Energy and Society

Introduction
Didier Pillet, Member of the General Economic Council

Reconciling economic growth and preservation of natural assets

Peak oil and the shale oil miracle
Michel Lepetit, Associate researcher at LIED (University Paris Cité) and Vice-President of The Shift Project

The global peak in “conventional” crude oil production occurred in the 2000s. There was no peak in crude oil at that time, because the “miracle” of American shale oil happened. Faced with the anticipated limits of conventional resources, the history of shale oil began in the 1960s and 1970s with research on massive hydraulic fracturing, and even nuclear fracturing. The explanation of the shale “miracle” by human ingenuity is therefore partly correct. The explanation by “abnormal”, massive monetary policy is less acknowledged. In 2020, the Covid-19 led to a return to normality in the oil market. The maturity of hydrocarbon deposits, both conventional and non-conventional, and the decreasing return of oil recovery techniques in geological reservoirs, make it possible to predict that the global peak in crude oil production in November 2018 will no longer be matched. The peak of conventional oil, the shale “miracle” and the return to “normality” will have consequences for the macroeconomic (growth), financial (inflation) and environmental (green finance) future of the planet.

Energy flows and the self-organization of societies as dissipative structures
François Roddier, French physicist and astronomer and **Mireille Roddier**, Associate professor and program director of architecture, University of Michigan

Complex system studies have shown that, under a sufficient flow of energy, dissipative structures appear and self-organize into periodic oscillations characteristic not only of Carnot cycles, but also of biological and economic cycles. We have also seen that the emergence of such cycles is the outcome of a common thermodynamic process known as the principle of maximum entropy production (Roddier, 2012). What happens when the flow of energy, which the system has structured itself to dissipate most efficiently, significantly decreases? Here we argue that this unsolicited shortage might be salutary to our interconnected ecosystems if we learn to couple our centrifugal phases of innovation and production with antagonistic centripetal phases of restauration and maintenance. Otherwise, whether we continue to exponentially consume energy from unforeseen new sources, or too abruptly cease all energy consumption without a process of adaptation, our globally interconnected ecosystems may prove too fragile to recover.

France will only be able to achieve its climate targets with ambitious, concerted planning
Emma Stokking, for the Shift Project

At the beginning of 2022, the think tank The Shift Project published its “Plan for transforming the French economy”, a vast programme aimed at decarbonising the economy, sector by sector during the 2022-2027 quinquennium, by promoting resilience and employment. More than a year after its publication, the diagnosis it makes and the proposals it puts forward remain adapted to the current climate and energy crisis.

The role of energy in the growth society as a complex system
Philippe Charlez, energy expert at the Institut Sapiens-Paris

Based on three pillars (a context: liberal democracy; a catalyst: technology; and a food: energy), the growth society is a gigantic dissipative structure out of equilibrium. Requiring a considerable flow of incoming energy (162 PWh, in 2021), it produces $90 T of wealth, but emits 35 Gt of CO_2 into the environment.

Like any dissipative structure, the growth society is an open (free trade), ordered (order, authority) and unequal (social inequalities) system. Poverty reduction requires the creation of wealth, so it is inextricably linked to openness, order and inequality. On the other hand, and contrary to what is rooted in the collective imagination, egalitarianism, disorder and closure (which corresponds to thermodynamic equilibrium) do not reduce poverty but, on the contrary, accentuate it.

Energy Return On Investment (EROI)

EROI and its importance in assessing the performance of energy systems
Gérard Bonhomme, Professor Emeritus, University of Lorraine and **Jacques Treiner**, Associate researcher at the interdisciplinary laboratory for tomorrow’s energies and Chairman of the Shift Project expert committee

Meeting the energy needs of our societies, in the context of the fight against global warming and prospects for the depletion of fossil fuel and mineral resources stocks, requires the implementation of alternative low-carbon solutions. The cost per MWh is undoubtedly a useful criterion, but, as we show in this article, physical criteria are essential for assessing technological solutions and possible energy scenarios. The most important of these criteria based on physical quantities is the Energy Return On Investment (EROI), which measures the efficiency of a system in providing society with energy that is useful for sectors of activity other than the energy sector itself.

The agro-industrial model and the decline in fossil fuels

Félix Lallemand, PhD in ecology

The agro-industrial model is now predominant in the food systems of industrialised countries. In this article, we present the energy sources that have led to the emergence of this model. We study the role of oil and gas in its functioning and seek to characterise its vulnerability in a world where fossil hydrocarbon production is in structural decline. We propose an evaluation of the EROI (Energy Return On Investment) of the French agro-industrial model and discuss the relevance of this indicator for the study of food systems.

Historical and trend evolution of oil and gas EROI

Louis Delannoy, **Emmanuel Aramendia**, **Pierre-Yves Longaretti** and **Emmanuel Prados**, INRIA Grenoble

As fossil fuels are exploited, they become more difficult to access and require more energy to extract. The continuing decline in the EROI of oil and gas therefore seems worrying, given that these two energy sources still account for 52% of global energy consumption. However, these ratios are measured at the primary energy stage and should instead be estimated at the final or useful stage, where energy is closest to the reality of economic processes. Following this principle, the EROI for fossil fuels is already comparable or even lower than that for renewable energies, even when short-term energy storage technologies are included in the calculation. This result is part of the emerging consensus of the net energy analysis scientific community, but its dissemination is hampered by the frequent misunderstandings about EROI inherited from the absence of a formal methodology before the 2010s. To remedy this situation, we summarise the various steps that led to this emerging consensus, present the EROI of oil and gas at the primary, final and useful stages from 1971 to 2019, and discuss the implications for the low-carbon transition.

