Energy, climate and structural change[1]

Nitin Desai

The study of human history suggests that the sources of the energy used to sustain production and consumption are the defining determinants of the productive structure, and by implication of the social structure. This article assesses the economic and sociopolitical changes that one can expect because of the major changes in energy sources required to tackle the threat of global warming. It spells out what we know at present about the risks of climate change arising from global warming, how they are being addressed at present and how the measures that are contemplated at present to cope with the threat of climate change will transform the global energy economy and why this makes possible a substantially more decentralised economy. But it also qualifies this vision and deals with the hurdles that will be faced in the structural transition.

Keywords: climate, decarbonisation, decentralisation, diplomacy, energy

I
Introduction

The structure of societies at each phase of social evolution rests on definite productive forces. The study of human history suggests that the sources of the energy used to sustain production and consumption are the defining

[1] This article is based mainly on the understanding that came from the author's engagement with the global climate negotiations in its early years from 1990 to 2003 as Deputy Secretary General of the Rio Earth Summit (1992), as the UN Under-Secretary-General for Economic and Social Affairs (1993–2003) and as the Secretary General of the World Summit on Sustainable Development, Johannesburg (2002) and his subsequent work with energy- and environment-related organisations.

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determinants of this productive structure and by implication of the social structure. The transitions from hunter-gatherer to settled agricultural societies and from agricultural societies to industrial ones have been marked by deep changes in the energy sources used by humans. The goal of this article is to assess, or, more accurately, guess the economic and sociopolitical changes that one can expect because of the major changes in energy sources required to tackle the threat of global warming.

This article begins with a section that elaborates a little on the link between energy sources and structural changes that we have experienced in history in order to justify the proposition that a response to climate change will also lead to substantial changes in economic and sociopolitical structure. The next section spells out what we know at present about the risks of climate change arising from global warming and how they are being addressed at present. The third section deals with the measures that are contemplated, at present, to cope with the threat of climate change, how this will transform the global energy economy and why this makes possible a decentralised economy with empowered local communities. The final section qualifies this vision and deals with the hurdles that will be faced in the structural transition.

II
Energy in history

A broad view of human history would suggest two great transitions from the hunter-gatherer stage—the agricultural revolution some 13,000 years ago and the industrial revolution 250–300 years ago. The energy use annually per capita was 3–6 gigajoules[2] at the hunter-gatherer stage. It increased to 18–24 gigajoules in agrarian societies and 70–80 gigajoules in industrial societies (McNeill and McNeill 2003: 231).

This capacity to mobilise energy sources well beyond their muscle power is not the only thing that distinguished humans from other species. A second crucial difference is the web of interaction between humans that allowed them to exchange information and knowledge and function as connected groups, a web that we call 'society'.[3] The point of this article

[2] A gigajoule is a standard measure of energy. It is equal to 278 kWh, which is sufficient to run a 60-W bulb continuously for 6 months.

[3] For a deeper dive into the human web, see McNeill and McNeill (2003).

is that these two distinguishing characteristics of the human species are connected.

Starting from the emergence of our bipedal ancestor, Homo erectus, some 2 million years ago, humans lived as hunter-gatherers whose only source of energy was their own muscle power. This may have led to differential survival advantages for groups that were superior in terms of muscle power. However, even hunter-gatherers had an additional source of energy when they discovered fire and used it to consume foods that they could not digest raw but could if it was cooked. In that sense, an energy source already distinguished humans from other hunter-gatherer species.

They lived as nomadic groups of 100 at most and foraged for fruits, nuts and plants and, over time, developed stone tools that allowed them to become hunters who preyed on animals. The women generally collected plant foods and water, while the men went out to hunt, a differentiation that probably also reflected the breastfeeding and the long period of nurture that human infants required (Ember 1978). However, there are some doubts about inferring the social structure of hunter-gatherers of prehistoric times from the life of today's hunter-gatherers (Widlock 2020). The egalitarian nature of their society can be seen in the few groups that survive as hunter-gatherers until recent times like the !Kung in the Kalahari Desert. One could argue that this egalitarianism was a product of the equal distribution of energy in the form of muscle power between families.

The total population of hunter-gatherers occupying the earth is uncertain and guesstimates of the peak population around 13,000 years ago vary from 5 million to 10 million, a number determined by the capacity of the available habitats to sustain foraging and hunting for food (Burger and Fristoe 2018). Many of the regions that supported the highest densities of hunter-gatherers still host some of the largest populations today. But there are some like equatorial Africa, India and eastern China, which are densely populated today but where hunter-gatherer numbers were limited by high disease burdens (ibid.).

The big change came, after the end of the last ice age, with the development of farming. This transition to settled agriculture is the true beginning of the social structure that we know at present. This agricultural revolution, when humans moved away from foraging to cultivating food, began in the Fertile Crescent around 10,000 BCE. There is some archaeological evidence that humans had started consuming wild cereals even earlier. However, there is no agreement among historians and archaeologists about the reason for this transition. What we know and accept is that relatively larger groups of people moved from nomadism to living in permanent settlements. We also know that the energy requirements of cultivation are significantly higher than foraging. This energy source came from domesticated animals who provided draft power and also other products like milk, meat, wool and skin for other uses. Humans are the only species to have domesticated other species. Without this new source of energy, the agricultural revolution would not have been possible (Childe 1964: 30). Besides animal power, the new sources of energy in agrarian societies were solar power—harnessed mainly through photosynthesis—flowing water, and wind and wood used for burning when high temperatures were required.

