Staying on Course for Energy/Climate Transition[1]

Foresight in Conditions of Uncertainty

By Patrick Criqui and Emmanuel Hache

With its Green Deal in 2019 and its "Fit for 55" package in 2021 (referring to the aim of a 55 percent reduction in carbon emissions by 2030), the European Union began this decade on a highly proactive trajectory in its fight against climate change. But although the COVID-19 crisis showed that lifestyle changes favoring energy sufficiency were possible, the subsequent return to more wasteful behaviors and, most importantly, the conflict in Ukraine substantially changed the context for energy transition. How are we to stay the course and advance into the future—and into a carbon-neutral future in particular?

Here, Patrick Criqui and Emmanuel Hache ask themselves that question and take the measure of this new context, which has become highly unstable for the energy-climate transition. They assess the geopolitical uncertainties (international climate negotiations; war in Ukraine and tensions between states; the energy crisis), as well as uncertainties around technology (endogenous technical progress; creative destruction and disruptive technologies; socio-technical transitions) and those of a societal nature (the levers for individual and collective change to promote energy sufficiency). Last, they sketch out four distinct climate-foresight scenarios for the years to 2050, combining a more or less cooperative pattern of international relations with the dynamics and pace

1. This article is partly based on an opening paper at the seminar "Energy Markets 2022 - Foresight for Sustainable Transitions: Modeling Tools and Methodology," organized by IFP Énergies Nouvelles on December 14–15, 2022, in Rueil-Malmaison. It was updated in November 2023 to reflect the recent conflict between Israel and Palestine.

of decarbonization. This foresight provides a solid base enabling a planning of technological transitions that identifies the most desirable future(s) and charts the best course for bringing them about. S.D.

Rarely in all of history has the world changed so much in so little time. As Olaf Scholz declared before the Bundestag, we are experiencing an epochal shift in global geopolitics, "*eine globale Zeitenwende*."[2] This planet-wide turning point started with the COVID-19 crisis, which cast greater doubt than ever on the benefits of continuing globalization and outsourcing value chains. The second phase was, of course, Russia's invasion of Ukraine, which marked the resurgence of power conflicts on a global scale. This turmoil in international relations is now amplified by the return of the Israel-Palestine conflict.

In this worldwide paradigm shift, however, the climate crisis has been a constant. On this issue, there have been no drastic changes enabling us to mark a before and after. Yet it poses a major existential risk, one that must be overcome within the next thirty years.

Despite the efforts made by various categories of actors to trigger the necessary transformations, nothing has radically changed. The transformations that are currently underway remain too slow and fragmentary, when they should be picking up speed and becoming systemic.[3] That is fundamental, if we are to achieve a real transition that, unlike the preceding ones, does not merely consist in adding new energy sources to those we already have.[4]

One of the obstacles (obviously not the only one) that hampers the sweeping transformation required to decarbonize the planet is that we are faced with a host of uncertainties, most of which are quite radical. They surround the geopolitical context, the future of technologies, and, finally, the societal conditions

2. Olaf Scholz, "The Global Zeitenwende: How to Avoid a New Cold War in a Multipolar Era," *Foreign Affairs*, January-February 2023.

3. See *Climate Change 2021: The Physical Science Basis. Summary for Policymakers,* Geneva: IPCC (Intergovernmental Panel on Climate Change), Working Group I contribution to the IPCC Sixth Assessment Report, 2021, accessed May 15, 2023. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf.

4. Jean-Baptiste Fressoz, "Pour une histoire désorientée de l'énergie," 25es Journées scientifiques de l'environnement ("L'économie verte en question"), Créteil, February 18–20, 2014, accessed May 15, 2023. https://hal.science/hal-00956441/document.

needed for a complete overhaul of the socio-technical system. These uncertainties render actions even harder to define and implement, and yet there is no doubt that now, in the first half of the twenty-first century, it is essential that we stay the course—the course of carbon neutrality by midcentury.

Geopolitical uncertainties

To steer through the abundance of geopolitical uncertainties, we shall restrict ourselves to two aspects of the subject: international climate governance and the new geopolitics of energy, as it has emerged following the outbreak of war in Ukraine. Both are shaking up pre-existing geopolitics of energy.

International climate negotiations

Following the ratification of the United Nations' Framework Convention on Climate Change (UNFCCC, 1992) and the signing of the Kyoto Protocol (1997), right up until the Paris Agreement (2015), the quest for global climate governance was directed at building a global and binding collective framework. The aim was to assign each country a greenhouse gas (GHG) emissions target, accompanied by flexibility mechanisms[5] so as to balance out efforts, particularly with regard to abatement costs. In this initial phase, which lasted almost a quarter of a century, negotiations between countries of the Global North (dubbed Annex 1)[6] and developing ones were already ruled by self-interest and power plays, as were negotiations among Annex 1 countries, and even within the European Union (EU) itself. Admittedly, the stakes were high, as the matter at hand was nothing less than identifying rights of access to a common good: the atmosphere's GHG storage capacity.

In 2009, despite the arrival of a US president (Barack Obama) more inclined to take up the fight against climate change, it became clear at the fifteenth meeting of the Conference of the Parties to the UNFCCC (COP15) in Copenhagen that the approach was failing. The main emerging countries of

5. The *flex-mex* of the Kyoto Protocol, or potentially a global emissions market that would in theory have allowed marginal reduction costs to be equalized, leading to maximum economic efficiency.

6. The countries of the Global North were identified as those belonging to Annex 1 of the UNFCCC; those of the Global South were described as "Non-Annex 1."

the BASIC group,[7] a set of nations essentially representing what is now called the Global South, refused to commit to quantified objectives. Subsequently, it took a few years—until the preparations for the COP21 in Paris in 2015—to get off to a fresh start. The method was then reversed, replacing the existing top-down approach with a bottom-up one: moving from a single, internationally established objective to Nationally Determined Contributions.[8] This was the key to success for the Paris Agreement, qualified by the COP21 president (Laurent Fabius)—doubtless a little too soon—as the first "universal and binding" agreement on the climate.

