 2015: 297).

The personnel composition of the TOC points also to forms of transnational and -continental system entanglements. Between 1948 and 1955, Henry Ballande served as vice chair. After leaving service, Ballande started a second career in the oil industry and utilized his contacts to encourage private capital to engage in crude oil searches in Africa (Boureille, 2010; Ballande, 1950). Pierre Desprairies followed Ballande. Like his predecessor, Desprairies was also linked with the French oil industry. From 1959 to 1966, he served as CEO for the "Société des pétroles d'Afrique équatoriale", followed by an engagement for the "Société Française des Pétroles d'Iran" from 1967 to 1974, and for the "Institut français du pétrole" from 1974 to 1986 (Blancard, 2009). Both, Ballande and Desprairies were particularly interested in the development of new oil wells in North Africa (Persée, Pierre Desprairies). The entanglement of French refinery infrastructure with North African oil wells became prevalent after the Suez crisis.

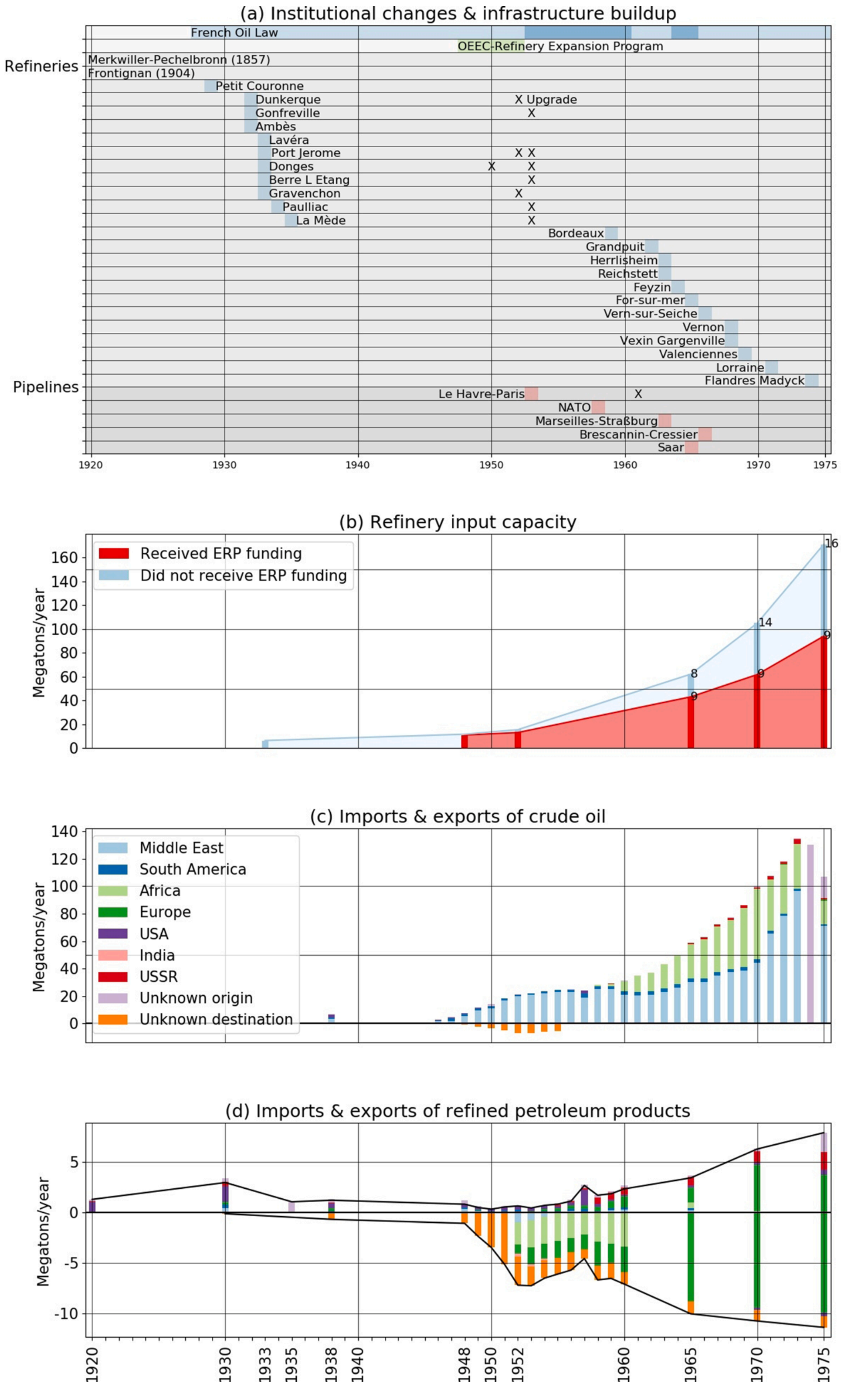

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Fig. 2. Emergence, acceleration, and consolidation of the petroleum-based socio-metabolic regime. Data from 1920 to 1975 on (a) institutional preconditions and establishment and upgrades of French refineries and pipelines; (b) development of French refinery input capacity with an indication of received funding. (c) French imports and exports of crude oil by trade regions; positive values represent imports while negative values represent exports, (d) French imports and exports of refined petroleum products by trade region. Data until 1952 was derived from NARA, RG 469, 2022, France, Boxes 2–4. Data after 1952 was taken from (Molle and Wever, 1984).