In the Fertile Crescent, settled agriculture and village life originated in hills and mountains, not in lowland river valleys. The Nile Valley entered the era of settled agriculture some 3,000 years after it started in the Fertile Crescent. Yet, in some parts, productive agriculture depended on controlled water supply, which led, in time, to large-scale irrigation systems that required centralised bureaucracies that were perhaps the case in the Indus Valley and the Yellow River and Yangtze valleys in China. But, according to Jared Diamond (1997: 23), the direction of causation is not clear and 'complex irrigation systems did not accompany the rise of centralised bureaucracies but followed after a considerable lag'. The agricultural revolution thrived in Eurasia because an East–West movement of techniques was easier because of a comparable annual climate cycle. Recent DNA analysis also suggests that migration from the Fertile Crescent and Iran may have carried the knowledge of agriculture to neighbouring parts of the earth (Reich 2018: 95–96).

As productivity increased, settlements became larger and led to the emergence of inter-settlement trade, partly to dispose of excess production and partly to obtain the materials needed to make the tools required for cultivation. This led to governance hierarchies that graduated into kingdoms and empires. Production in excess of the needs of the growers became the basis for the sustenance of the upper echelons of the governance and, in time, the religious hierarchy and also slavery and forced labour. All of this was made possible by the availability of a new source of energy that allowed higher production.

This agriculture-based social structure survived for several thousand years. This was not static. Energy use developed with the invention of windmills and watermills. Wood was burnt not just for domestic use but also for manufacturing purposes. Some innovations improved productivity, supported large-scale construction of pyramids and, later, of temples and cathedrals, and growing use of metals for tools including armaments, and even chemical innovations like gunpowder. But pre-industrial society depended largely on decentralised energy—mainly solar, wind and flowing water—with some innovations in watermills and windmills.

Energy sources were freely available, and no proprietary rights constrained their use. This decentralised energy system supported decentralised production and provided the basis for the power of local potentates or, to take another example, village autonomy in India. Empires existed because of the developments in the organised use of water through surface irrigation, in the instruments of war and the growth of centralised bureaucracies. But these empires had to share power with local potentates as in feudalism and other forms of decentralised society.

The industrial revolution that began in the mid-18th century in Britain and later in Europe changed this completely. A new source of energy from coal-based steam engines altered the scale of energy availability and use by several orders of magnitude and replaced decentralised energy with much more centralised sources. Initially, coal replaced wood and allowed a huge jump in energy use, which would not have been possible with the pre-industrial energy sources:

> In Great Britain, the substitution of wood by coal created a quantity of energy that would have required forests many times the size of existing wooded areas if energy had still depended on solar radiation. By the 1820s, coal 'freed', as it were, an area of land equivalent to the total surface area of the country. By the 1840s, coal was providing energy that to obtain from timber would have required forests covering twice the country's area, double that amount by the 1860s and double again by the 1890s. (Mitchell 2009: 402)

The growing dependence on coal led to greater centralisation of manufacturing production and rapid urbanisation as coal deposits were not widely distributed and were restricted to a few areas like northern England, Wales, the Ruhr Valley and Appalachia. Even in India, where the coal revolution came later, and more because of railway demands, coal availability is largely restricted to the eastern part of north and central

India. When the railways was developed to transport coal, the scale of the movement encouraged urban concentration even in the destination areas.

The population concentration brought about by the coal revolution had a paradoxical consequence. It led to the formation of workers' organisations, collective bargaining, growing confrontations between workers and employers in which miners played a major role, the emergence of a welfare state to stave off unrest and, in time, the movement of the democracy towards universal suffrage in the Western world, though the process stretched well into the 20th century. But it also led Britain and Europe to establish colonies in Asia and Africa to provide the raw materials required for their manufacturing industries, and the markets required for the products of these industries. In some ways, one could consider this the beginning of globalisation. Hence, one can argue that the shift from rural-to-urban population concentration, colonialism, globalisation and the growing power of the proletariat were all products of the energy transformation based on coal.

The coal-based energy system was soon modified substantially by the emergence of electricity and petroleum in the latter half of the 19th century. Electricity can be transmitted and that reduced the comparative advantage of coal-rich regions and spread industrialisation much more widely. The discovery and growing use of petroleum had an even greater impact on production and consumption trends. It made possible a revolution in transportation and the development of new products like plastics and chemical fertilisers. The ease with which petroleum could be transported reinforced the dispersal of manufacturing. The low cost of oil until the price hike of 1973 led to the spread of a pattern of production and consumption based on cheap energy.

