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A rapid transition of the world's energy systems

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The world is changing but not quite fast enough. The warming of the Earth, caused by rising greenhouse gas emissions, has raised enough concern among the political leaders of the world for them to finally take action. The Paris Agreement, now ratified by 168 member states within the United Nations Framework Convention on Climate Change (UNFCCC), has set the ambitious goal of radically reducing greenhouse gas emissions until the middle of this century. The aim is to confine the increase in mean worldwide temperatures to less than 2 °C above pre-industrial levels, and possibly only 1.5 °C. But scientists are warning that greenhouse gas emissions are still increasing and will continue to do so for some years to come – maybe so much that the 2 °C limit will be impossible to maintain and substantially higher mean temperatures will be reached.

However mankind changes its unsustainable lifestyle and whatever solutions are developed and implemented, one thing is obvious: we are living in a time of transition. On an economic and technological level, and on the level of geo-historical consequences, we are living at the beginning of the Anthropocene, an era in which human action is having long-lasting planetary effects and which is currently discussed as a new geological time period. The next decades will see dramatic changes in industrial production with new material cycles, new forms of labour, necessary global cooperation, exchange of technology and, in particular, in energy production. A future energy system is crucially important for all the other processes and their impact on the Earth system.

The societal and cultural implications of developments in the energy and resources sector are poorly understood. It is all too often visible that the humanities on one hand and natural and engineering sciences on the other hand live in different worlds. All too often, scientists spend little time outside the realm of their own discipline. In many cases, technically, this might work. But when it comes to challenges on historic and geo-historical scales, the lack of a broad historical perspective may also

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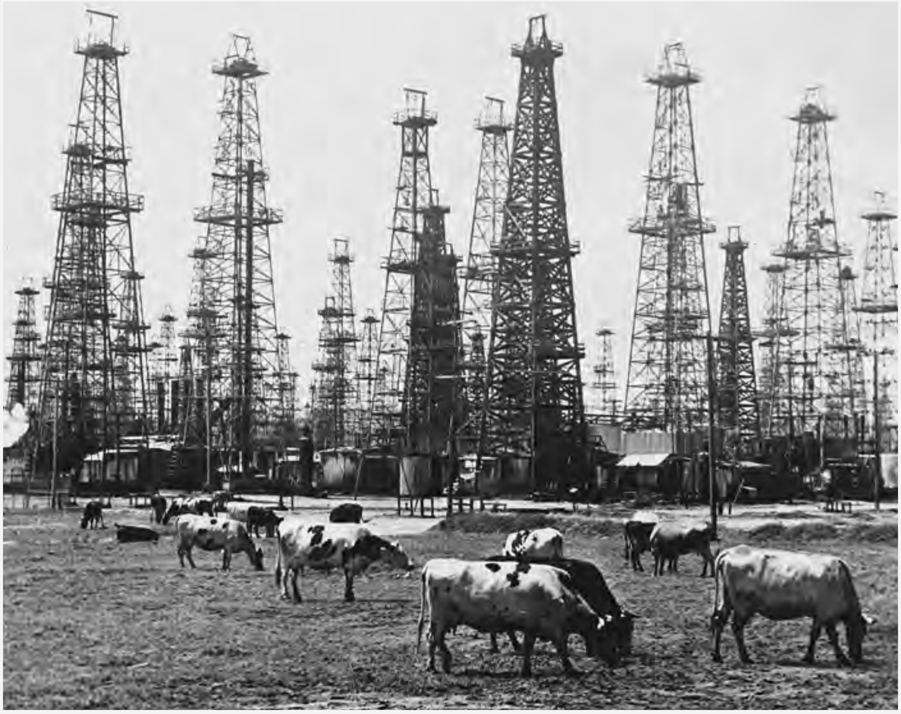
Power plant in Barstow, Mojave Desert, California, United States.



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An oilfield in Pennsylvania, United States.

severely limit the possibilities of properly managing the transition process. A deeper understanding of the historic background of energy transformation processes is not only of academic value, it is the only way to gain a clear understanding of the dimension of ongoing development.