3.1. The impact of the ERP on crude oil and petroleum product trade relations

WWI represents a turning point in the history of French energy systems. During the war, France was forced to import nearly 90% of oil products required within the framework of the Inter-Allied Petroleum Conference. The war has drawn France, the UK and Italy "closer together by the imperative to maintain constant supplies of oil", and it amplified the geostrategic relevance of the Middle East (Johnstone and McLeish, 2020: 6). After 1918, France's dependence on imports from Standard Oil and Shell Oil remained. However, in 1923, President Raymond Poincaré commissioned Ernest Mercier to create a sufficiently large Petroleum company to supply France. French objectives turned towards the Turkish Petroleum Company operating in the Near East (Ludwell, 1928; Zedalis, 2009). In 1924, Mercier founded the "Compagnie Française des Pétroles" (CFP) (Sassi, 2003: 18).

When the Baba-Gurgur oilfields in Iraq were discovered, France invested heavily in developing this up-and-coming field. By doing so, the CFPs rise as an internationally competitive oil company was sealed. In addition, the French state enacted the first Oil Law in 1928 (see Fig. 2a), under which crude oil and petroleum product trade was monopolized and private refinery companies' investments were secured (Poppe, 2015). In 1929, the "Compagnie Française de Raffinage" (CFR) was founded to increase domestic refinery capacities and ease import dependency. Orchestrated by the French state, CFP and CFR could count on the convention that sales and

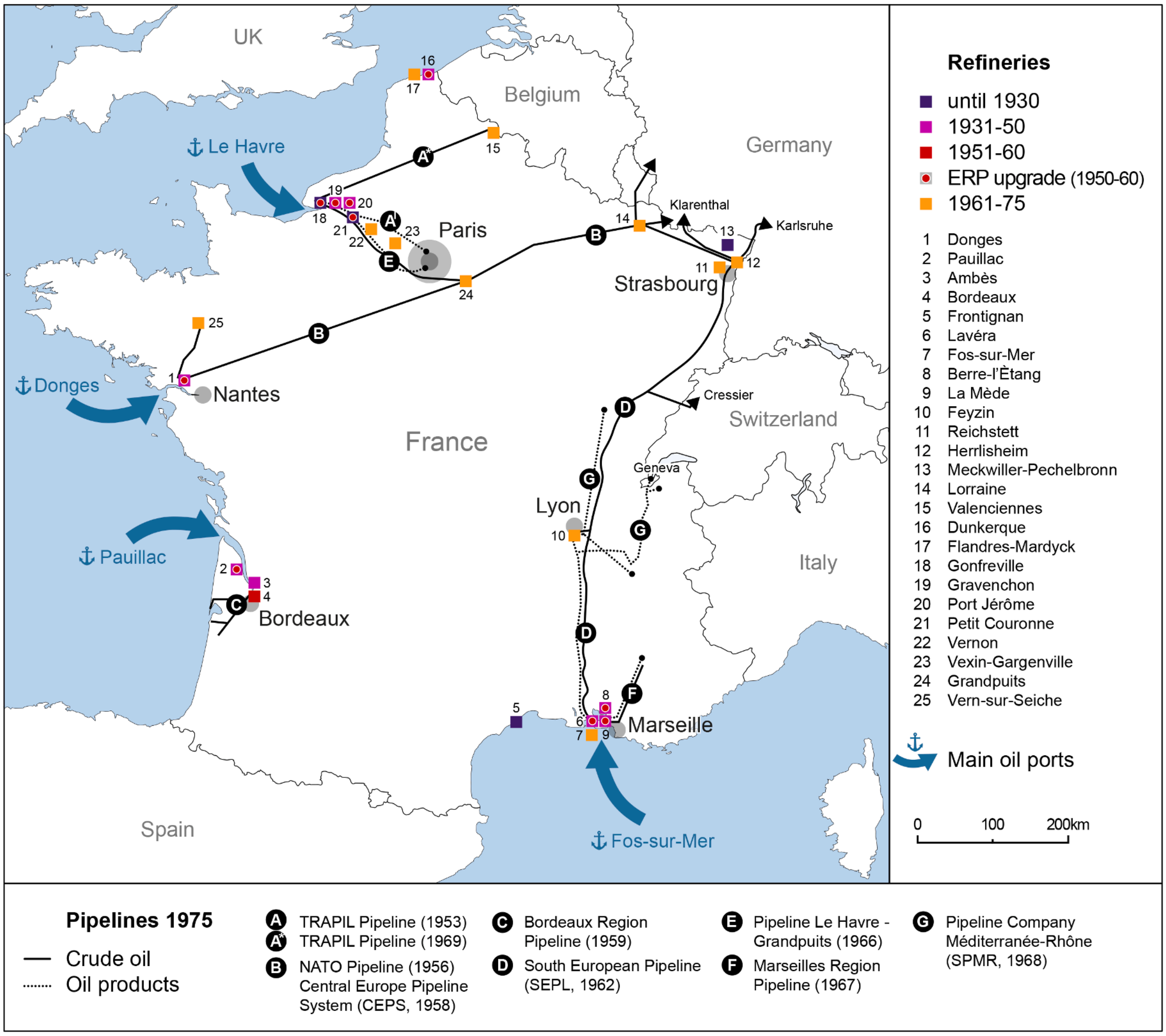

Fig. 3. Map of the spatio-temporal development of refineries and pipelines in France. Based on Poppe, 2015; Molle and Wever, 1984; and NARA, RG 469, 2022, France, Boxes 2–4: Own map created by Friedrich Hauer.

distribution companies took over a fixed proportion of refined products corresponding to the market share of the respective company (Sassi, 2003: 22). These developments strongly affected the ensuing trajectory of the French energy system.