However, the most dramatic impact was in the internationalisation of the energy market. Coal is a bulky resource, and its availability is well spread globally, though within countries it is often more concentrated. World trade in coal was and is modest compared to total consumption. Petroleum is radically different. Its availability, particularly in low-cost deposits, is highly concentrated globally. Major energy users like Europe, India and China are largely dependent on imports.

This led to a form of imperial control with Western oil majors acquiring control over the oil deposits in the principal surplus area, the Middle East. In the latter half of the 20th century, this changed with the governments of oil-producing countries acquiring control and, later, most of them forming a cartel—Organization of the Petroleum Exporting Countries (OPEC). But that did not dilute the control of the big Western oil companies often described as the seven sisters.

The sharp escalation in oil prices in 1973 served the interests of the West. It put money in the hands of the Middle Eastern states that recycled the windfall back to the West for arms purchase and for investment. The higher oil prices also made more economical the exploitation of higher-cost oil sources close to the West like the North Sea.

Summarising the overview of the link between energy and its impact on productive forces, Lewis Mumford (1934: 110) said: 'Speaking in terms of power and characteristic materials, the eotechnic phase is a water-and-wood complex: the paleotechnic phase is a coal-and-iron complex, and the neotechnic phase is an electricity-and-alloy complex'. From the perspective of energy use, we are still in the neotechnic phase and have reached a point of energy consumption when the risks of climate change pose a major threat to our life and livelihoods.

III
Climate change and the response so far

The primary source of energy for the Earth is solar radiation. The radiation received is reflected back into space so that there is no net accumulation of heat in the Earth. If this was not the case, the accumulating heat would have converted this Third Rock from the Sun into liquid or gas. There is an equilibrium temperature at which the reflection of heat radiation from the Earth into space balances the solar radiation received. Given the distance of the Earth from the Sun, this equilibrium temperature, in the absence of any atmospheric barrier, would be about −18°C, an average level that would hardly permit human life to exist.

However, the earth has a blanket of greenhouse gases in the upper atmosphere that holds back some of the returning heat radiation and directs it back to earth, thus, warming it. This returned radiation is re-reflected back into space to preserve a balance between incoming and outgoing radiation. With the present composition of the greenhouse gas layer, the equilibrium average temperature of the earth is 14°C.

As more greenhouse gases are added to the atmosphere, the blanket becomes thicker, so to speak, and the equilibrium temperature rises. That is the problem of global warming, which will lead to the climatic changes that will cause extensive disruptions in ecosystems, economies and societies. Water vapour is the principal element in the blanket, but its quantity fluctuates at the surface of the earth. The more stable greenhouse gases are carbon dioxide (CO_2), methane, nitrous oxide, synthetic halocarbons and tropospheric ozone.

The CO_2 emitted by fossil fuels accounts for the bulk of the rising accumulation of greenhouse gases in the post-industrial era. It is now widely accepted by scientists that this human-induced increase in greenhouse gases is the principal factor behind the rising average surface temperature of the earth (Intergovernmental Panel on Climate Change [IPCC] 2014: 8). Unlike the past changes that were caused by natural factors and led to the sequence of ice ages and warmer periods, what we are experiencing now is happening at a much faster rate and is attributable largely to human actions.

The science that connects CO_2 with average global temperature has been known for some time. But it was in the 1980s that the issue moved out of scientific circles into the global policy discourse as evidence of an increase in atmospheric concentrations of CO_2, and forecasts of climatic impact became available. This led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 because of the global scientific cooperation promoted by organisations such as United Nations Educational, Scientific and Cultural Organization (UNESCO), World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP), and the growing influence of world-wide environmental non-governmental organisations (NGO) networks.

The impact of global warming on the earth and on human societies is a part of the scientific assessment carried out by the IPCC and is summarised below as reported in its fifth assessment released in 2014:

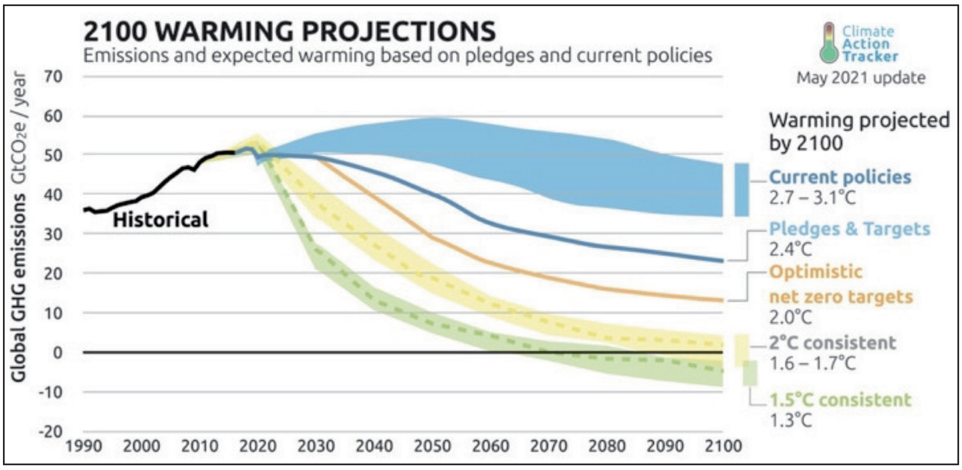
- There will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. Heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur (IPCC 2014: 10).
- Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will become more intense and more frequent (ibid.: 11).
- The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and northern hemisphere subtropical regions (ibid.: 11).