The United States later withdrew from the Paris Agreement under the Trump presidency, and then rejoined it under Joe Biden. COP meetings have continued, showing some progress but no decisive action. Ever since COP26 in Glasgow (late 2021), the issue of the US$100 billion promised by the Global North to compensate for "losses and damages" suffered by countries in the Global South has been at the top of the agenda. This is a contentious issue. Substantial funds have already been mobilized, but not at the scale required to finance the needs of Global South countries, both with regard to mitigation (i.e., emission reduction), and to adaptation of the most vulnerable countries and regions.

This matter of funding probably constitutes a core uncertainty; and it is a Gordian knot for future negotiations on international climate change action. The crucial question is: will Global North countries, themselves sometimes in economic difficulties, acknowledge that they must—in their own interest as well—provide financing on a mass scale to fund the transition in Global South countries? Will they have the determination and capacity to do so? One thing's for certain: the foremost issue in the future will be that of financing Global South climate policies.

The invasion of Ukraine and the resurgence of power conflicts

The invasion of Ukraine, on the heels of the two-year COVID-19 crisis, marked a new turning point. It brought armed conflicts

7. Brazil, South Africa, India, China.
8. Nationally Determined Contributions (NDC) (to the fight against climate change).

back to the fringes of Europe. But, unlike the Balkan crises of the 1990s, the impacts of this crisis are destabilizing the entire global geopolitical balance.

Since the end of the Soviet Union, a great body of work has appeared on geopolitics, interpreting major historical developments to shape the ways we think about the state of the world and its future. While these contributions are not always aligned in their interpretations and diagnoses, they all bring elements that are useful to a multifactorial approach—the only appropriate way to address the topic.

The first of these works, a famous paper and then book entitled "The End of History?"[9] was published in 1989, even before the dissolution of the Soviet Union. In this intendedly prophetic work, Francis Fukuyama explicitly adopted a Hegelian-Kojevian perspective, thus overcoming the accusations of intellectual shallowness that had been directed at him. Fukuyama's central argument is that the weakening of the Soviet Union and its foreseeable end signal the superiority of liberal democratic regimes, a model over which no alternative seems able to prevail. While this does not mean the end of all conflict, it does mean that, to some extent, the game is over between the two major

Map 1. **Rupture between the Western Christian world and the Orthodox and Islamic worlds around 1500**

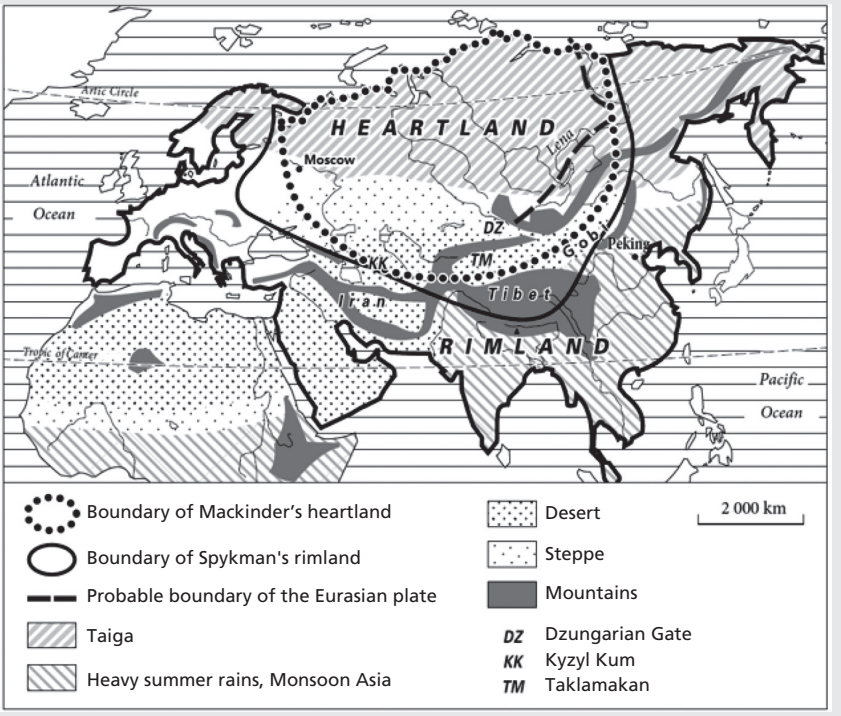
Source: Samuel Huntington, "The Clash of Civilizations?", *Foreign Affairs* (Summer 1993): 30.

9. Francis Fukuyama, "The End of History?", *The National Interest* 16, (1989): 3–18, accessed May 15, 2023. https://www.jstor.org/stable/24027184. Note the question mark in the title.

socio-political models that opposed each other throughout the twentieth century.

In 1993, with "The Clash of Civilizations?",[10] Samuel Huntington responded to Fukuyama. Instead of approaching the subject from the angle of the twentieth century's two great political models, Huntington explores it from that of civilizational fractures deeply rooted in ancient history (see the illustration from the original article, depicting the rupture between the Western Christian world and the Orthodox and Islamic worlds around 1500, Map 1: there are distinct echoes with the current situation). When this thesis came out, it was also widely misunderstood. Far from advocating the clash of civilizations in an aggressive bid to

Map 2. **Mackinder's *heartland***



Source: Heartland Theory by Sir Halford Mackinder in Yves Lavoste's "'The Geographical Pivot of History': A Critical Reading," *Hérodote* 146–147, no.3 (2012): 139–158.