For this reason, the Human Science Section of the Max Planck Society is exploring the possibility to establish a new research initiative. A pilot project, a department, or even an entirely new institute could be built around one simple yet far-reaching question: How do technological changes in energy regimes interact with societal and cultural conditions and, in particular, with knowledge systems? The new Max Planck initiative will take a broad historical and systematic perspective on scenarios between the Neolithic and the present. It will involve experts from different academic fields to establish novel methods for historical energy transformation research. The importance of a broad historic perspective will be the first founding principle. The second one will be the conviction that the ongoing energy transition interacts with the core of our societal system. This calls for a broadly conceived reflective approach since such basic modern concepts as individual freedom, wealth and progress have coevolved with the current fossil-energy regime. The third principle concerns energy transformation processes, which must be analyzed in the material context of industrial plants, mining districts and global cycles of production, consumption and pollution.

New forms of analysis and description must focus on the historic interactions between specific microspheres and the planetary macrosphere. Not least, the Anthropocene and associated Anthropocene research will be a guiding principle of the interdisciplinary scientific endeavour in the new research initiative.

In keeping with the tradition of the Max Planck Society, the scholars involved in the Max Planck initiative will have ample room to develop their own ideas and work on problems of basic research. This kind of working environment will help in understanding the societal challenges of the energy and resource dynamics behind climate change. Young researchers will have great opportunities and freedom, but will also be part of a truly interdisciplinary working atmosphere.

Understanding energy and societal change

Reflecting on events from the beginning of the age of industrialization, it is conceivable that the next years and decades will also be turning points in the history of mankind. The invention of the steam engine changed the face of the world. The possibility to move objects that were nearly unmovable with the power of heat and steam, and the possibility to scale up factory production with machines to formerly unprecedented levels has slingshot our species into the modern era. At the dawn of the industrial age, coal was the energy carrier that fuelled steam engines and then power plants. Together with steel, coal enabled the construction of railroads, large-scale factories, and the electrification of cities.

Since then, new materials and technologies have done their share to change the face of the world – and humans, too. Up to every third nitrogen atom in our bodies is considered to have originated in industrial Haber–Bosch plants for ammonia and fertilizers. Chemical industrial processes have had a global impact on agricultural, biological, cultural and political processes.

After coal came oil, then plastics, and then silicon. The advanced integrated circuits based on the electronic properties of this element gave computers unprecedented power to calculate and simulate all kinds of problems. The computer age led to the age of the Internet with all the amazing cultural phenomena we experience today. But although we still struggle to understand the global cultural implications of the Internet age, with the worldwide exchange of ideas, opinions, fashion or music, we are facing the urgency of incorporating our insights into the greater picture of how mankind will live in the future. The well-being of future generations will depend upon our decisions, such as how we share knowledge and make it productive.

We are standing at a crossroads yet our maps of the areas ahead are partly blank. And that is not only due to the need for further research on the fundamental chemical, physical and biological processes in the Earth system. It is also the case that we do not know enough about how human societies interact with this system and how they will cope with the challenges of climate change and other transformations of our planetary environment. It is not clear which political, economic and technological measures will lead us into a more sustainable future. Research will help us to determine the fastest and most efficient way to implement secure and reliable grids for renewable energy sources, which are more prone to fluctuations than conventional fossil or nuclear power plants. Many political questions are connected with these problems. If one looks at an integrated regional entity such as the European Union, with all its many opinions and different interests, one gets an idea of how difficult it will be to find global agreements on the steps towards a sustainable future in energy production.

Paris is only the beginning

Massive worldwide investments in renewable energy production are necessary to avoid excessive environmental warming. The 2 °C limit is not an arbitrary decision. The consensus among scientists is that even higher temperatures will have dramatic consequences for many regions of our world, some of which we are already seeing today. Global rainfall patterns will change, causing harsh drought in some places and heavy thunderstorms in others. The altered weather systems will lead to widespread changes in agriculture and increase the possibility of famines, which in turn will provoke migration and presumably armed conflicts in many of the poorer parts of our planet. The increase in atmospheric temperature will not be evenly distributed and some regions will actually get colder. Other areas, such as the Persian Gulf region or parts of Africa, will experience much higher temperature extremes, especially in the summer months, which may mean people must stay indoors during periods of intense heat.

Underdeveloped countries will suffer most from global warming, though they are least prepared to deal with it and have not contributed to it. By far the largest share of greenhouse gases have been emitted by industrialized regions, particularly Europe and the United States, but China and other industrializing countries are now joining the club.

The Paris Agreement is of crucial importance but also has its drawbacks. It is not binding; no sanctions may be invoked against countries that fail to achieve their promises to reduce greenhouse gas emissions. Even the methods of measuring carbon dioxide emissions are not unequivocally agreed upon by many governments. Instead, they are the cause of ongoing and future discussions.