- About 70% of the coastlines worldwide are projected to experience a sea-level change (ibid.: 13).
- There will be a global increase in ocean acidification, which will adversely affect marine life (ibid.: 12).
- Near-surface permafrost extent at high northern latitudes will be reduced, leading to the release of the greenhouse gas methane (ibid.: 12).
- The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease. This will have serious adverse consequences for snow-fed rivers (ibid.: 12).
- A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century (ibid.: 13).
- Climate change is projected to undermine food security and reduce renewable surface water and groundwater resources in most dry subtropical regions (ibid.: 13).
- Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income (ibid.: 15).
- In urban areas, climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea-level rise and storm surges (ibid.: 15).
- Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (ibid.: 16).
- Climate change is projected to increase displacement of people (ibid.: 16).
- Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases (ibid.: 16).

Several studies since the fifth assessment report have argued that the pace of global warming is faster and its potential impact more deleterious than what the Fifth Assessment Report of the IPCC suggests (Woetzel et al. 2020; Xu and Ramachandran 2017; Xu et al. 2018).

[AQ1]

Figure 1
Emissions and Warming Projections (2100)



Source: https://climateactiontracker.org/global/temperatures/ (accessed 11 June 2021).

Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels (IPCC 2018: 4). The extent of increase in greenhouse gases and the global warming that we can expect are projections, which can vary a little with the methods used. One such assessment by a global NGO, Carbon Action Tracker, is given in Figure 1. This figure gives an estimate of the increase in the average global temperature that we can expect if we do nothing (4.1–4.8°C), what is likely on the basis of current policies (2.7–3.1°C) and current pledges (2.3–2.6°C).

The IPCC has played a major role in shaping a global scientific consensus on the facts and projections about the risks of climate change that the world faces.[4] The scientific consensus-building exercise is crucial because powerful governments and corporations have been asked to act before the worst effects of global warming are actually seen. As is to be expected, scepticism about the work of IPCC was promoted by the

[4] This scientific consensus is available in the intergovernmental Panel on Climate Change (IPCC) reports, which can be accessed at its website www.ipcc.ch. Lay readers can get most of the information they need in the Summary for Policymakers. There have been five assessments so far and the sixth one is due over in 2021 and 2022, with the main synthesis report scheduled for release in June 2022. There are many websites, which provide information about climate change. One useful site that provides information on actions is https://climateactiontracker.org/

potential losers like oil companies. But the one positive feature is that scepticism about climate change has declined steadily over time. Now, most of the public criticism about the IPCC assessments is that they have underestimated the scale of the risk. Today, the resistance of the losers is manifest less in the denial of facts and projections and more in resisting rapid change in energy use.

The concerns about climate change underlying the formation of the IPCC also led to an agreement on a global negotiating process on climate change, which led to the United Nations Framework Convention on Climate Change (UNFCCC) that was opened for signature at the 1992 Rio Earth Summit. The assessments in the IPCC reports have formed the basis for the diplomatic negotiations in the meetings of the Parties to the UNFCCC. (Kuyper et al. 2018)

In some ways, the climate negotiations are quite unusual as countries are negotiating to avoid risks, which have not yet been seen fully rather than the more common diplomatic process of finding solutions to problems that have already arisen. This has occurred because the countries realised that the impact of climate change would be widespread, and the response to it would require deep changes in practically every area of economic activity and most particularly in the energy system.

The diplomatic negotiations for the Climate Convention have gone through three phases.[5] The first phase after the negotiations began in 1990 was driven by the difference of opinion between European countries and the USA on the degree of certainty about the projections of climate change, the role of human actions in causing them and the need for mandatory negotiated limits to emissions. The developing countries focused their efforts primarily on assigning the blame on the industrial countries and succeeded in including the principle of common but differentiated responsibility in the convention. The Framework Convention opened for signature at the Rio Earth Summit in 1992 was mainly an aspirational statement without any formal applications to limit emissions.

The second phase began with the negotiations for the Kyoto Protocol in which industrial countries accepted binding obligations on emission reductions by 2008–12. That protocol also brought developing countries indirectly into the mitigation effort through the Clean Development Mechanism (CDM). China and India were major users of this CDM and

[5] For a fuller description of the process, see Desai (2012, 2018).

that injected awareness about carbon emissions into corporate strategies. However, the impact of the protocol on the prospects for climate change was greatly reduced by the failure of the USA to ratify the protocol and, later, the withdrawal of Canada. Moreover, the economies in transition (Russia and the former communist countries) had been given exceptionally high quotas based on their high carbon emissions in the pre-transition days.

The third phase began in the early years of the new millennium when there was a growing concern about the rising emissions from a rapidly growing China, which was heavily dependent on carbon-intensive coal-based energy. The industrial countries and some global NGOs argued that any reasonable goal for allowable temperature increase is unattainable unless the large emerging economies join in the mitigation effort. This effort was driven, in large part, by the aggressive stance of the USA, which refused to take on any obligations unless the emerging economies were brought into the commitment framework.