Uranium as an energy source: medium to long term prospects

J. W. Storm van Leeuwen, Member of the Nuclear Consulting Group, and **Didier Pillet**, Member of the General Economic Council

Uranium is the only metal used as energy source. The extraction of uranium from the Earth's crust involves a complex chain of physical and chemical separation processes and the consumption of large quantities of energy, and of different chemicals.

The energy and chemicals consumed during extraction increase exponentially with decreasing ore grade, accompanied by an exponentially increasing emission of CO_2. The grades of the available uranium resources decrease with time, because the mining companies mine the richest resources first, and because these offer the highest return of investment. Above phenomena cause the existence of the "energy cliff" and the "CO_2 trap". They thus call into question, for the century to come, the viability of a nuclear based solely on ^{235}U extracted from natural uranium whose geological occurrence couldn't suffice to make it self-evidently an energy resource.

One way to overcome this ^{235}U limitation would be to exploit ^{238}U resources. Nevertheless, this requires the industrial development and worldwide deployment of reactors operating in fast neutron mode (e.g. FNR). However, a significant share of the energy produced by such reactors is difficult to envisage at a world level before the end of this century, as we shall see in this article.

Reflections on the concept of EROI. Illustration with photovoltaics and hydrogen

Didier Pillet, Member of the General Economic Council

In the context of the energy transition and the decarbonisation process of the economy, low-carbon energy is expected to play a leading role. These include renewable energies such as photovoltaics and wind power, as well as nuclear power, whose carbon footprint remains relatively low to this day. However, when it comes to implementing their basic infrastructures, these energy systems are still heavily dependent on fossil fuels. Fossil fuels still have relatively favourable energy ratios (EROI), which influences the EROIs of photovoltaic and wind energy systems, leading to an overestimation of their energy performance. A closer look at the physical principles underlying the evaluation of the EROIs of these two systems, both of them are based on the exploitation of energy flows, also provides a better understanding of their real potential in terms of energy performance. Particular attention is paid to photovoltaics, in terms of the scope to be taken into account when assessing the energy consumed when implementing this energy system. Lastly, the way in which the notion of efficiency comes into play in the evaluation of EROIs, a notion that is particularly sensitive in the case of hydrogen production, highlights the importance of having an underlying energy base that is abundant, cheap and has relatively high EROIs, all elements that are essential to the smooth running of the economy, and which complicate the process of decarbonising it.

Issues and challenges relating to raw materials and EROI

Electric vehicle batteries: what are the alternatives to lithium ion technology?

Victoire de Margerie, Founder and Vice-President of the World Material Forum

The end of combustion engine vehicle production by 2035, in favour of electric vehicles, poses the challenge of the raw materials required by the latter. The current very strong growth in vehicle production will not be enough to meet demand, nor will recycling, although essential, insofar as there will not be enough vehicles to recycle in the medium term and there are foreseeable shortages of copper and nickel and geopolitical uncertainties for the rest. The acceptability of short-range cars is limited. Technological innovations will therefore have a crucial role to play: iron, sulphur or sodium batteries, reduced consumption of critical materials in other activities, etc. While technical progress has in the past made it possible to solve many other complex problems, the pace of this transition is unprecedented.

Criticality and geopolitics of the raw materials required by low-carbon technologies

Emmanuel Hache, **Vincent D'Herbemont** and **Louis-Marie Malbec**, IFP Énergies Nouvelles

Since 2010 and the Rare Earths crisis, countries consuming mineral resources, concerned to secure their supplies to meet their strategic needs, have tried to establish quantitative criteria to assess their criticality. However, these indicators often lack the long-term, holistic view of the value chain, from mine to product, which is necessary in the face of emerging uncertainty in materials markets. This high level of uncertainty is the result, on the one hand, of consumer countries seeking autonomy in a context of strong growth in demand and constrained supply, and, on the other hand, of the strategies envisaged by producing countries aimed at benefiting from the financial windfall of their resources without repressing their economies. In this uncertain geopolitical context, all producers and consumers should take advantage of the dynamics linked to metals to structure the markets in a global manner, by integrating social and environmental criteria and by setting up a global governance of materials.

Minimum EROI and economic growth

Victor Court, Engineer and economist, Centre Économie et Management de l'énergie, IFP Énergies Nouvelles, and **Florian Fizaine**, Economist, Institut de recherche en gestion et économie, University Savoie Mont-Blanc

The concepts of net energy and EROI have gradually gained in popularity since their emergence in the 1970s. Although they are particularly useful for characterizing the state of abundance and the difficulty of extracting energy from the environment respectively, measuring them is proving difficult. In recent years, in a context of scarcity of hydrocarbons and a switch to low-carbon energy sources, a number of studies have attempted to estimate the impact of a fall in EROI on the functioning of an industrial society. Another way of approaching this subject is to ask whether it is possible to estimate the minimum value of EROI required to sustain economic growth. Due to some methodological weaknesses, the results of this field of research remain heterogeneous and difficult to interpret, especially as they are part of a context of re-qualification of the objective to be achieved (economic growth or quality of life), to which science will not be able to respond alone.

Lithium mining projects in France and Germany... possible convergence or unbridled competition?

Alain Liger, Former Secretary General of the Strategic Metals Committee

Lithium is in high demand worldwide, driven by the growing use of rechargeable batteries. Europe has classified it as a strategic metal, but is totally dependent on producers outside the continent. An examination of lithium extraction projects in France and Germany shows strong industrial investment in this major mining issue, the fate of which nevertheless depends on the continuation of studies, the acceptance of projects by local populations and the authorizations required by the mining laws of each country.

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Didier Pillet