10. Samuel Huntington, "The Clash of Civilizations?", *Foreign Affairs* (Summer 1993), accessed May 15, 2023. https://www.foreignaffairs.com/articles/united-states/1993-06-01/clash-civilizations. Once again, note the question mark.

defend the West—though Huntington certainly emphasizes the reality of the danger, in his many interviews—the author urges that all efforts must be made to avoid aggravating the situation.

Following "The End of History?", another milestone was set in 2012 with a book entitled "The Revenge of Geography," by journalist Robert Kaplan.[11] It is mainly concerned with revisiting the theories of late nineteenth- and early twentieth-century geopolitical strategists. The arguments of American naval officer Alfred Mahan, who advocated the importance of controlling the oceans, are set in opposition with those of English geographer Halford Mackinder, who considered control of the central Eurasian island-continent to be of supreme importance and drew a distinction between the center of the continent and its borders: the *heartland* and the *rimland*. This, again, powerfully resonates with the current geopolitical situation, with regard both to the concept of the Eurasian continent and the importance of controlling its limits.

The geopolitical *heartland* view can be used today to explain the Eurasian Union initiative proposed by Vladimir Putin in 2011 and rejected by Ukraine, Moldova, and Georgia. Similarly, it provides insights about the Belt and Road Initiative, the "new Silk Roads," launched by China in 2013. One last original contribution that follows the same lines is Jeffrey Mankoff's work considering the future of the "Empires of Eurasia"[12] (Russia, Iran, Turkey, China) in the coming world order.

Continuous shifts in the geopolitics of energy

Energy lies at the heart of the economic transformations observed since the 1970s. And now, the energy sector is facing a whole set of new challenges. The very foundations of technology are shifting, strategies among actors in the sector are changing, resources are being nationalized, prices are volatile… the list goes on. While these challenges are known to us, uncertainties arising from the consequences of war in Ukraine and the resurgence of the Israel-Palestine conflict on the one hand and the need

11. Robert D. Kaplan, "The Revenge of Geography," *Foreign Policy*, 172 (May–June 2009): 96-105, accessed May 15, 2023. https://www.jstor.org/stable/20684874.
12. Jeffrey Mankoff, *Empires of Eurasia: How Imperial Legacies Shape International Security* (New Haven, CT: Yale University Press, 2022).

to decarbonize energy systems on the other make the future of energy an extraordinarily open field.

Geopolitics is forever being shaped by struggles related to hydrocarbons and the resulting economic rivalries, as described by Daniel Yergin in *The Prize*[13] and *The Quest.*[14] The invasion of Ukraine has brought energy security issues back to the forefront. It could therefore serve as an accelerator for decarbonization and energy sovereignty policies. For instance, the *REPowerEU* plan launched in March 2022 (aiming to provide the EU with affordable, secure, and sustainable energy) reconciles these two dimensions, with actions to diversify suppliers and raise targets for renewable energy penetration by 2030.

Nevertheless, as the transition takes its course, fossil fuels retain a central role. For example, there is a possibility that some states may turn to safer fossil fuels, such as coal or shale gas. And the oil sector may have to manage a growing demand for oil, in a context where actors may not invest enough for fear of stranded assets or due to social or financial pressures. It may therefore be that the war in Ukraine and the resurgence of the Israel-Palestine conflict mark the start of an energy future at even more volatile prices.

In this future, oil demand is set to peak by 2030 or 2040, depending on the scenario. While this peak demand on the horizon is reassuring for transition policies, it is not yet a reality. Moreover, efforts to mitigate the social impact of inflation are leading to a resurgence of subsidies for some fossil fuels.[15] Between 2021 and 2022, oil subsidies alone doubled to nearly $350 billion, delaying price effects and consumer adjustment.

With the war in Ukraine, a kind of "bloc" logic is emerging once again at international level that may challenge the Western paradigm of liberal democracy. This throws the future form of

13. Daniel Yergin, *The Prize: The Epic Quest for Oil, Money and Power* (New York: Simon & Schuster, 1990).

14. Daniel Yergin, *The Quest: Energy, Security, and the Remaking of the Modern World* (New York: Penguin Press, 2011).

15. According to the International Energy Agency (IEA), subsidies have primarily focused on establishing price ceilings for end-users or limiting price increases. See Toru Muta and Musa Erdogan, "The Global Energy Crisis Pushed Fossil Fuel Consumption Subsidies to an All-time High in 2022" (IEA, February 16, 2023), accessed May 15, 2023. https://www.iea.org/commentaries/the-global-energy-crisis-pushed-fossil-fuel-consumption-subsidies-to-an-all-time-high-in-2022.

Table 1. **Structuring elements of a geopolitics of fossil fuels and a geopolitics of renewable energies**

	Fossil fuel energies	Renewable energies
Reserves and production	Centralized production	Decentralized production
Trade	Sea routes, oil pipelines and gas pipelines	Interconnections
Risks	Geographical: straits, sea routes	Fragility of technical systems, cybersecurity
Structure of the markets	International markets	Local, regional markets
Actors	National companies, international companies, states	States, public policies, and private actors
Organization of markets	Oligopoly (OPEC) and competitive fringe	Competition
Economic competition	Very strong, global	Strong, indirect via access to equipment and materials
Geopolitical tensions	Recurrent and related to access to reserves; resource nationalism	Under construction and related to access to low-carbon equipment and critical materials
Governance	Multiple (IEA, OPEC, etc.) and fragmented	Multi-scale, in construction and seeking leadership

OPEC: Organization of the Petroleum Exporting Countries; IEA: International Energy Agency

geopolitical interactions into doubt: conflicting blocs logic versus cooperative multilateral logic, revival of globalization versus deglobalization. The outcome will determine the structure of future economic relations and, ultimately, the configuration of the energy markets.