The main substantive outcome of this third phase is the Paris Agreement, signed in 2015, in which the countries agreed on voluntary actions to limit the risk of climate global warming to 2°C with an aspirational goal of 1.5°C.

As a follow-up to the Paris Agreement, in 2018, the IPCC produced an influential report, which highlighted substantial difference in impact between 1.5°C increase and the agreed goal of a 2°C. Just a few of the conclusions in this report are that limiting the warming to 1.5°C would allow the following:

- At 1.5°C warming, about 14% of Earth's population will be exposed to severe heatwaves at least once every 5 years, while, at 2°C warming, that number jumps to 37%.
- Between 184 million and 270 million fewer people would be exposed to increases in water scarcity if the likely temperature increase is limited to 1.5°C rather than 2°C.
- Risks from forest fires, extreme weather events and invasive species are higher at 2° warming than at 1.5° warming.
- Limiting global warming to 1.5°C rather than 2°C will reduce the number of people susceptible to climate-related poverty risks by as much as several hundred million by 2050.

This report has ignited a debate on accelerating the pace of transition envisaged in the Paris Agreement. However, the gap in the greenhouse gas emissions that are likely in 2030 on the basis of current policies (59 GTCO2e)[6] and what they need to be if the world is to be on a 1.5°C track (25GTCO2e) is very large. If current policies are modified to fulfil the pledges made at Paris, the gap will be narrowed (3-6GTCO2e) a little (United Nations Environment Programme [UNEP] 2020: 26). But the concern about the rising risks of global warming and the associated climate changes has led to a spate of announcements by countries pledging or proposing net-zero[7] carbon emission by 2050 (International Energy Agency [IEA] 2021).

The pressure to increase mitigation commitments is now building up and has been reinforced by the change in administration in the USA. Hence, one can assume that the drive to decarbonise the economy will accelerate, and the global economy will move to a carbon-free future perhaps a decade or two later than the proposed target year of 2050.

IV
Towards a decarbonised world

The fossil-fuel-based energy system that has characterised the industrial revolution has had a deep impact on climate, and addressing the challenge of climate change inevitably involves a radical move away from carbon-emitting fossil fuels. The transition to a carbon-emission-free world could, in theory, be based on technologies for carbon absorption and carbon storage. However, at present, because of the high costs involved and uncertainties about reliable storage of captured carbon, this is not the primary option for most countries. The preferred path involves reduction in carbon emissions by moving away from fossil fields.

The transition to decarbonised consumption and production will require reduction in energy demand and a radical shift in the sources of energy. The reduction in demand will have to come from improvements in the energy efficiency of appliances and machines, substantial redesign of settlements and buildings to reduce the energy required for transport, lighting, space heating and cooling, extensive recycling of scrap material and, the most important of all, behavioural changes.

[6] $GTCO_2e$ is giga (billion) tonnes of CO_2 equivalent.

[7] Net zero is different from zero-emission commitment as it allows for some reabsorption of emitted carbon through afforestation or some other measure for carbon capture.

The decarbonisation of the economy will require substantial demand side adjustments, particularly in the consumption patterns of the rich. Out of the 2015 level of CO_2 emission of 35.5 billion tonnes, the richest one% of the world's population account for 15%, the top 10% for 48%, the middle 40% for 44% and the poorest 50% for just 7%. Around half the consumption of emissions of the global top 10% come from citizens of high-income countries, and most of the other half from citizens in middle-income countries (UNEP 2020: 62–63). Clearly, a substantial change in the lifestyles of the rich is required if we are to move to a net-zero-emissions world.[8] One way of moving towards this would be to start charging a price for carbon emissions as part of energy pricing and thus encouraging energy users to economise on energy use and thus reduce carbon emissions.

On the supply side, the major impact of decarbonisation on production structures will come from a radical shift in the sources of energy and the pattern of energy use from the present state of dependence on fossil fuels as a primary source of energy. The principal thesis of this article is that historical experiences suggest that such a radical shift in energy sources will lead to changes in the structure of productive forces and have a consequential impact on sociopolitical structures.

The most important change in the pattern of use will be a shift towards electricity as the primary mode of energy use even for activities like cooking. A recent study by the International Renewable Energy Agency (IRENA) has projected that in a zero-net carbon emissions world in 2050, the share of direct electricity use would go up from 21% in 2018 to 50% in 2050 (International Renewable Energy Agency [IRENA] 2021: 14). A comparable study by The Energy and Resources Institute (TERI) about how India could achieve zero-net carbon emission by 2050 projects 100% dependence on direct electricity in domestic and commercial uses, around 90% in agriculture, 65% in transport and 30% in industry (The Energy and Resources Institute [TERI] and Shell India 2021: 16).

