Energy and Health 1

A global perspective on energy: health effects and injustices

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The exploitation of fossil fuels is integral to modern living and has been a key element of the rapid technological, social, and cultural changes of the past 250 years. Although such changes have brought undeniable benefits, this exploitation has contributed to a burden of illness through pollution of local and regional environments, and is the dominant cause of climate change. This pattern of development is therefore unsustainable at a global level. At the same time, about 2·4 billion of the world's population, disadvantaged by lack of access to clean energy, are exposed to high levels of indoor air pollutants from the inefficient burning of biomass fuels. Even in high-income countries, many people live in fuel poverty, and throughout the world, increasingly sedentary lifestyles (to which fossil-fuel-dependent transport systems contribute) are leading to chronic disease and injuries. Energy security is also an issue of growing concern to many governments in both the developed and developing world, and a potential source of international tension and conflict. In this Series, we examine the opportunities to improve health, reduce climate effects, and promote development through realistic adjustments in the way energy and food are produced and consumed.

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This is the first in a Series of six papers about energy and health

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Energy use, health benefits, and challenges ahead

The harnessing of energy sources in the service of human needs—fuel for cooking and space heating; electricity; transport enabling access to livelihoods, social networks, and services; industrial production; and communications—enhances and protects human health in many ways. Indeed, one reason why low-income groups are generally less healthy than high-income groups is due to a lack of access to these benefits.

At the same time, energy production and use currently pose health effects both on workers and the public through industrial hazards, environmental pollution, and injury risks. In view of the scale of the energy enterprise in society, the resulting burden of disease is substantial globally, albeit of differing character in rich and poor nations. Another aspect of the present system of world energy is the lack of energy security. Poor people tend to have an insecure energy supply at the household and local levels, which can have important health effects. Additionally, energy security is a problem at the international level that affects all energy-importing countries, and could alter foreign policy in ways that damage health.

Disturbingly, however, the way that energy is generated and used is clearly moving the world into global climate change. Health consequences will mainly affect people who are already impoverished—eg, making rainfall even more precarious in parts of Africa, changing the patterns of vector-borne diseases, flooding low-lying areas such as Bangladesh, destroying glaciers in the Andes and the Himalayas on which large populations depend for irrigation, and increasing the frequency of extreme weather events such as hurricanes. These consequences are already beginning to happen, and they have serious health effects, both directly and indirectly—eg, through the mass displacement of populations.

Furthermore, in addressing the climate crisis, the measures adopted could affect health, by raising energy prices and forcing people to adopt highly polluting fuels

Key indicators related to health effects

- Proportion of people without access to electricity
- Greenhouse-gas emissions per person per year
- Proportion of households relying on unprocessed coal and biomass fuels

Specific targets are discussed in the last article in this Series.

Key messages

1. Although exploitation of fossil fuels has delivered many benefits to mankind, their use is the main cause of impending climate change, which demands urgent and widespread action to reduce CO_2 and other greenhouse-gas emissions
2. 1·6 billion people are exposed to adverse health risks because of lack of access to electricity
3. Reliance on (unclean) burning of household coal and biomass fuels is responsible for much ill health in the poorest countries
4. Over-dependence on energy contributes to unhealthy lifestyles in relation to diet and levels of physical activity
5. Insecurity of energy supplies and volatile prices can have adverse consequences on health, especially for low-income countries, because of their effects on affordability and continuity of energy supplies; internationally, the need to safeguard supplies is a potential source of tension and conflict
6. Energy use causes substantial health burdens through outdoor air pollution and injury risks
7. Current and future effects on human health associated with points (1) to (6) are serious challenges to public health worldwide
8. Formidable social, political, economic, and technological barriers obstruct a more equitable and sustainable use of energy, but the potential health benefits of overcoming these barriers are high

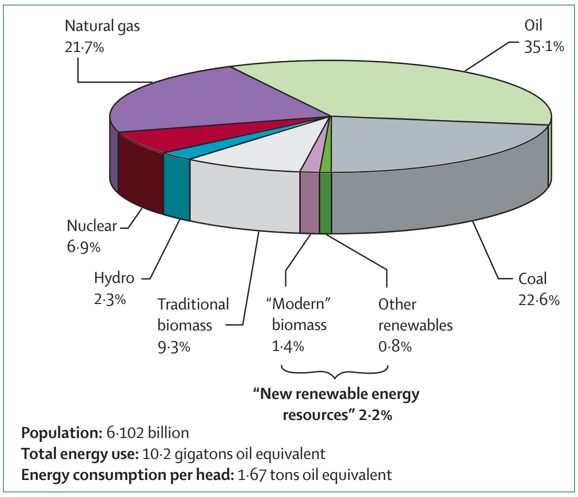

Figure 1: World energy use in 2001[1]