The French strategy to bring the oil system under state control materialized in the form of eleven new refineries built between 1932 and 1935 in addition to the two existing ones (Fig. 2a).Figure 2

Fig. 2a also depicts the OEEC Refinery Expansion Program (REP). The OEEC proposed the first REP in 1948, which envisaged bringing French refinery capacity (18.8 Mt/yr) into line with that of the UK (19.4 Mt/yr) in 1952 (OEEC, 1951b: 26). The ECA rejected this proposal because it "doubt[ed] if there will be sufficient oil burning apparatus available to the participating countries […]" (Washington Conversations, Proposed Questions for Discussion with CEEC Delegates, 1947). France planned to install refinery capacity sufficient to supply Metropolitan France and its overseas territories, which was considered to be uneconomical by the ECA (Ibid.). In addition, the ECA showed dissatisfaction with the level of cooperation among OEEC member states. The rejection forced OEEC members back to the negotiating table. In 1949, the OEEC proposed a much less ambitious REP that included a significant shift in priorities (Trebat, 2018: 317). While the OEEC limited France's capacity to roughly 16 Mt/yr, it increased the UK's capacity to 21.3 Mt/yr (OEEC, 1951b: 26). Moreover, the ECA approved US $ 1.2 million for the Moroccan refinery Petit Jean (CFP and the French state held the majority) via the Overseas Territories Development Funds, which allowed France to control parts of the North African market (Field Report Petit Jean 1951).

Several considerations motivated the ECA to fund crude oil deliveries and refineries. First, the US sought to minimize the influence of labor organized by communist parties, in particular among coal miners (Mitchell, 2011: 28). Second, crude oil production in the Middle East had reached a level that the US national economy could no longer absorb without impeding domestic crude oil production by US companies (Painter, 1984; Trebat, 2018). Third, Western Europe would not have been able to import the necessary quantities of expensive refined petroleum products after the ERPs termination in 1952 without jeopardizing other critical imports for France's reconstruction (OEEC, 1951b). Thus, the OEEC calculated US $ 138.46 million investment requirements for the French refinery sector. The ECA took over roughly 13% (US $ 17.45 million) (MSA, 1953, 31).

Fig. 2a lists the eight biggest French refineries that expanded their capacities as part of the REP. The share of ERP-funded refinery capacity (by crude oil input) versus the overall increase of refinery input is depicted in Fig. 2b. Although just eight out of 13 refineries received ERP-funding, these plants accounted for almost the entire refinery input capacity in 1952. In combination with the CFP/CFR monopoly, the REP marked the emergence of stable and steadily intensifying growth of refinery capacity (Milward, 2005: 216). If one compares Fig. 2a and b, it becomes clear that ERP-funded refineries' dominance only declined when a second refinery boom took place during the 1960s. These results suggest that the ERP fostered growth and stabilization of the petroleum-based energy system.

The spatial positioning of refineries interlinks transportation and trade aspects. Refineries opened until 1951 were mostly situated at the coasts, close to the large oil harbors (Fig. 3). One exception is Merkviller-Pechelbronn, operated with locally produced crude oil (Hall and Ramírez-Pascualli, 2013).

Petroleum products from these refineries were transported either by product pipelines (e.g., TRAPIL, stretching from Le Havre to Paris) (see A and A' in Fig. 3), tank trucks, or trains. The second refinery boom was spatially interlinked with the building of transnational pipeline systems. The NATO pipeline from the Atlantic coast to Metz (B) began to operate in 1958 and became part of the transnational Central European Pipeline System. Along this crude oil pipeline, four new refineries were constructed after 1960. The same applies to the South European Pipeline System (D) that has been connecting Marseille with Strasbourg and Karlsruhe since 1962. The development of the product pipeline system had a particular impact on the exports of petroleum products. A more detailed view of bilateral trade statistics allows understanding how entangled infrastructure and trade flows were.

Fig. 2c shows that before WWII France imported its crude oil from the USA, Colombia, Venezuela, Iraq, and Iran. In 1948, however, the US cut its deliveries to secure its energy sovereignty by utilizing domestic petroleum exclusively for domestic markets (Painter, 2009: 165). As a result, Iraq, Kuwait, Saudi Arabia, and Iran became the main trading partners. Simultaneously, as Fig. 2c shows, Algeria, Libya, and Nigeria, became the most crucial source regions of crude oil imports and overtook the Middle East in the late 1960s. In the 1950s, Algerian petroleum imports did not yet play a role but contributed 6.5 Mt/yr in 1960 and 27 Mt/yr in 1970.

The ERP, OEEC, and French officials, such as Pierre Guillaumat of the "Direction des Carburants" (Fuels Division), managed this shift. Guillaumat was appointed by Charles de Gaulle as head of the "Bureau de Recherche de Pétrole" (BRP). In this function, he built up a national crude oil program that fostered Frances' integration into the global oil system after 1945 (Sassi, 2006: 2). BRP collaborated with associations in France, Algeria, Tunisia, and Morocco and the CFP. In 1948, BRP subsidiaries could convince the TOC, vice-chaired by Henry Ballande to fund French plans to intensify crude oil explorations in Northern Africa with a US $ 1.45 million fund (Ballande, 1950; MSA, 1953). The first crude oil shipments reached France in the mid-1950s (Bini, 2015: 210). The French government fostered these imports by increasing its competitiveness through tax privileges (Poppe, 2015). As Fig. 2c shows, Algerian crude oil lost importance after the wells' nationalization in 1971. Other former colonies, Congo and Gabon, followed, with 0.1 Mt/yr in 1957, 1.1 Mt/yr in 1965, and 2.4 Mt/yr in 1973. This shift went hand in hand with the former TOC member, Pierre Despairies, becoming CEO of "Société des pétroles d'Afrique équatoriale" (Persée, Pierre Desprairies, 2021).