Electricity production, storage and distribution is only one of the key problems in combating climate change. The emissions of all kinds of traffic – by land, sea and air vehicles – are even more difficult to substitute by sustainable energy sources than the generation of electricity. The same holds for emissions from agriculture, heating and industrial processes.

The state of affairs in climate politics

Yet, there is some reason for optimism. In a globally competitive economy, energy prices are major contributors to the competitiveness of any nation. Thanks to decades of dedicated

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Koepchenwerk is one of the first large-scale pumped storage power plants to be built in Germany (1927–1930).

work by scientists worldwide, the cost of electricity production by renewable energy sources has arrived at about the level of fossil fuels. The prices for wind energy in wind-rich regions have been competitive for some time. And the past years have seen a rapid decrease in the cost of photovoltaic power production. In some areas with high levels of solar irradiation, photovoltaic power plants are already the cheapest energy source available – as long as the Sun is shining. Storing heat or electricity for the night or on rainy days is expensive and presents basic scientific and technological challenges. To integrate volatile electricity into energy systems that consist of both electrical and molecular energy carriers, it is not sufficient to consider renewables and storage as 'drop-in' solutions. We need to redesign the whole system of energy and material supply. The redesign includes technical, economic, regulatory and societal aspects and must be based on a rigorous understanding of the interrelation between technical and societal interactions mediated through economic and regulatory measures. With this perspective, it is timely to begin with a holistic consideration of structures and concepts in our energy systems.

The energy markets are moving with growing speed. It is maybe not pure chance that the Paris Agreement was signed in 2015 – the same year that the newly built renewable electric power capacity for the first time in history overtook the addition of fossil power plants. The importance of these technological and economical advances cannot be overstressed. Investors and insurance companies are starting to think about investing in renewable energy packages on very large scales.

To reduce investment risks, actors in the financial markets are trying to find the best ways to implement huge investment packages, where the failure – technological or political – of one big project will not endanger the whole investment. These considerations are especially important because many investment opportunities will be in parts of the world that are not politically, socially or economically stable. The negotiations in Paris were primarily about finding an agreement that nearly all countries would be ready to sign. One year later at the climate summit in Marrakesh, Morocco, many discussions focused on new technological solutions and business opportunities.

Culture as a driver for innovations

How and with what speed all these problems will translate into noticeable societal developments is not easy to anticipate. The new Max Planck research initiative will address many of the open questions – and while trying to find answers will probably raise new questions. The initiative is driven by an interdisciplinary collaboration within the Max Planck Society, building on its strong tradition in Earth system sciences, represented by several institutes. Scientists at the Max Planck Institute for Chemical Energy Conversion are working on finding new ways of how energy can be efficiently converted into storable and usable forms. The Max Planck Institute for the History of Science has experience in many of the fields that touch the problems of societies that undergo technological revolutions. Scientists at the institute are versed with comparative studies of different cultures in the north and south, in the east and west, spanning centuries and millennia of scientific, social and technological developments. For a deep understanding of the fundamental challenges of our time, new knowledge is required. Examples of future research might be about human interventions in Earth system cycles, bottlenecks in socio-technical systems or interactions between social networks and networks of chemical reactions. Future research will have to involve a broad array of earth system sciences.

Understanding all the fundamental chemical reactions, the distribution of greenhouse gases, the production or conversion methods, and the possibilities of replacing one energy source with another would not be sufficient for a satisfactory assessment of the problems of our time. The reason is because societal changes and cultural developments are not only the outcome of technological revolutions, but also their cause. The interplay between science, technology and culture is incredibly complex. Sometimes new technologies – such as the invention of the printing press, the radio, the television or the Internet – may lead over time to a new order of society.

But often it is culture that drives technology. Without the demand for books in early modern times, there would have been little incentive to develop the printing press. In past decades, growing concerns about sustainable living has led to a globally visible movement towards healthier food production, the conservation of nature and protection against environmental pollution. In major cities across the globe, we have seen the renaissance of the bicycle – an old, yet practical, environmentally friendly and healthy means of urban transport. But all too often, technical solutions alone do not pay off. Combustion engines have become much more efficient, and although this reduces fuel costs for goods transport, it is not effective in reducing fuel consumption in the private sector. Consumers buy bigger cars because fuel is still affordable.