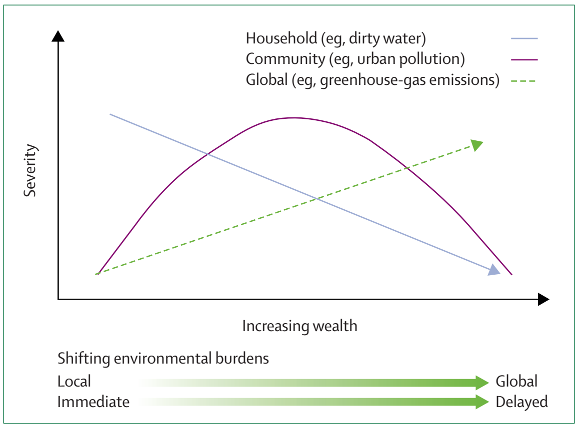

Figure 2: Environmental-risk transition framework[2]

See Online for webpanel

(or to go without), or conversely by encouraging an energy-independent lifestyle (ie, more physical activity and less pollution).

The challenge, therefore, is to redouble efforts to address the current effects of energy use but also address the climate change crisis to increase health benefits and reduce risks. In particular, the measures adopted, with policies to facilitate economic development, should aim to generate substantial health gain in individuals who are presently most in need.

Adverse health effects of current energy systems

Most, but not all, of the serious health risks associated with human use of energy are linked with the current patterns of extracting, transporting, and burning of carbonaceous fuels. Nearly 80% of human energy use is in the form of oil, gas, and coal, the fossil fuels that together have grown in use exponentially since the industrial revolution, and exert substantial health risks at various points in their fuel cycles (figure 1).[1]

However, traditional use of biomass fuels (in the form of wood and agricultural residues), which account for nearly 10% of human energy use and a much higher proportion in poor countries, also continue to impose important health and environmental effects. None of these fuels is inescapably damaging to health, but the technologies used are not clean enough to protect health, and because of the scale of use nearly all humanity is affected. In the next decades, society should find ways to reduce these effects substantially through a combination of efficient use of energy to obtain services needed for economic and social development, clean technologies for use of these fuels, and switching to clean energy sources. Although we recognise the potential health effects of other energy sources such as hydro and nuclear power, we focus on carbonaceous (fossil plus biomass) fuels, which account for some 90% of human energy consumption.

The health effects of fuel combustion occur at several levels (from household, workplace, community, regional, to global),[2] which mainly result from the airborne products of complete and incomplete combustion. The form of environmental risks and exposures is related to wealth, a finding that has been described with a transition framework.[3] In this framework, household risks fall, community-health risks rise and then fall, and imposition of global risks rise with current patterns of development (figure 2).[2] However, for experienced risks, global risks follow the same pattern as household risks because they mainly affect poor individuals.[4]

Although not fully addressed in this article, the extraction of fuels—such as oil drilling, coal mining, and wood harvesting—create substantial environmental effects globally. The direct public-health effects from these activities are relatively low compared with those due to other parts of the fuel cycles. We also do not cover occupational-health and safety issues in the energy system, which are by far the most serious in the extraction phases of fuel cycles. Some of the highest risk professions anywhere are in the energy industry, for example offshore oil drilling, as are some of the most damaging industries overall, especially coal mining. The international Comparative Risk Assessment project of WHO (WHO CRA) estimated that the burden of disease from occupational hazards is responsible for 1·6% of the total burden of disease globally, a substantial proportion of which is attributable to energy systems.[5]

	Global estimate	Asian estimate (% of global)*
Unsafe water and sanitation	1 730 000	730 000 (42%)
Urban outdoor air pollution	799 000	487 000 (61%)
Indoor air pollution from household solid fuels	1 619 000	1 025 000 (63%)
Lead	234 000	88 000 (38%)

*Includes south and southeast Asia and western Pacific islands region.

Table 1: Excess premature deaths per year from selected environmental factors worldwide and in Asia[8]

Fossil-fuel cycles are responsible for most pollutant emissions to the environment, but the source of greatest human pollution exposure is probably biomass fuels.[6] More than 2·4 billion people continue to rely on biomass (wood, charcoal, animal dung, crop wastes) and coal for most household energy needs. These fuels are often burned inefficiently in households using rudimentary technology that leads to levels of indoor and local air pollution many times higher than international standards of ambient air quality. Exposure to such pollution, particularly of women and children, seems to account for a substantial proportion of the global burden of disease in developing countries (table 1).[7,8]

WHO CRA estimated that indoor smoke from solid fuels (biomass and coal) causes about 36% of DALYs (disability-adjusted life years) lost from lower respiratory infections, 22% from chronic obstructive pulmonary disease, and about 1·5% from lung cancer, which equals about 1·6 million premature deaths every year.[9] Indoor air pollution was also associated with tuberculosis, low birthweight, cancer, cataracts, and possibly asthma and heart disease. About a third of the attributable burden of disease worldwide due to indoor air pollution occurs in Africa and 37% in southeast Asia. The ultimate cause of this pollution is poverty, because these populations cannot afford the clean fuels and vented appliances needed to keep their households clean.