Trade liberalization was high on the ERP/OEEC agenda (Schmelzer, 2016: 44; Milward, 1984). Fig. 2d shows that France imported 0.46 Mt/yr in raw petroleum compared to 3.4 Mt/yr in refined products in 1930. The refinery boom and the ERP reversed this pattern. Imports of refined products plummeted to 1.88 Mt/yr in 1955, while crude oil imports increased to 24.74 Mt/yr. In 1938, 40% of total refined product imports came from the USA. The share declined to 6% in 1960 and 3% in 1970. This resulted from both US-export restrictions and the French government's rule that petroleum product distributors should meet 90% of their requirements from French refineries (Milward, 2005: 216). France became an exporter of petroleum products. Between 1948 and 1952, France's petroleum product net exports sextupled to 7.25 Mt/yr. The leading export destination for French petroleum products was Algeria, which received 44% of French exports in 1956 and 48% in 1960. These exports also aimed at getting rid of heavy petroleum products, which were difficult to sell in Western Europe (OEEC, 1951b: 67–68). These findings on the history of oil trade underline the unequal nature of this exchange, which contributed to industrialized Europe's economic prosperity while acting out as a "resource curse" in Algeria (Hornborg, 2011; Chekouri et al., 2017).

Overall, one finds a shift of petroleum product exports from North Africa to Europe facilitated by infrastructure and fostered by trade liberalizations (Woodward, 2009). In 1951, the OEEC estimated that 10% of the total output of Western European refineries was traded between member countries (OEEC, 1951b: 26). France quadrupled its petroleum product exports until 1965 and further increased them to 9.73 Mt/yr after the pipelines had been built (Fig. 2d). Soon after the product pipeline between Marseille and Geneva (SPMR) was put into operation in 1968, Switzerland became, after West Germany, the most important export destination of French oil products. In this technological interlocking of refinery and pipelines, the objective of a "hidden integration" of Western European national economies pursued by the ERP and the OEEC policies was put to work (Misa and Schot, 2005; Schmelzer, 2015). Furthermore, the French case demonstrates the outcomes of the system entangling activities of the OEEC, which focused on the co-transition of energy systems and transport infrastructure and were inherently tied to new business networks between the oil elites in Metropolitan France and decolonizing African nations.

3.2. The technological interlocking of crude oil inputs and petroleum product output

The following section presents a fine-grained analysis of the impact of ERP-funding on the entanglement of refineries and end-use technologies. Table 2 gives an overview of the changes implemented in French refineries.

Three different aspects characterized the REP with regard to sociotechnical systems' entanglement. First, diversification by adapting refineries to allow the processing of crude oil from the Middle East with high sulfur content. The TOC and the Technical Committee for Chemical Products worked out plans to equip refineries with recovery units to turn sulfur from waste into a resource for the chemical industry, linking the transition of the energy with the industrial system (OEEC, 1951b: 44). Second, operational flexibilization by introducing catalytic cracking technologies (Ayres and Ezekoye, 1991). Catalytic cracking rested largely on the "Houdry Process", named after French engineer Eugene Jules Houdry. During the 1930s, Houdry had cooperated with the US oil industry that applied his invention to large-scale production (ACS, Houdry Process for Catalytic Cracking, 2021). Catalytic cracking allowed increasing the share of high-octane fuel for the war machinery and later, adapting refineries to meet demand changes; a precondition for the entanglement of refinery output and the combustion engine sector (Johnstone and McLeish, 2020: 11). Third, improving the efficiency of the refinery process through, for example, gas recovery systems to provide petrochemical feedstocks to synthesize new compounds that literally transformed all aspects of modern life and also interlinked the transition of the energy and the food system (via agrochemicals).

Table 2
Overview of all refineries in France differentiated by the amount of ERP funding. Shown are share of ERP in total investments, changes in the refinery crude petroleum input, and technological modifications, in particular in the areas of catalytic cracking (cat. crack.) and lube production (lube prod.) between 1950 and 1955. Source: NARA, RG 469, 2022, France, Boxes 2–4.

Refinery	Main shareholder	ERP investment (1000 US$)	ERP share of total investment (%)	Crude oil inputs in 1948 (1000 mt/yr)	Crude oil inputs in 1952 (1000 mt/yr)	Cat. crack.	Lube prod.
Gonfreville	55% Compagnie française des pétroles; 10% Government;	3,000	29	1.9	2.5		X
P. Jerome	55,05% Standard Oil USA, 18,35 Gulf Oil USA,	3,178	19	1.8	2.2	X	X
La Mède	55% Compagnie française des pétroles; 10% Government;	3,000	29	1.7	3.3	X	
Etang de Berre	60% Shell, 40% Produits chimiques et raffinerie de l'Etang de Berre	1,050	5	1.0	2.3	X	
Petit-Cour.	60% Shell Française; 40% Produits chimiques et raffinerie de l'Etang de Berre	–	–	2.0	2.0		X
Pauillac	60% Shell Française 40% Produits chimiques et raffinerie de l'Etang de Berre	1,050	5	0.3	0.3		
Lavéra	Anglo-Iranian Oil Company	–	–	0.4	0.9		
Dunkerque	100% Société Générale des Huiles de Petrol (70% Company stocks owned by Anglo-Iranian Oil Company)	4,005	11	0.9	1.3	X	X
Donges	55% Compagnie française des pétroles; 10% Government;	1,320	8	0.8	0.8	X	X
Ambès	CALTEX	–	–	0.6	0.8		
Gravenchon	Socony Vacuum Française	850	14	0.8	0.8		X
Frontignan	Socony Vacuum Française	–	–	0.2	0.4	X	
Merkv.-P.	Société Anonyme d'Exploitations Minière	–	–	0.8	1.2		X
Total		17,500	13	13.2	21.4		