As a result, the transition strategies of the actors involved will continue to be shrouded in uncertainty, putting a question mark on such matters as oil companies turning into global energy companies; hydrocarbon-producing states diversifying to becoming potential winners or losers of the transition; OPEC either disappearing or mutating into an energy alliance of Global South countries that incorporates the new hydrogen or solar paradigm. The role of states as coordinators of decarbonization and ecological planning policies will therefore have to be asserted, particularly in Europe.

Technological uncertainties

While it has become apparent that the energy-climate transition cannot succeed without significant behavioral and institutional changes, it is just as clear that technological innovations will play a crucial role. And it is not "technological solutionism" to consider that we must strive to properly coordinate all three aspects of required change. The difficulty that emerges, then, concerns the uncertainties that the prospect of technical change brings into the decisions we are now making.

The fact that these uncertainties lie in different categories only adds to their weight. We must therefore learn to distinguish between them. On the one hand, there are endogenous or incremental technical changes, related to improving existing solutions, while on the other, there are exogenous changes, arising from radical or disruptive innovations. The combination of these two dimensions of technological change can, furthermore, lead to the deployment of new socio-technical systems in the energy-climate transition.

Endogenous and incremental innovations

Following Kenneth Arrow's original work on "learning effects,"[16] neoclassical economists incorporated the concept of endogenous technological change into growth models. These effects explained, in particular, the enhanced productivity of production factors, opening the door to the endogenization of technological progress in long-term growth models (Paul Romer, Robert Barro).[17]

Energy models began to be applied to the economic analysis of climate policies in the 1990s.[18] As the field has progressed, exploring technologies that may provide alternatives to fossil fuels, the matter of cost has grown increasingly important. Since the cost of these alternatives has been observed to drop substantially when they are actually rolled out, explicit

16. Kenneth J. Arrow, "The Economic Implications of Learning by Doing," *The Review of Economic Studies* 29, no. 3 (June 1962): 155–173.

17. Patrick Artus, "Croissance endogène: revue des modèles et tentatives de synthèse," *Revue économique* 44, no. 2 (March 1993): 189–227, accessed May 15, 2023. https://www.persee.fr/doc/reco_0035-2764_1993_num_44_2_409448.

18. Alan McDonald and Leo Schrattenholzer, "Learning Rates for Energy Technologies," *Energy Policy* 29, (December 2001): 255–261, accessed May 15, 2023. https://pure.iiasa.ac.at/id/eprint/6522/1/RR-01-14.pdf.

"learning curves" have been introduced into the models, to forecast expected future costs. Constructed based on statistical observations, these learning curves establish a relation between the increase in a technological option's installed capacities and the decrease in cost of that option. Econometric studies on technological objects in various industries show that each doubling of capacity results in a cost reduction ranging from 10 to 30 percent. Thus, between 1980 and 2020, the price of a photovoltaic module dropped by a factor of over 100 (Figure 1).

Since the first decade of the twenty-first century, large energy models have taken learning effects into account, sharpening the accuracy of assessments relating to key questions: how incentive policies for renewable energy development affect the cost of renewables; how different energy technologies are entering into conditions of relative competitiveness; and last, how much greenhouse gas emissions reduction policies cost society.[19]

The endogenization of technological progress in energy models is advancing a step further with the introduction of two-factor learning curves—"learning by doing" and "learning by searching"—, which account for the impact of research and development (R&D) and demonstration efforts.[20] While it is clear that R&D has an impact on technological performance, progress in this direction is hampered by the difficulty of measuring that impact in econometric terms.

Breakthrough innovations and creative destruction

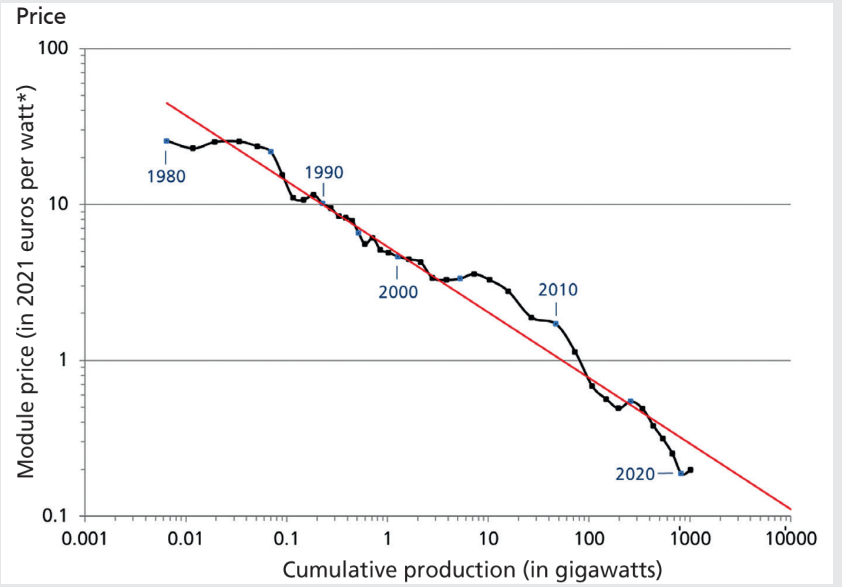
Joseph Schumpeter was the first economist to highlight the role of innovation in "economic evolution,"[21] preceding Kenneth Arrow's work on learning effects by several decades. During the interwar period, Schumpeter introduced key concepts such as "creative destruction," "technological clusters," and "long waves of economic growth."

19. See, among all European research initiatives on this subject, the TEEM (Technology Evolution and Energy Modelling) project, presented in Pantelis Capros and E. Lakis Vouyoukas, "Technology Evolution and Energy Modelling: Overview of Research and Findings," *International Journal of Global Energy Issues* 14 (2000): 1–32.

20. Nikolaos Kouvaritakis, Antonio Soria, and Stephane Isoard, "Modelling Energy Technology Dynamics: Methodology for Adaptive Expectations Models with Learning by Doing and Learning by Searching," *International Journal of Global Energy Issues* 14 (2000): 104–115.