A major shift here will be towards the electrification of rail and road transport, which may take place through a conversion to electric vehicles,

[8] To give some indication of the scale of change required, one may note that an air conditioner used for 10 h a day for 100 days in the year, a likely level of usage in a hot climate, would lead to carbon emissions of about 2 tonnes of CO_2 which is equal to the rate of aggregate per capita CO_2 emissions in 2030 that would be consistent with a 1.5°C path.

mostly for two- and three-wheelers, buses and cars. But there are transport means like heavier freight vehicles and aviation, which remain outside the scope of electrification, at present, which may continue to require liquid fuels that could come from green hydrogen.

In a household, electricity is the obvious route for lighting and space heating and cooling. Cooking can, in principle, use solar energy directly and that may well happen. However, the real challenge for converting all cooking to be electricity based is the need for flame-based cooking in many cuisines. This need may be the most serious barrier to the conversion of all energy used for cooking to electricity, a goal that is common in zero-emission scenarios.

For productive applications where motive power is required, electricity as a source is quite obvious and so also where high levels of heat are needed for process purposes. Certain productive applications like drying could use solar or wind power more directly as we have done for ages to dry washed clothes!

Zero-net carbon emission will require a shift in energy source for electricity generation away from fossil fuels towards renewable sources like solar and wind and non-carbon-emitting sources like hydroelectric power and nuclear power. The IRENA study referred to earlier projects that 90% of electricity generation will be from renewable sources by 2050 if zero-net emissions is to be achieved by then (IRENA 2021: 14). The TERI study's projections for India are similar (TERI 2021: 15).

The world is already shifting electricity investments quite decisively towards renewables whose cost reduction has made them competitive with fossil-fuel-based electricity. In 2019, at the global level, investment in renewable energy power, amounted to US$311 billion as against US$130 billion in fossil-fuel-based power (IEA 2020: 12). India is committed to a target of 40% of power capacity being based on renewables by 2030, a goal that it may well overachieve, given the pace at which renewable electricity capacity is being installed at present.

The growing importance of solar and wind power and small-scale hydroelectric power will lead to a radical decentralisation of energy sources comparable to what we had in the pre-industrial world. However, the manner of use of this decentralised power will be substantially different. In pre-industrial times, these sources were used more or less directly for productive purposes. Now, they will generally be converted to electricity, a form of energy unknown in pre-industrial times, and used through electrical appliances and equipment for production and consumption.

In principle, this decentralisation of energy sources holds out the possibility of a move away from the centralisation of production and human settlements that has characterised the centuries since the start of the industrial revolution. Decarbonisation can increase attractiveness of smaller-scale production that can be more decentralised, particularly if the policy measures include a carbon tax. Such a carbon tax will, for example, encourage a shift from large-scale smelting of ores to produce metals towards smaller-scale recycling of scrapped and waste metals, using electricity from non-carbon-emitting sources.

However, one cannot expect the pre-industrial type of decentralisation, like the village autonomy that is supposed to have been common in India. Local self-sufficiency is not possible. Consumption standards are now such that every local area will have to import consumer goods produced elsewhere and, in turn, produce services or products that can be exported to pay for these imports. To an even greater extent, the technologies of production, including in areas like agriculture, will require inputs that will have to be imported from outside the area.

This need for interaction between local areas need not erode local autonomy. The emergence of an infotechnic era in human history holds out the possibility of allowing contacts and information exchange that will permit the economic interconnections between decentralised production and consumption centres to take place without needing the same degree of centralisation of trade and finance that we have at present.

There is one climatic factor that will be easier to handle with greater decentralisation of political power. The climate change that is unavoidable, even if countries fulfil the emission reduction pledges that they have made, will lead to greater unpredictability and more frequent climatic stresses that will vary greatly from area to area. As the COVID-19 epidemic has shown, coping with such natural disasters and crises whose impact varies greatly from area to area requires flexible response. This is easier when local authorities have the autonomy to take decisions about the best response rather than be dictated to by some central authority. But it also shows the need for central intervention (like in vaccine development) in matters that are beyond the competence of a local authority.

The principal determinant of the trend towards decentralised or centralised governance is the change in energy use to electricity generated from locally available renewable resources. An important dimension in this context is the changing nature of the electricity grid that will be required to cope with the many decentralised sources of power supply. Solar and wind power, which are the basis for this prospective decentralisation, are available when the sun is shining or when the wind is blowing. An interconnection between sources is necessary to moderate this episodic character and to provide alternative sources when the demand cannot be met by localised wind and solar power units. However, the electricity grid that will be required will be very different from the present one, which involves highly centralised control over generation and transmission. One can envisage a hierarchic grid with micro-grids connecting a small number of local settlements, regional grids, a national grid and even international ones. The balancing of demand and supply would take place at each level, and power exchange among micro-grids, regional grids and national grids would take place on the initiative of the lower level whenever required.

The net-zero emissions future that is promised by what the countries are contemplating today will mean the end of a globalised world energy economy. In a world where fossil fuels are used only on a very limited scale as compared to the present international trade in petroleum and coal will come to an end for all practical purposes. This reversal of globalisation will reinforce the case for decentralisation at the national level.