All these cultural developments influence and depend on the way we live, the way we build our cities, the way we move, and the way we work. For these reasons, bringing together the skills and knowledge of both the humanities and the natural sciences is crucial for any analysis of the current state of affairs. The problems we are facing are manifold – in fact, so manifold that the prospects can seem intimidating. Looking at the influence modern mankind has on our planet, one can easily subscribe to the definition of a new geological epoch: the Anthropocene, which is the currently discussed new geological time period characterized by the global impact of humanity.

Although there is debate among geologists about whether the Anthropocene should be officially recognized, one thing is obvious: if mankind vanished tomorrow, we will have changed the chemical and meteorological parameters of our planet. We are already experiencing the consequences of our way of living on a planetary scale. This creates a number of problems, ranging from global warming and ocean acidification to the deterioration of the soil and loss of cropland. The consequences of such changes include increasing difficulties of food production and conflicts of migration.

Lessons from the past

History teaches us how dramatically many climatic changes of the past – mostly due to natural causes – have influenced human societies. Some highly developed ancient cultures have vanished, leaving only ruins of stone buildings, overgrown by rainforests or buried under sand dunes. Some of these societies had elaborate systems of agricultural irrigation and drinking water supplies, which broke down after climatic changes. Today, even some parts of the industrialized world experience water shortages. How will our society move forward and face the possibility of drastic changes that are unprecedented in the history of our planet?

Many lessons of past industrial developments are still to be learned. The fossil background of modernity has become almost self-evident for us and has thus escaped the attention of many cultural theories. While the beginning of the age of industrialization has been analyzed in many respects, some perspectives are still missing. The social and historical sciences have focused on the political and societal changes rather than the new material cycles that accompanied the new methods of producing power and goods. One of the major tasks of the Max Planck initiative will be to examine these developments and to enrich our understanding of the dynamics of new technological regimes.

The Industrial Revolution was not a singular event that led to a new societal state. Instead, it involved several major transitions with the age of oil following the age of coal. Due to its liquid form, oil is much easier to use in combustion machines. It can be transported in pipelines, pumped from tankers to refineries, cracked and re-synthesized to produce a huge variety of fuels, lubricants and materials, from plastic chairs to medicines. The availability of petrol has also enabled private transport for large parts of our modern society – an important contribution to the personal freedom that everybody cherishes.

NASA

Lights show hundreds of fishing vessels in the sea surrounding Taiwan and the coast of mainland China in this image taken from the International Space Station Expedition 40 (July 27, 2014).

When oil was first introduced into industrial procedures it had no specialized infrastructure. Over time, new technologies and infrastructures were developed for an oil-based society. The transition from coal to oil might seem natural now, but it came with a huge restructuring of the existing industrial and urban infrastructure at the time. That transition also brought along new companies, new possibilities and new freedoms – but it also threatened many people's jobs. What lies ahead of us will by no means be less exciting times. The technological developments also provoked a change in the mentality and self-image of people. The personal freedoms, the value systems, the whole set of beliefs and rules upon which societies rely have undergone huge changes that cannot be separated from the material basis of their culture.

In any contemporary industrial culture based on fossil energy carriers that produces goods in abundance and often in wasteful ways, individuals have many more opportunities to participate in society and to express themselves when compared to older agricultural economies. In contrast, in these older economic systems, self-sufficiency and avoiding shortages in food and basic goods were already an important aim.

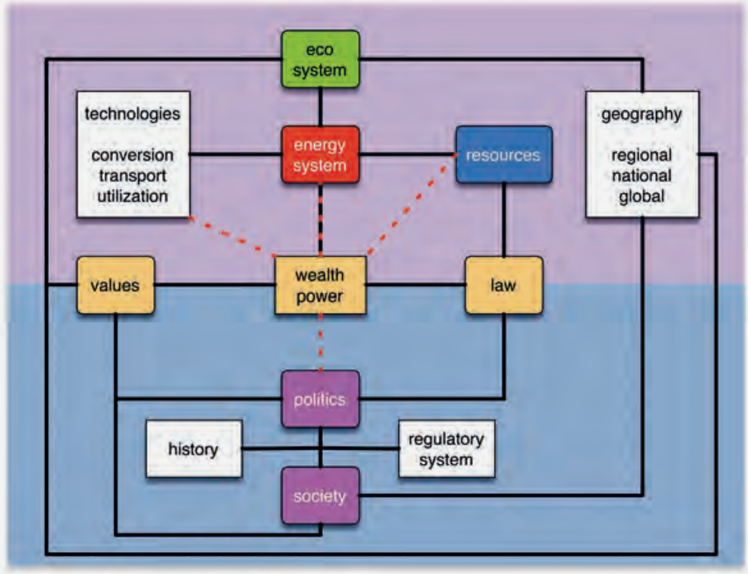
Another period of swift societal change is the epoch of the 'great acceleration'. This era began around the 1950s and is marked by a global increase in population, energy consumption, rising concentrations of carbon dioxide, nitrogen dioxide, fertilizer consumption, damming of rivers, loss of ecosystems, species extinctions and many more effects of the global industrialization. Today, this development is propelled by the global aspiration to participate in the Western culture of material abundance, with all its amenities and drawbacks.