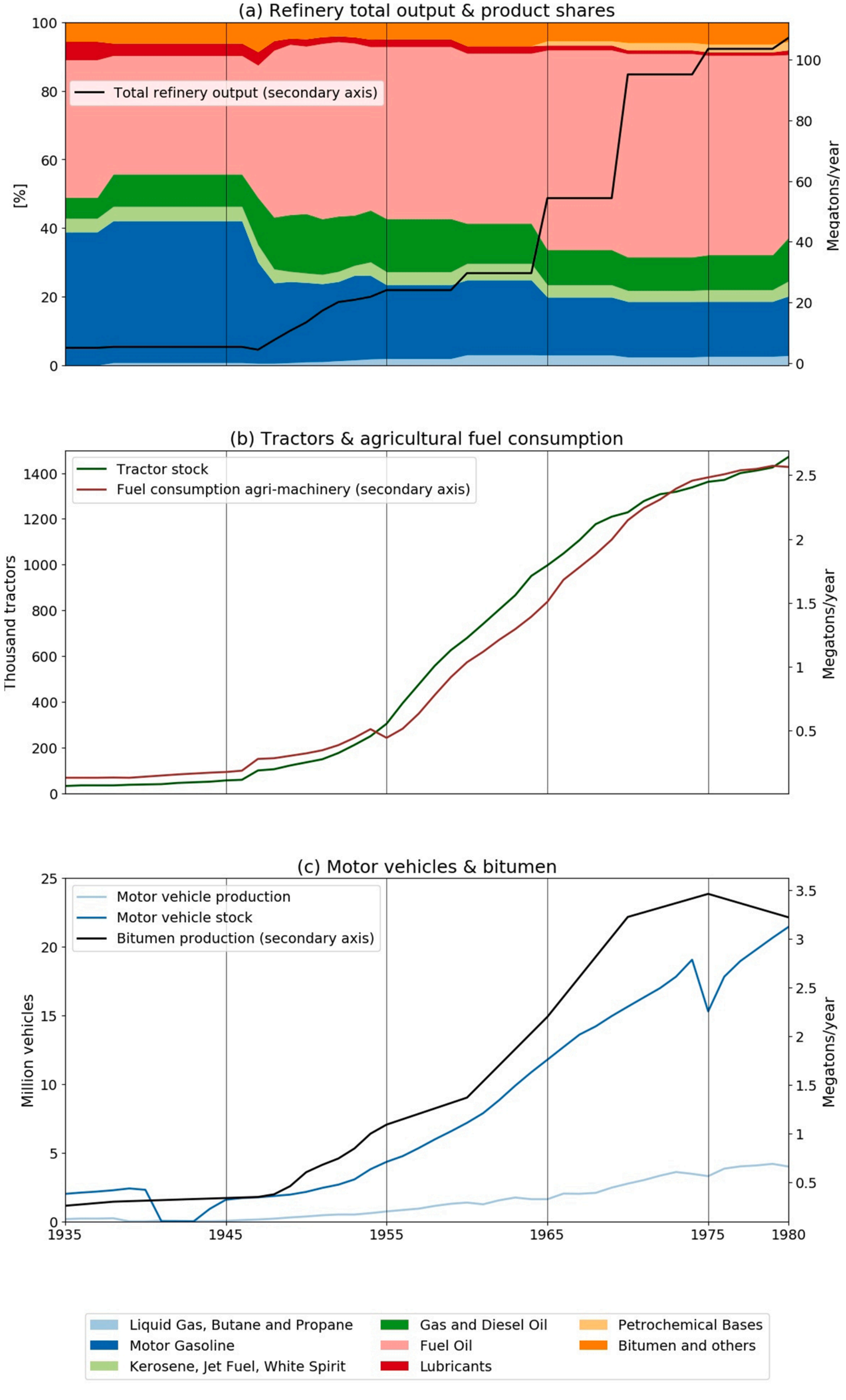

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Fig. 4. Refinery output & machinery: (a) development of total refinery output and product shares from 1935 to 1980 (Comité Professionnel du Pétrole); single-year data points of product shares were kept constant until the next value was available, (b) Number of tractors and fuel consumption in agriculture (Harchaoui and Chatzimpiros, 2018). (c) French motor vehicle production & motor vehicles in use (Mitchell 2003); note: the slump in motor vehicle stock in 1975 results from a change in accounting procedures (Magalhães et al., 2019).

In total, ERP-funding (US $ 17.5 million) included eight refineries, as shown in Table 2, and contributed on average 13% to the total costs. ERP-funding was used exclusively to import technologies from the USA. The three refineries operated by CFP (Gonfreville, La Mède, Donges) received nearly 42% of the total ERP investment and the highest shares of funding related to the overall costs for modernization. The second-largest recipient (22.9% of the total ERP investment) was the "Société Générale des Huiles de Pétrole" (Dunkerque) dominated by the British Anglo-Iranian Oil Company, followed by the refinery in Port Jerome (18.2%), in which Standard Oil and Gulf Oil (both US corporations) were the largest shareholders. The Dutch Shell Corporation followed suit, with 12%. Finally, Socony-Vacuum from the USA got 5% to upgrade the refinery in Gravenchon. In other words, refineries controlled by the French state profited the most from the ERP with 42%, followed by those managed by the US (23.2% in total), the UK (22.9%), and the Dutch (12%).