21. Using these terms, he places economics in a historical and Darwinian perspective, an economic Darwinism, obviously distinct from social Darwinism.

Figure 1. **Evolution of the price of a photovoltaic module as production capacity increases**



*Adjusted for inflation.

Source: Photovoltaics Report, Fraunhofer Institute for Solar Energy Systems (ISE), February 21, 2023: 48, accessed May 22, 2023. https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf.

In Schumpeter's view, economic history is characterized, and largely explained, by the emergence of radical innovations during periods of slow growth, followed by the coalescence of different solutions within clusters of innovations, and finally, their diffusion into the economy and society in big waves of powerful growth.[22] According to the long-wave theory (with economic cycles of about twenty-five + twenty-five years), we are currently experiencing the fifth wave since the Industrial Revolution. While we must guard against too mechanistic a cyclical view, this idea of successive waves of innovations appears to be strikingly useful in explaining the evolution of the global economy.

Schumpeter's contributions to the analysis of technological change do not stop there, however. He also called attention to the role of individual entrepreneurs as pioneers who introduce

22. Arnulf Grübler and Nebojsa Nakicenovic, "Long Waves, Technology Diffusion and Substitution," *Review (Fernand Braudel Center)* 14, no.2 (Spring 1991): 313–342.

radical innovation, as well as that played by big companies in fine-tuning industrial processes and rolling out "large-scale"[23] production. This resonates with today's descriptions of the respective roles played by start-ups and large corporations in the discourse surrounding the France 2030 transition plan.

New energy technologies and geopolitics of raw materials

As new energy technologies are deployed, questions arise about the raw material needs generated by the transition. Metals are considered the pillars upon which rests the deployment of low-carbon equipment (electrified vehicles, batteries, wind, solar, hydrogen electrolyzers, and fuel cells). Aluminum, cobalt, copper, lithium, nickel, and rare earth elements have, accordingly, become essential to technological innovations. Nevertheless, they may hamper the dynamics of transition and the field is riddled with uncertainties.

This is particularly the case in such matters as: assessing future demand; the mining sector's ability to meet that demand; the environmental consequences of new exploitation; and, last, how to define the new geopolitical situation these markets are creating. On the demand for metals, the International Energy Agency (IEA) for example estimates that in decarbonization scenarios, by 2040, the need for lithium could rise by a factor of 42, for nickel and cobalt by nearly 20, and for copper by nearly three, to be used in electrifying transportation.

However, while the boost in demand for metals is a definite trend in the low-carbon transition, this does not erase the accompanying technological and behavioral uncertainties. The foresight scenarios struggle to account for possible disruptions in demand, for instance arising from the chemistry of batteries, potential market entry of less metal-consuming equipment (low-tech vehicles), and changes in mobility behaviors (soft mobility, de-mobility, etc.).

On the supply side, the future production of metals gives rise to economic and financial concerns, alongside environmental ones. It is in this context that a new geopolitics of raw materials is

23. Some considered that there was a change of perspective between the "young" and the "old" Schumpeter, which somewhat corresponds to a historical evolution of capitalism in the US with the emergence and consolidation of large industrial companies.

emerging. The principal consumer countries or blocs (China, the United States, Japan, the EU) are all developing strategies centered around the development of domestic mineral and metal production, the establishment of recycling channels, and the pursuit of alliances with major producer countries. For example, the United States is developing bilateral agreements with major mining countries and constructing multilateral initiatives concerning critical metals.[24]

For the EU, the main goal remains to gain control over its dependence, since for raw materials it has an external dependence rate of over 90 percent. The US is in a similar position: as early as 2017, it qualified issues relating to critical materials as "extraordinary threats". The Critical Raw Materials Act released in March 2023 by the European Commission[25] helps set specific targets for production, processing, and recycling on European soil by 2030. By comparison with US policies, however, this Act seems incomplete and not ambitious enough. Through the Inflation Reduction Act, the US has also introduced all the ingredients for a new era of trade uncertainties. Granting subsidies only for electric vehicles produced on American soil and requiring battery metal production to take place in the US, this Act could potentially close American markets off to many foreign companies.

The Chinese strategy also needs to be analyzed from various angles. As the world's leading refiner of transition metals, China holds a potential strategic weapon. Since the early 2000s, it has focused on acquiring stakes in mining companies or purchasing them, and entering into concession agreements or barter arrangements (infrastructure in exchange for mineral supply) with major producer states. Following the rollout of the new Silk Roads in Central Asia, China's entrance into Latin America's mining industry could become a major point of friction with the US.

However, it is important not to confine our perspective to that of systematic confrontation.[26] As much as they compete with one

24. See initiatives around, on the one hand, Australia, Brunei Darussalam, South Korea, India, Indonesia, Japan, Malaysia, New Zealand, Philippines, Singapore, Thailand, and Vietnam; and on the other, Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, the United Kingdom, and the European Union.

25. *Critical Raw Materials Act*, March 2023. See the dedicated website, accessed May 16, 2023. https://single-market-economy.ec.europa.eu/publications/european-critical-raw-materials-act_en.

26. Graham Allison, *Destined for War: Can America and China Escape Thucydides's Trap?* (New York: Houghton Mifflin Harcourt, 2017).

another, China and the US also complement each other. Indeed, American assets (energy and agricultural raw materials) represent China's main dependencies, while China's main strength (metals) represents the US's main dependency. Thus, the rivalry between the two global hegemons could be replaced by a form of systemic cooperation. It is true that this scenario does not seem to be the likeliest one today; but, regardless of the future envisaged, we must ask ourselves what role Europe should take as it confronts the growth of the two global hegemons.