But there are other economic systems revolutions that are worth analyzing in a deeper way from an interdisciplinary perspective. One historically important transition, for instance, happened in the time of colonization by the major European powers when the use of large sailing ships facilitated intercontinental trade and transport. This led to modified methods of production and led from a system of local agrarian production to a global colonial regime. In this era, for the first time in human history, a truly global economic system emerged.

Lessons for the future

Understanding historical developments both in their material complexity as well as in their societal impact will require new forms of collaboration between the humanities, the social sciences and the natural sciences in dealing with the co-evolution of human, biological and geo-historical processes. The collaboration will have to take over and further develop historiographic perspectives that have been established in the context of recent approaches to global and environmental history and to the history of the Anthropocene. Accordingly, it has to deal, on the one hand, with global constellations and long-term processes and, on the other hand, with events and processes that are only accessible to microhistory. The combination of analyses pursued on a planetary macro-level on the basis of big data with detailed historical investigations at a micro-level may contribute to a new, empirically based approach to societal transformations.

Important questions to ask in future investigations will be: How can we identify long-term and far-reaching transformation processes in the area of energy resources? How can historical methods help to detect causal connections between the technical usage of different energy carriers and social processes? What kind of analysis of historical epochs can reveal fruitful insights for reflection on the current transition of energy systems? How can one combine the information density and proximity to the events of microhistory with general claims about the macro-processes of historical transformations? Which historical case studies are particularly promising for reflections on the current energy transition? How can theoretical models from various disciplines be methodically integrated into the historical reflection about resource and energy transformation processes? Which new types of sources and data must be integrated into such research?



The socio-technical energy system is controlled by a variety of factors through a system (black) of checks and balances. Wealth and power as central drivers sometimes circumvent these control systems (red).

Many different theoretical models from different disciplines will have to be brought together to enable analysis of these developments. Large data sets will be needed to identify general traits in different historical epochs and although the natural sciences are used to dealing with big data, its incorporation into historical research will break new ground. New methods will have to be devised to extract new insights from the data sets.

In the natural sciences, energy is one of the most fundamental and general concepts. All processes in the natural world involve the conversion of different forms of energy. In a similar way, the concept of energy connects almost every expression of societal and cultural life. In modern times, wealth, freedom and progress are almost directly interconnected with high individual energy consumption. And abundance is not only significant for modern economies. Since the prehistoric taming of fire for cooking and cult, for hearth and altar, energy conversion and overspending has fuelled many cultures. Slash-and-burn agriculture, artisanal and industrial processes, transport, communication, warfare and even religious practices have been based on some form of energy conversion. But the historiographical account of these far-reaching contingencies is still tenuous.

Thinking about the material culture of today inevitably leads to thinking about the influence of mankind on the material conditions that our lifestyle imposes on the global ecosystem. The Earth as a system of material cycles enables the development of advanced human cultures but is also vulnerable to overuse and short-sighted exploitation of natural resources. The problem that mankind has to solve consists not only in finding solutions for many technical aspects of our energy and factory production, traffic and heating. The question also remains as to whether we can change our value systems fast enough. The middle of this century is roughly one generation away, which leaves us very little time for a thorough change of mentality. But past historical transitions have involved rapid changes in our ways of thinking and acting, and today, modern information and communication technologies have dramatically enhanced our possibilities for the co-production and sharing of new ideas and knowledge.

We will have to find answers to the question of how to enable a society with personal freedom within the limitations of the Earth system, while responding to the undeniable quest of less-developed countries to enjoy at least a modest part of the luxuries of the age of industrialization. This quest for participation can hardly be denied, yet forces the industrialized world to engage even more forcefully in a rapid transition of its energy systems. This transition requires new knowledge that can only be achieved by fundamental research, free from economic and political constraints, and free to rethink our current predicament. It is to this fundamental research that the new Max Planck initiative intends to contribute.