The focal points of investments differed from refinery to refinery. Dunkerque, Gravenchon, and Donges were damaged by air raids and rebuilt after that. While Dunkerque experienced a considerable capacity upgrade, Donges and Gravenchon were reconstructed at nearly the same level. Table 2 further indicates that all three plants were technologically upgraded by either catalytic cracking or lubricant production. Port Jerome, La Mède, Etang de Berre played a somewhat different role. They experienced capacity increases and were equipped with catalytic crackers and lubricant production (see Table 2). Except for Frontignan, which was dominated by a French subsidy of Socony-Vacuum and Petite-Couronne and Merkviller-Pechelbronn, refineries not participating in the ERP did not experience the same technological transformation as the ones funded by the ERP. This overview suggests that the ERP did play a critical role in shaping the trajectory of the petro-based energy system and paving the way towards petroleum dependency in France.

3.3. Entangling refinery products and end uses

This section highlights how the development of the French petroleum sector and refinery output went hand in hand with the diffusion of petroleum-based technologies. The discussion focuses on agriculture and transport/mobility and on the system entangling function of the OEEC. Fig. 4 depicts qualitative and quantitative changes in petroleum product output (4a) and the development of motor vehicle numbers, bitumen production, and agricultural fuel consumption (4b & c).

Refinery output was very low until 1948 (4.4 Mt/yr) and rose quickly until 1955 to about 20 Mt/yr (Fig. 4a). The output of liquid gas, butane, propane, kerosene, and jet fuel increased ten-fold between 1938 and 1955. At the same time, motor gasoline production tripled, gas and diesel oil increased six-fold, fuel oil nine-fold, lubricants and bitumen quadrupled. The composition of products also changed after 1945. The share of gasoline declined while heavier products (fuel oil, gas, and diesel oil) rose until 1955, followed by another increase around 1965.

Agriculture as well as transport and mobility became dependent on combustion engines during and after WWII (Johnston and McLeish, 2020: 10). The growing significance of the combustion engine interlinked agricultural and mobility practices with refinery output; a process which was not simply self-reinforcing, but was governed by the French state and accelerated by the ERP.

The OEEC promoted the entanglement of food and energy systems as "the only permanent solution to the crisis of food insecurity so drastically revealed by the war" (Biebuyck, 2019: 32). The French delegation to the OEEC particularly emphasized, "that millions of [farm] holdings remained non-mechanized, dependent on manual labor, and used only organic fertilizers" (Ibid.: 35). The OEEC as a system entangler aimed to replace human and animal labor with machinery and to create a rising demand for heavy gas and diesel oil and lubricants (OEEC, 1951b: 5; OEEC, 1951c). This would stabilize the post-war situation among the population and create co-benefits within the food and energy systems by increasing both agricultural output and refinery sales.

The political agenda for entangled food and energy systems resulted in US $ 4.6 million ERP-funding (about 35.4% of total costs) in France to an affiliate of International Harvester Co. from Chicago, the "Compagnie Internationale de Machines Agricoles" to build a plant with a capacity of 7500 tractors per year (MSA, 1953: 28). Additionally, the OEEC and ECA organized productivity tours for 60 French experts between 1949 and 1951 (OEEC, 1951a: 87–100). The productivity-increasing efforts in agriculture also became the most crucial aspect of the agricultural Monnet Plan. More than two-thirds of funds were devoted to agricultural mechanization (Lynch, 2006).

Fig. 4b hints to these measures' effects. In 1935, France's farmers used 32,000 tractors. By 1947 this number had more than tripled to 100,045, which consumed 45% of the refinery output of gas and diesel oil. Until 1952, the number of tractors had doubled and it doubled again until 1960, when agriculture consumed 30% of all gas and diesel oil. The number rose to 1.23 million tractors in 1970, consuming 23% of the total refinery output of gas and diesel oil. The agricultural energy transition was accompanied by the disappearance of draft animals. In 1950, roughly 2.5 million horses, 1.8 million cows, and 0.8 million oxen were used to provide draft power. By 1970 the number of horses was down to only 0.1 million and the use of cows and oxen for draft power was completely abandoned. Through this petroleum-driven abolishment of animal power, large amounts of agricultural land and biomass previously required to feed draft animals became available for other applications; another side effect of the entanglement of food and energy systems that becomes visible when the socio-metabolic and deep transition perspective are brought into conversation (Harchaoui and Chatzimpiros, 2019).

Industrial fertilizers were another focal point of the OEEC's system entanglement efforts. The Technical Committee for Food and

Agriculture worked out plans in cooperation with the Chemical Products Committee of the OEEC arguing that an annual increase in fertilizer application (nitrogen, phosphate and potash) by about 10% could boost productivity by about 66%. "The new world of European farming would be based in chemicals […], (Biebuyck, 2019: 36). In fact, synthetic fertilizer consumption increased from 0.02 Mt/yr to 8 Mt/yr between 1948 and 1974. The agro-chemical world was itself an energy transition manifestation, as the industry switched from carbochemical to petrochemical feedstock after 1945, which allowed the food and energy system to transition in parallel, entangled by the technical committees of the OEEC (Stokes, 1994).

The productivity surge unleashed by petroleum-based technologies irrevocably changed France's social metabolism and its embeddedness into global socio-metabolic networks. France depended on biomass imports until 1960; with the petroleum-based industrialization of agriculture, it turned into the second largest exporter of agricultural products after the US in 1974 primarily targeting African and Asian markets (Magalhães et al., 2019: 298). Growing networks of paved roads and trucks powered by internal combustion engines facilitated the shift (Johnston and McLeish, 2020: 9). The entangled transition of energy and food systems multiplied area and labor productivity but also turned agriculture from a net source of useful energy to a consumer of fossil fuels (Harchaoui and Chatzimpiros, 2019; Krausmann, 2004; Stanhill, 1984).