In other producer countries, there are calls to establish genuine cartels for strategic metals, mirroring OPEC, which was created in 1960.[27] In November 2022, Indonesia was pushing to set up an organization of battery metal-producing countries. In Latin America, some are considering a lithium OPEC centered around Argentina, Bolivia, and Chile. Messages like the ones these producer countries are sending out indicate a need to organize commodity markets. Setting up an international organization for minerals and metals could, furthermore, create a platform for exchange between producers and consumers, thus regulating the effects of competition. But the construction of such an organization is not yet on the agenda.

Geostrategic challenges of the industrial growth of decarbonized technologies

The new geopolitics of mineral raw materials must also be analyzed as the site of competition throughout the value chain of low-carbon equipment. Two sources of uncertainty need to be explored. The first relates to the competition observed in low-carbon innovation patents and thus to the question of technological sovereignty. The second concerns the industrial capacity to manufacture low-carbon equipment, and thus industrial sovereignty.

While low-carbon patents are still predominantly divided between Europe, Japan, and the United States, it is apparent that China and, to a lesser extent, South Korea have made significant progress in this field in recent years. Through its "Made in China

27. Emmanuel Hache, Pauline Bucciarelli, and Valérie Mignon, "Métaux stratégiques: et si les pays producteurs se regroupaient en cartel du type OPEP?", *The Conversation*, November 23, 2022, accessed May 15, 2023. https://theconversation.com/metaux-strategiques-et-si-les-pays-producteurs-se-regroupaient-en-cartel-du-type-opep-194749.

2025" plan, launched in 2015, China aims to become the global leader in low-carbon technologies, robotics, and information technologies.

In addition to these questions about innovations, there are also concerns about the production of low-carbon equipment. China is the world's largest exporter of low-carbon equipment, ahead of the United States, Germany, and Japan. Notably, it controls the value chain for electric vehicle batteries and photovoltaic panels.

Low-carbon technologies are therefore a source of intense rivalry between the US, Europe, and China. The same is happening in the microprocessor sector. Through its "China Standard 2035" plan, Beijing also aims to become a major influencer of international standards in all future sectors; these standards are key drivers of economic competition. Low-carbon technologies are therefore leading the energy transition to entrench current dynamics of technological and industrial sovereignty.

Paradigm shifts and socio-technical transitions

In the 1990s and first decade of the twenty-first century, the evolutionary or neo-Schumpeterian economy reviewed all the concepts and issues raised by Schumpeter against a new background: the emergence of green innovations, driven by environmental concerns and the fight against climate change. A notable example of this was Christopher Freeman's work, introducing the "green techno-economic paradigm." As climate constraints increased and the concept of carbon neutrality gained ground, it became clear that, if we are to drastically reduce emissions, the whole system of production needs to be overhauled, especially the components relating to energy and agriculture.

Analyzing socio-technical transitions[28] calls for recourse to a wide range of scientific bodies of knowledge that are not yet unified, encompassing economics, sociology, political science, and behavioral sciences. Research conducted at the University of Sussex's Science Policy Research Unit has been centered on the historical dimension of the process.[29] The latest studies describe

28. Frank W. Geels and Johan Schot, "Typology of Sociotechnical Transition Pathways," *Research Policy* 36, no. 3 (April 2007): 399–417, accessed May 15, 2023. https://www.sciencedirect.com/science/article/abs/pii/S0048733307000248.

29. Christopher Freeman and Francisco Louçã, *As Time Goes By: From the Industrial Revolutions to the Information Revolution* (Oxford: Oxford University Press, 2001).

Figure 2. **Multi-level perspective on transitions**

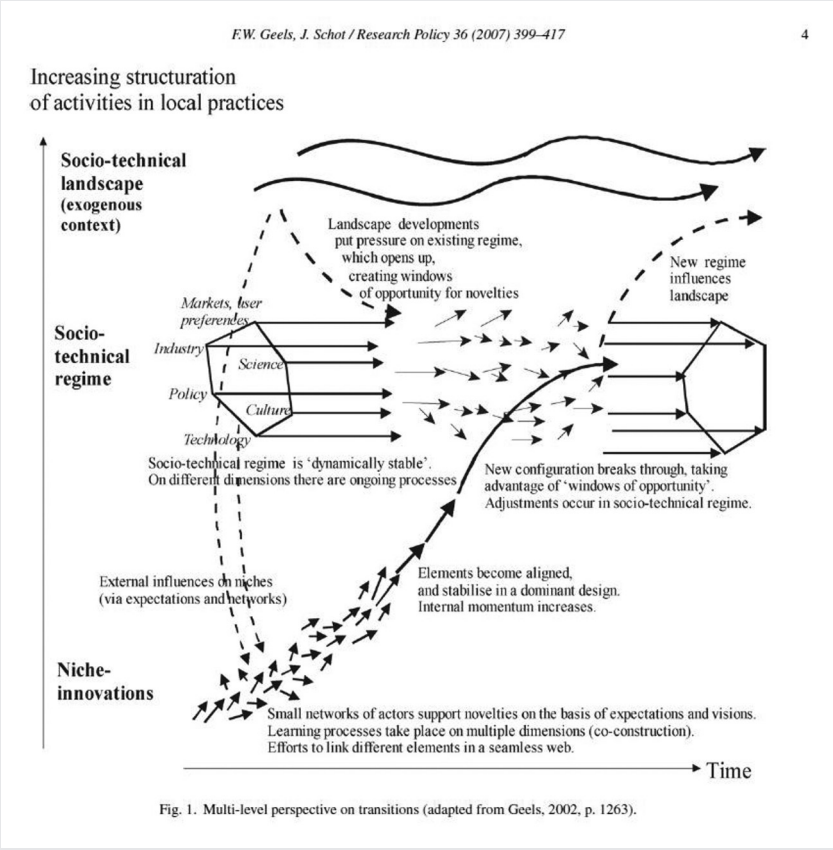


Fig. 1. Multi-level perspective on transitions (adapted from Geels, 2002, p. 1263).