However, one cannot assume that global interlinkages will disappear, and we would be back at the gentler global web of pre-industrial times. There are certain products essentially for renewable energy, batteries and infotech products such as lithium, cobalt and rare earths in which a few countries account for the bulk of global supply. But that will not be as potent a force as petroleum oligopolies in making it difficult for countries that lack these mineral resources to follow the logic of localised power and decentralisation.

Coping with the threat of climate change will require more than just a focus on carbon mitigation. Even if the temperature change is limited to 1.5°C, significant changes will take place in ecosystems, living conditions, production parameters for agriculture and industry, and the risk of disasters, all of which will require adaptations of present modes of living, working and producing to take account of these changes. This focus on adaptation is particularly important in managing land and water use and in designing buildings in urban areas. In order to ensure this, there will have to be much closer integration in the governance arrangements for different sectors at every level from the local to the national to the international.

The most important barrier preventing the transition to a zero-carbon economy is the current orientation of the negotiating process to secure agreement between countries, without which, given the global nature of the greenhouse gas impact, local and national action has a limited impact. The negotiating process, today, is being conducted in the classical diplomatic framework of reciprocal concessions. The dynamics of the negotiations are shaped by the criticality of each country's participation as measured by the proportion of global emissions for which it is responsible. From this perspective, the global climate negotiations are taking place in a world with a 40:40:20 distribution of power. The first 40 include the two big emitters, China and the USA, whose participation is a precondition for an effective agreement. The second 40 consist of about 18 countries, each one of which accounts for 1% or more of the global carbon emissions. They matter as a group, but, individually, they do not have the de facto veto power that the two big emitters have. The balance 20 consist of about 180 countries that are at the receiving end of what the big players decide.[9] They exercise some influence through the public influence of scientific organisations and global activist groups that bring to the table a concern about the issue that looks beyond narrow national interests.

Climate change is a threat faced jointly by all countries. Their cooperation has to be organised the way a village facing a disaster would bring together all inhabitants and expect them to contribute towards the effort in proportion to their capacity. The new element in the climate change negotiations is the argument that culpability should also be a factor determining how much each country would contribute to the effort. This argument arises from the moral notion of responsibility.

The word responsibility has two meanings. In one sense, it means culpability, and, in another, it means duty. Both of these are relevant for climate justice. The scale of effort by any participant must reflect the extent to which the participants' past activities have led to the problem. Equally, since all are affected, all participants have a duty to join in the measures to resolve the problem in proportion to their capacity. On both counts, the rich nations need to do far more in containing their own emissions and in helping poorer countries with finance and technological support to address the problem.

[9] The actual distribution of emissions between these three groups in 2018 was 43:36:21. The 40:40:20 is more a symbolic representation of relative influence first presented in Desai 2012.

The strong consensus-building process on the science built up in the IPCC provides basis for unified action. As Greta Thunberg said in a 2019 address to the US Congress, 'You must unite behind the science. You must take action. You must do the impossible. Because giving up can never ever be an option' (cited in Tortell 2020).

However, climate change, like most environmental problems

> [I]nvolves an injustice between groups, regions and generations taking the form of an unrequited passing on of environmental costs to others. Redressing this requires a political process that is capable of enforcing the rights of those who lack market or political power and the obligations of those who have such power. The challenge is to express this ethical dimension in norms or legal principles that sufficiently constrain the exercise of power to protect the requirements of justice. (Desai 2010: 136–37)

If an agreement on climate justice can be added to the consensus on the science, the human community will be well set for meeting the climate change challenge.

V
Future perfect or imperfect?

The strategies that are being presented at present to reach a stage of complete decarbonisation by the middle of the century are based very much on decentralised energy systems that, in turn, can support a more decentralised production structure and with that a political system of empowered but interlinked local communities. The social consequences of this could be a strengthening of local democracy, a reduction in social barriers between workers, who will have to be highly skilled, and white-collar managers and much more.

But this idealistic vision of the future is not a forecast. It will be resisted by those who stand to lose like the fossil-fuel-producing countries and companies. An estimated third of oil reserves, half of gas reserves and more than 80% of known coal reserves should remain unused in order to meet global temperature targets under the Paris Agreement (McGlade and Elkins 2015). Even in India, the transformation to a decentralised energy system will be resisted by large public and private sector entities in the coal and power sectors. The heavy dependence on revenues from fossil fuels may well dim the ardour of the government in pursuing the decentralised energy path.

The implied transformation of the global power game will also be resisted. The vision of decentralised power sources leading to decentralised production and empowered local communities has to be reconciled with the fact that the transition of energy economy is being led by countries and companies, which are today's established powers. There are other trends implied by the transition paths to zero-net emissions that will work against a possibility of a transition to empowered local communities, based on the decentralisation of energy sources, and the emergence of new information-technology-based modes of economic and social interaction.

In the realm of energy supply, complete dependence on solar and wind power is unlikely. The episodic nature of this power will mean that there will be continued investment in large hydroelectric power projects and nuclear power plants, which will be centralised sources of supply to multiple local regions. Moreover, there is the possibility of continued use of fossil fuels, with carbon capture and storage being used to remove carbon and sequester it in. Even solar and wind power has attracted the attention of large investors, including some whose economic clout comes from their control on fossil fuels. Already, there is a move away from local production of renewable energy to large wind and solar farms owned by big companies. There are pressures, similar to the ones that led to 19th-century colonialism, from areas deficient in renewable energy resources, to set up international grids to tap solar power in areas like the Sahara and Gobi deserts (Gellings 2015).