The transport sector provides a telling example for the hegemonic position of the USA as aid donor to Western Europe. In 1947, the later OEEC members agreed to expand inland transport capacity by 25% to accelerate economic recovery (CEEC, 1947: 15). The considerations were, however, primarily related to the railroad sector, which displeased the ECA. The participating states and the OEEC would largely neglect highways and combustion engines because "government-owned European railways had a major influence in government policy […]" (Washington Conversations, Proposed Questions for Discussion with CEEC Delegates, 1947). The State Department considered road transport as more flexible, efficient, and thus, eligible for funding (Schot and Schipper, 2011; Schipper, 2007). Thus, the US provided only 26,000 out of 104,000 rail freight cars requested and covered the difference by trucks. France imported the largest number of automobiles and trucks within Western Europe and the French automotive industry (Simca and Citroën) received US $ 5.83 million to foster the transport/mobility transition based on the increase of the significance of motor vehicles (ECA, 1950; MSA, 1953; Schipper, 2007).

French automobile production (Fig. 4c) had slumped during WWII. The 1938 level (0.23 million vehicles) had roughly been reached again in 1948. Then, production more than doubled to 0.5 million until 1951 and doubled again until 1958. The total number of motor vehicles used in France increased rapidly. In parallel, the demand for iron and steel, a key resource of the automotive industry, soared from 13.5 Mt/yr in 1920 to 37.8 Mt/yr in 1960 and it is worth mentioning that the ERP provided roughly US $ 79 million for the steel industry and a further US $ 4 million for iron ore mining (MSA, 1953).

The TOC reviewed trends in the automotive sector regularly to entangle refinery expansion, the automotive industry, and technical developments of the combustion engine industry. The OEEC aimed to avoid unfavorable developments, e.g., when Western Europe ran short of lead ethyl, an antiknock agent, or when the refinery industry was about to produce overcapacities of expensive high-octane gasoline (OEEC, 1951b: 19–38). When crude oil supplies threatened to falter in 1956, individual transportation represented an important lever for controlling Western European consumption of petroleum products if necessary (Graf, 2014: 55).

In parallel to the entangled energy and mobility/transport transition, road building in France began to flourish, supported by the ERP and the French government. Roughly, US $ 11 million came from the counterpart funds to accelerate road building. Additionally, 30 French road traffic experts were sent to the US to study how the interstate highway system could be adapted to France (Lynch 2006; Schot and Schipper, 2011; Schipper, 2007; OEEC, 1951a). The boom also affected the resource demand, primarily bitumen, a by-product of the refinery process and key material for road construction with asphalt layers. Fig. 4c shows that bitumen output accelerated after 1947 and increased by 28% until 1955. The output further doubled until 1965 and grew to 3.46 Mt/yr in 1975. In parallel, DMC of non-metallic minerals (Fig. 1a) increased rapidly. The extraction of sand and gravel alone rose more than tenfold from 31 Mt/yr to 340 Mt/yr between 1948 and 1973, with a significant share of this increase due to the large sand and gravel requirements in asphalt production and road construction.

The widespread use of the car was a key factor in shaping the spatial organization of society (e.g., urban sprawl) and related mobility patterns and the lock-in of petroleum product consumption and CO_2-emissions (Mattioli et al., 2020; Pfister 2010; Krausmann et al., 2017). Biomass, iron and steel as well as non-metallic minerals are telling examples for the systemic repercussions the energy transition from coal to oil had on the socio-economic metabolism in France. The discussed changes in social metabolism suggest that energy transitions are not isolated but intertwined phenomena that encompass several sociotechnical systems in parallel and are guided by system entanglers, such as the OEEC.

4. Discussion

Scholars have debated the ERPs' role in fostering the economic miracle of the post-WWII era for many decades. These discussions resulted in two opposing positions: "[O]n the one hand, the view that it constituted a crucial contribution to European recovery and, on the other, the opinion that its effects were minimal" (Schipper, 2007: 211). This study goes beyond these positions by focusing on how ERP and the OEEC policies expanded the petro-based energy systems, created cross-system interlinkages between the energy, food, and the transport/mobility systems, and, by doing so, triggered socio-metabolic repercussions within the French national economy.

In our first research question we asked about the influence of the ERP on the historical development of the petro-based energy system in France and the making of petroleum dependency. The origins of the petroleum-fueled energy system go back to the building of refineries after WWI. The take-off followed during the interwar period and was considerably accelerated after 1945 under radically altered geopolitical framework conditions: First, tapping Middle Eastern oil fields was a significant factor in the US allies' defeat of Nazi Germany and had allowed the US to cement its economic hegemony. Second, the US bundled existing aid efforts within the framework of the ERP, which helped Western European countries to reconstruct and transform their national economies, industries, and infrastructure. Third, the ERP included a political agenda of preventing national economies from relapsing into seclusion, as in the 1930s. To this end, the US called for the establishment of the OEEC to force the ERP participating countries to the negotiating table and stimulate free trade in Western Europe. Fourth, the OEEC as a new actor appeared in this process, providing space for the entanglement of individual actors from all sectors and participating countries. Fifth, the OEEC laid considerable effort to converge the US and Western European productivity levels, facilitated by implementing novel management practices and technological change.