Source: Frank W. Geels and Johan Schot, *Research Policy* 36 (2007): 399–417

a multi-level process: 1) innovations emerge in niche markets; 2) the technological trajectory is then consolidated through learning effects, ultimately altering the socio-technical regime as new actors and institutions gather around the technical objects; and finally, 3) at the highest level, the technological landscape itself is affected and leads to the creation of new innovation opportunities.

Since these socio-technical processes remain difficult to model, few studies have formally integrated them into foresight work. Nevertheless, the distinction drawn between the projection or forecasting approach and the backcasting approach can take

account of all the changes that need to be made in the socio-technical system in view of achieving a transformative goal as radical as carbon neutrality.

Societal uncertainties

The low-carbon transition also poses an unprecedented challenge in terms of societal challenges: unprecedented in terms of the magnitude of the changes to be made, and unprecedented in terms of the speed at which they must occur—that is, within a few decades. Another unprecedented aspect is that, unlike previous energy transitions, this transition cannot occur merely through the addition a new energy source;[30] instead, it must drive the process of replacing carbon-based energies with decarbonized ones, while at the same time limiting consumption.

Such a transformation, in so short a time, calls for the mobilization of all levers of change at both collective and individual levels. The success or failure of the low-carbon transition will likely depend on the synergies between collective and individual changes.

The collective dimension

In urbanized and specialized societies—in other words, societies characterized by strong interdependencies—individual decisions cannot be considered independently from the material and immaterial infrastructures that create opportunities for action while at the same time reducing room for maneuver. This holds true for each of the major categories of needs that energy helps fulfill: food, housing, daily transportation, long-distance transportation, clothing, and equipment.

With food, the problem is three-fold: the impact of meat or non-meat foods; the issue of processed or non-processed foods; and finally, the matter of organic products. The consequences of individual choices in this field are as important for health as they are for the climate. Of course, consumers may be considered masters of their choices, but this is obviously only partially true, as such choices are guided by the commercial system of

30. Jean-Baptiste Fressoz, *Histoire désorientée*

advertising and distribution, and constrained by the economic dimension of product costs.

The housing-automobile transport system accounted for 42 percent of the final energy consumed in France in 2019,[31] with an average household expenditure of €1,600 for housing energy and another €1,600 for fuel.[32] Here too, while individual decisions regarding the size of housing or automobiles matter, it is clear that when it comes to commuting, the overriding factors are localization and land development policies, together with availability of public transportation infrastructure.

Finally, as regards consumption of industrial products for clothing or equipment, choices are limited and the end consumer has no control over the carbon content of products. The growth of the circular economy (the three Rs, reduce-reuse-recycle) and the functional economy, where ownership of material is substituted by the purchase of a service, must be driven by both the government and businesses.

The individual dimension or how to make sufficiency desirable?

If we are to achieve collective success, it is important that a significant portion of the population should have the ability to make choices at their level regarding the size and energy performance of their housing, as well as the distances traveled and driving behaviors. As this is indeed the case, the matter hinges on whether or not people are inclined to sufficiency.

To be desirable, sufficiency policies must mobilize economic, sociological, and psychological approaches. Moving toward a dynamic of frugality means transforming social norms, representations, and values to achieve what André Gorz, in his article "L'écologie politique entre expertocratie et autolimitation,"[33] refers to as the norm of "sufficiency."

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31. Specifically, 21 percent for home energy and 21 percent for automotive fuels. *Source:* Patrick Criqui and Carine Sebi, "Sobriété pour l'Ukraine, sobriété pour le climat: quelles sont nos marges de manœuvre ?", *The Conversation*, September 18, 2022, accessed May 15, 2023. https://theconversation.com/sobriete-pour-lukraine-sobriete-pour-le-climat-quelles-sont-nos-marges-de-manoeuvre-190016.

32. Ibid.

33. André Gorz, "L'écologie politique entre expertocratie et autolimitation," *Actuel Marx* 12, no.2 (1992): 15–29, accessed May 15, 2023. https://www.cairn.info/revue-actuel-marx-1992-2-page-15.htm.

By redefining the ways in which we organize work and daily practices, while calling into question the idea of ownership as a fundamental value, sufficiency should encourage an economy of functionality, sharing, and sociable behaviors. It should encourage us to envisage more equitable societies, based on needs rather than on the accumulation of goods. Narratives, as tools for individuals to envision the future, should promote both individual and collective frugality while simultaneously avoiding the promotion of mimicry and social symbols of waste.[34]

Given the importance of quantifiable economic indicators, making frugality desirable also means being able to measure its effects on shared values: reducing inequalities, limiting environmental damages, ensuring safety and peace. Unless they incorporate the dimensions of social and environmental justice, narratives about sufficiency will not be appealing. They should therefore highlight everyday indicators such as health, education, a concern for healthy eating, and the reduction of working hours. These indicators focus on genuinely living well and people's well-being.

Striving toward *Homo sobrius*[35] should lead states to turn sufficiency policies into levers of collective autonomy and sovereignty. Systemic sufficiency policies could serve as powerful tools to promote the reduction of unnecessary consumption and respect for the planet's limits. To this end, they would foster goals of strategic autonomy and energy security, reduce imports, and improve the trade balance.

Sufficiency could then be integrated into the concept of "soft power," defined by Joseph Nye[36] as a country's ability to inspire adherence to its values. International leadership based on moderation[37] rather than on military or economic power relations (as is currently the case) would enable a new global norm of cooperation to be envisioned, far removed from the hubris of

34. In *Luxury Fever: Why Money Fails to Satisfy in an Era of Excess* (New York: Free Press, 1999), Robert H. Frank stigmatizes the ostentatious competition between neighbors in the US: the "Keeping up with the Joneses" (to borrow the title of Greg Mottola's film, released in 2016).