Big companies will continue to play a major role in another area of energy. There is a continued need for liquid fuels not only for cooking, as mentioned earlier, but also for transport needs like aviation and heavy freight movement. The answer for this need that is being projected at present is the development of biofuels from biomass. This biofuel can be burnt to generate electricity or be converted to biofuels for use in cooking or in transport. It is carbon neutral as the carbon released when it is burnt or used as biofuel is carbon that was sequestered from the atmosphere during photosynthesis by the source biomass. Yet another area of large-scale energy manufacture in the zero-carbon future is hydrogen made by electrolysis of water or conversion of methane-rich biomass.

The development of biofuels and hydrogen from electrolysis of water or conversion from green methane will require an understanding on the part of the companies producing the energy source and the companies designing and producing the products to use these new energy sources, and this will generate a centralising tendency.

These new options for new energy sources for liquid fuels, which are carbon neutral, require another major change. They will require substantial areas of land for the cultivation of the biomass required for the production of biofuels. India's requirements of diesel for heavy transport vehicles will be about 200 million tonnes in 2050.[10] To produce this through biomass will require the allocation of at least 20 million ha of land, which is very large relative to the current cultivated area of 155 million ha. The land requirement can be lower if the source biomass consists of agricultural residues, cellulosic wastes and used oils. The zero emission projections also call for forestry to be used to absorb the carbon emissions in industry that are unavoidable. This too may put pressure on agricultural land, though this could be mitigated by relying mainly on reforestation of currently degraded forest lands.[11]

Technological options that bypass carbon emission mitigation are very much on the table. The most prominent one is carbon capture and storage (CCS), where carbon is captured and stored in deep underground storages from where it cannot leak out. There are many doubts about the availability of such storage, and there are now attempts at carbon capture and utilisation options, where the carbon is converted into some useful product. The cost-effectiveness of these technologies, at present, does not make them viable options to the carbon mitigation measures that have been discussed earlier. But these technologies will continue to be pursued by enterprises that stand to lose from large-scale decarbonisation and may be used even in the net-zero-emission options to absorb emissions from industries like steel and cement where full decarbonisation may not be technically feasible.

[10] Estimate based on 3.5% growth per year on 2020 consumption of diesel of 73.8 million tonnes.

[11] The Energy and Resource Institute (TERI) 2021 assumes a 30% improvement in the rate of carbon sequestration in forests and a doubling of carbon sequestration in trees planted outside forests and estimates the absorption to go up by 0.9 million tonnes of CO_2.

In some ways this dependence on the present structure of market power is similar to what happened in the early stages of the industrial revolution when the first mines were opened by landowning feudal lords who also became the first capitalists. But that changed over time as the centralisation of production and urbanisation led to the emergence of new entrepreneurs, a middle-class and working people's organisations that became the basis for substantial social and political changes. The pressures that led to the collapse of colonialism, which was an important part of early-stage capitalism, were also very similar. All this occurred in different ways and at a different pace in different parts of the world. But the pattern of social and political relationships at the national and global level today is substantially different from what they were when the industrial revolution started.

What is the change that is most likely to alter the dynamics of economic development, and, by implication, of social and political evolution? It is probably the reversal of globalisation in energy supply. With renewable energy as the primary source, all countries, including China, India and Europe, will be liberated from the power of the countries and companies that control oil and coal supplies. From a historical perspective, this is a huge change. It provides greater autonomy not just to countries but to regional and even local areas within the country. Thus, any attempt to exploit centralised ownership of power supply can be challenged by resorting to local exploitation of the sun and wind.

How would decentralised producers acquire a measure of control over the few things that will inevitably be centralised? Could it be through cooperative ownership and control over more centralised sources of inputs exercised through new forms of industrial organisation or through a political process dominated by empowered local communities? One does not know the answer at present, but one can foresee the social and political forces that may be unleashed by the liberation of energy from oligopolistic ownership and centralised control.

The world is now moving beyond the neotechnic phase of technological development into an infotechnic phase based on artificial intelligence, machine learning and big data that will transform the organisation of production and consumption. The new options for communication and transaction management, emerging from this infotech economy, will also be a factor supporting decentralisation. In fact, the pattern and spread of the infotech economy are not driven by the source of energy, and we may be moving beyond the energy–economy–society link spelt out in this article.

At present, the outcome may look uncertain. But that it will be different from the present structure of production and sociopolitical relationships seems certain, judging by the historical examples of the impact of radical changes in energy sources. The structure most consistent with the decentralisation of energy sources and the new infotech economy is decentralised production and local empowerment. There will be a period of competition and conflict between the present centralising forces and the new forces of decentralisation. But sooner or later, the historical links between sources of energy and economic structure will become manifest, particularly so in a world that manages the challenge of climate change successfully.

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