These changed framework conditions converged during the ERP in an aid package that aimed at Western Europe's political stabilization and fighting the assumed Communist danger by overcoming (among others) the threat of energy shortages (Mitchell, 2011: 29). By providing substantial funds for petro-aid, the ERP allowed the French government to save US $ 347 million for other investments. Furthermore, our analyses show that petro-aid included in the ERP connected Western European industries to Middle Eastern oil fields and helped to technically adapt refineries to handle larger quantities and new types of crude oil and provide novel petroleum products (Grubler et al., 2016; Nelson, 1976). The ERP and the OEEC accelerated the energy transition by incentivizing the emerging petroleum system to mature and by shaping the course of the energy transition. Although coal-aid was as significant as petro-aid (18% versus 16% of the total ERP), a comparable expansion of the coal-based energy system failed to materialize; in this respect we corroborate previous findings (Holter, 1985; Mitchell, 2011). This observation points to the role of path dependencies: Interventions during the early phase of a development path may have more substantial effects than more extensive interventions at a later stage. Thus, the energy transition during and after the ERP might point to a lock-in that perpetuated the long-term petroleum dependency of the national economy (Pierson, 2011).

The second research question focused on the role of the OEEC as a collective actor that linked and transformed different socio-technical systems in parallel. Here we identified several activities: Firstly, the OEEC/TOC collected and merged national data to make features of the oil-based energy system visible, negotiable, and governable in a forward-looking manner (Schmelzer, 2016: 67). While France had developed a national strategy in the 1930s, the establishment of the OEEC opened up a novel pan-European leeway of transnational system entanglements. France took part in the "empire by invitation" and profited from US-aims to "to reconfigure the European scientific landscape, and to build an Atlantic community with common practices and values under US leadership" (Krige, 2008: 3; Lundestad, 1986). This transnational cooperation made it possible to navigate an expanding petro-based energy system through the Korean War and the Suez Crisis backed by the Technical Committees of the OEEC.

US hegemony in the oil sector began to crumble once CFP/CFR became "the top European oil group" (Sassi, 2006: 15). Our analyses suggest that the rise of CFP/CFR was accompanied by soaring growth rates in petroleum and products consumption (see Fig. 2b), resulting from diversified and expanding import systems which superimposed on each other (Fig. 2d). This observation suggests that expansion by transnational system entanglement was related to the economic exploitation of less developed countries and allowed for the externalization of social and environmental costs of extraction to the detriment of African oil-exporting countries - another research desideratum that arises from the combination of the socio-metabolic and the Deep Transition approaches (Infante-Amate and Krausmann, 2019).

Besides transnational system entanglements, we identified two cross-system fields in which the OEEC and its Technical Committees engaged as system entanglers. The first refers to the creation of a refinery-agrochemical-agricultural machinery nexus to increase agricultural productivity and overcome food scarcity. It aimed at linking farming practices, refinery output, chemical industries and the combustion engine industry. The second aspect dealt with transforming and expanding transport and mobility systems to crank up the economic growth engine. While the OEEC and national experts focused primarily on railway capacity, they were overruled by US interests, which materialized in funds for the automotive industry and increased demand in bitumen, building material, steel, and iron. These examples demonstrate how different sociotechnical systems were directed in parallel by the OEEC and its Technical Committees towards increased flows of raw materials, energy carriers, goods, knowledge, and capital, to overcome short-term economic problems. Furthermore, the combination of the Deep Transition and socio-metabolic approach suggests, however, that the entanglement of socio-technical systems during the early Cold War escalated unsustainable trends of the first Deep Transition in the long run.

While counterfactual historical scenarios can only be speculative, it seems that if the ERP had not existed, France may have remained with already established petroleum supply networks and sociotechnical refinery configurations after 1945, resulting in slower growth of oil consumption (Fig. 1b) during the 1940s and 1950s, and slowly starting petroleum product imports from Northern African countries. Considering that the ERP funded primarily novel technologies unavailable in Western Europe, the diversification of product output and its expansion would likely have been slowed down, affecting fuel-consuming sectors, such as agriculture and mobility/transport. Cities and transport networks might have been rebuilt with more emphasis on railways and a slower road system expansion with different - and maybe more sustainable - path dependencies. Another hypothetical scenario is the following: As the ERP was a tipping point for the division of Europe into two hostile blocs, reconstruction without US involvement might have resulted in strengthened crude oil and petroleum product trade with the Soviet Union or Romania. If the ERP had not existed, the OEEC might not have been established. The United Nations Economic Commission for Europe (UNECE) could have taken over the coordinating function of the OEEC. France could then have counted on Soviet oil for two reasons. First, French leaders had strong alliances with Soviet Russia until 1947 (Conlin, 2018). Second, Gunnar Myrdal, head of the UNECE, favored the economic integration of Eastern and Western Europe (Milward, 1984). France might then have experienced delayed refinery expansion and prolonged petroleum product scarcity because WWII left the Soviet oil industry damaged and disrupted by equipment shortages and transportation problems (Painter, 2009: 163).

5. Conclusion

This study focuses on the impact of the ERP on shaping and creating petroleum dependency in the French energy transition after WWII, and by doing so, exacerbating the first Deep Transition's impacts on resource use and climate change. The OEEC provided the transnational framework to entangle several sociotechnical systems in parallel, enabling and accelerating the uptake and diffusion of petroleum products into a wide range of applications. Petroleum dependency radically altered the socio-economic metabolism of France. Historical actors considered these effects as rise in productivity. However, the dependency on petroleum also drove the unsustainability of the French socio-economic metabolism, making another Deep Transition towards climate-neutrality and sustainability an urgent necessity.

Our study has shown that to gain a better understanding of socio-metabolic transitions it is useful to combine quantitatively and qualitatively focused approaches. Combining the Deep Transition approach with a socio-metabolic perspective on energy transitions has shown how novel technologies and energy carriers did not simply displace traditional energy sources, but rather add up if no targeted and determined political action is taken. We propose to apply such interdisciplinary approaches to empirically evaluate the socio-metabolic impact of political interventions into energy systems to be expected, and, by doing so, to provide evidence-based scenarios for future transitions, which are "helping to move society in the direction of sustainability" (Köhler et al., 2019: 2).

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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.

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