35. See in particular Christophe Bouton, "Pour une anthropologie de l 'Anthropocène," *Le Grand Continent*, November 17, 2022, accessed May 15, 2023. https://legrandcontinent.eu/fr/2022/11/17/pour-une-anthropologie-de-lanthropocene/.

36. Joseph S. Nye Jr, *Bound to Lead: The Changing Nature of American Power* (New York: Basic Books, 1990).

37. Emmanuel Hache, "La sobriété, vecteur de puissance?"», *Revue internationale et stratégique* 128 (Winter 2022): 77–86

existing powers. Narratives of sufficiency should particularly emphasize the resilience of frugal societies in the face of upcoming climate and geopolitical crises.

Staying the course for carbon neutrality, through the fog of transition

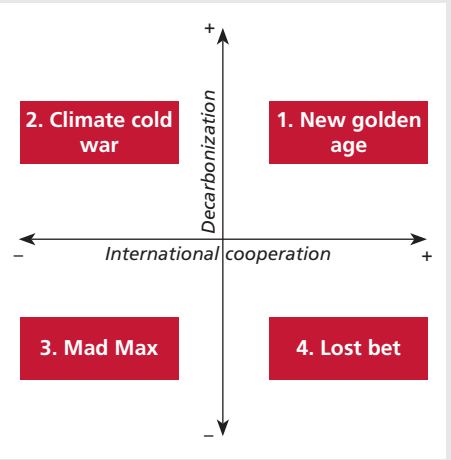
Given the numerous uncertainties we have identified, there is a great temptation to give up and just "let it be." However, we argue for the contrary: in the fog of transition, we must stay the course. Because this course really does exist. It was spelled out in no uncertain terms by the "1.5°C" Intergovernmental Panel on Climate Change (IPCC) special report:[38] carbon neutrality must be achieved as soon as possible after 2050. In view of this extraordinarily ambitious goal, we need to identify the mutations that have to take place, analyze the fundamental uncertainties in the evolution of socio-technical systems, and then generate narratives of desirability.

The variety of future energy sources requires us to approach the matter as sociologists, in order to gain a measure of the depth of the envisaged behavioral changes; as teachers, to empower future generations to develop and control technologies; as economists, to calculate estimated costs, prices, and technological transformations; and finally, as geopoliticians, to anticipate new power rivalries. The consequences of ongoing or recent changes (such as COVID-19 and the war in Ukraine or in the Middle East) should inform discussions and narratives on decarbonization policies; at the same time, we should keep in mind the range of future transformations that may be generated by a situation of multiple crises.

Watchfulness, a quality so often associated with the exercise of foresight, is of critical importance in this context of radical uncertainties. To see far into the future, we need to explore possibilities and identify the key variables structuring potential world states. We shall take the risk of simplifying the analysis by combining two all-encompassing perspectives.

38. *Global warming of 1.5°C. IPCC Special Report on Global Warming of 1.5°C* (Geneva: IPCC, 2019), accessed May 15, 2023, https://www.ipcc.ch/sr15/.

Figure 3. **Matrix of scenarios presented**



The first axis, horizontal in Figure 3, characterizes the future state of international relations, describing a world of conflict at one end and a world based on a multilateral cooperation of states at the other. The dynamics and pace of decarbonization defines the second, vertical axis in Figure 3: it ranges from continuing at the too-slow pace at which policies are currently advancing, to applying vigorous efforts to speed them up and reaching the timing required to attain carbon neutrality by midcentury.

Intersecting these two dimensions enables us to envisage four distinct scenarios: 1) cooperative-decarbonized, 2) non-cooperative-decarbonized; 3) non-cooperative-scarcely decarbonized; 4) cooperative-scarcely decarbonized.

1. **New golden age:** the first scenario is dominated by a logic of international cooperation and a strong dynamic of decarbonization policies. It enables us to envisage a solution, even if only partial, to the climate issue, hand in hand with continued globalization. Technology transfers and all the financing that accompanies them are crucial in helping emerging countries to catch up. Systemically establishing frugality in Global North countries would usher in a new spring of sovereignty, based on moderation in all areas.

2. **Climate cold war:** this scenario depicts a world in the process of decarbonization, but split into two blocs, with the West on one side and China on the other. Here, the world is economically "deglobalized" and value chains are organized around the two poles of power. Nevertheless, scientific warnings are taken seriously and global leadership is sought on environmental issues, thus enabling ambitious climate goals to be attained.

Within power blocs, technologies are shared. This scenario is marked by a pronounced resurgence of ideologies intensely competing for global governance.

3. **Mad Max:** this scenario depicts a fractured world incapable of successfully implementing the necessary decarbonization policies. The exacerbation of climate change and its impacts are the source and consequence of the "free riding"[39] behavior exhibited by states. In this scenario, competition for resources and technologies is extremely intense. Sporadic conflicts break out and lead to recurrent shortages. The policies of sufficiency are driven by supply constraints more than by self-limitation efforts.

4. **Lost bet:** in this scenario, there is cooperation and a common search for solutions to minimize climate change, but the changes required are not sufficiently accepted by society and the level of decarbonization investments remains too low. The costs of climate change adaptation burden national budgets and lead to significant economic and social instability, as well as to general helplessness. Sufficiency is not considered in a systemic manner, and technological developments remain incremental.

Each of these four states of the world belongs to the realm of possibilities. In today's world, the mission of foresight work is clear. We should direct our efforts at identifying robust strategies for the range of potential environments, while fostering the emergence of any development that may increase cooperation and efficiency in the fight against climate change. ■

« Pour ce qui est de l'avenir, il ne s'agit pas de le prévoir, mais de le rendre possible. »
Antoine de Saint Exupéry, *Citadelle,* 1948 (in French, from IPCC's Website on the 1.5°C Special Report page)

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39. Behavior that consists in taking advantage of the effects of actions taken by others, without having participated in the political or financial effort required to implement them (editor's note).

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