Much ill health is also produced by community and regional pollution generated mainly by the fuel cycles for fossil fuels (extraction, processing, distribution, combustion). The effects of fine particles and photochemical smog, which mainly derive from energy activities, in urban air are of particular concern.[10] Although adverse trends in airborne pollution have been reversed or at least slowed in high-income countries in the past 50 years, cities in many low-income and middle-income countries have shown striking deterioration, where rapid industrial growth has occurred often with weak environmental controls. WHO CRA estimated that every year, fine-particle air pollution ($PM_{2.5}$) in urban areas causes 0·8 million premature deaths (1·2% of the global total) and 6·4 million years (0·5%) of life lost, mostly in Asia from cardiovascular disease, lung cancer, and acute respiratory infections (table 1).[8–10] 16 of the 20 cities with the most polluted air are in China.[11] Much of the effect of lead exposure shown in table 1 is due to the combustion of leaded petrol in low-income countries.

The global effect of greatest future concern is climate change. Atmospheric concentrations of the key greenhouse gases—those trace constituents of the atmosphere that adsorb infrared radiation and retain heat through the greenhouse effect—have risen substantially in the industrial era (figure 3).[12]

The rise in concentration of carbon dioxide (CO_2), quantitatively the most important anthropogenic greenhouse gas, has risen largely because of fossil-fuel

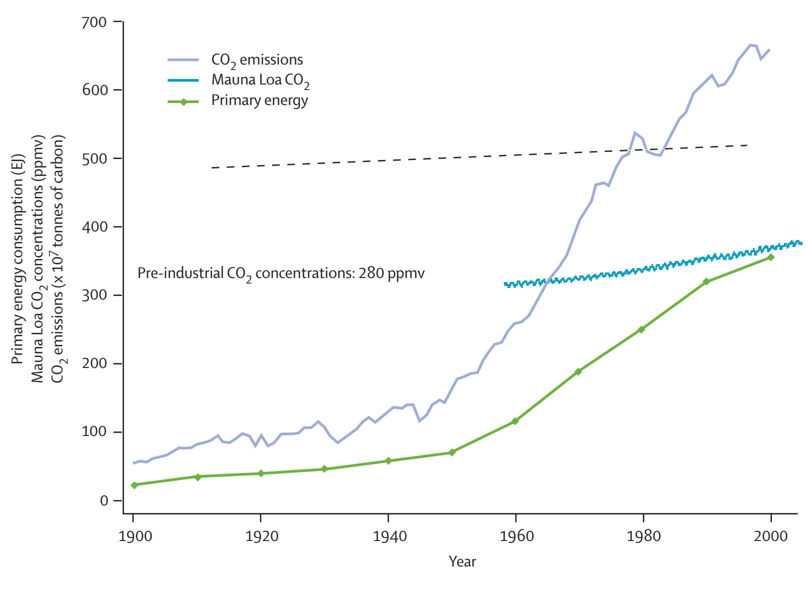

Figure 3: **Trends during the 20th century in energy use, carbon dioxide (CO_2) emissions, and atmospheric CO_2 concentrations[12]**
Data measured at the Mauna Loa observatory, Hawaii, USA. EJ=exajoules (10^{18} joules).

Panel 1: Climate change—summary of science and economic consequences

The fourth assessment report of the UN's Intergovernmental Panel on Climate Change (IPCC) concludes that available evidence now provides very high confidence that the net effect of human activity of the past 250 years has been to produce climatic warming, and that "continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed in the 20th century".[15] Central estimates of temperature change under emissions scenarios (developed for the Special Report on Emissions Scenarios for the IPCC Third Assessment Report, webpanel) suggest increases in mean surface air temperatures by 2090–99 (compared with 1980–99), ranging from 1·8°C (probable range 1·1–2·9) to 4·0°C (2·4–6·4, figure 4).[15] If realised, such changes would represent a rate and magnitude of climatic warming not experienced since the end of the Younger Dryas 11 500 years ago, the last major climate event of the northern hemisphere after the last glacial maximum.[16,17] It would also be the most important climatic change at any point since the inception of agriculture and major human settlements. Consequences for ecological systems and human populations are only partly predictable and could be profound, with potential environmental,[18] economic,[19] social, and health effects,[20,21] such as adverse outcomes on water resources, vector-borne diseases, food production, and coastal flooding because of sea level rise (figure 2).[2,18]

Effects of the IPCC scenarios could even be conservative if feedback mechanisms amplify the release of CO_2 from ecosystems as temperatures rise and important ecological tipping points are reached. Possible risks include: potential weakening or alteration of the thermohaline or deep-ocean currents; release of methane (a powerful but comparatively short-lived greenhouse gas) from enormous ocean hydrate stores and from thawing of permafrost; and weakening or reversal of natural carbon sinks.[15]

The total economic effect of climate change is potentially large. The UK Stern Review,[19] for example, concluded that without action, the economic costs and risks of climate change would be "equivalent to losing at least 5% of global GDP each year...[and that if] a wider range of risks and impacts is taken into account, the damage could rise to 20% of GDP each year".

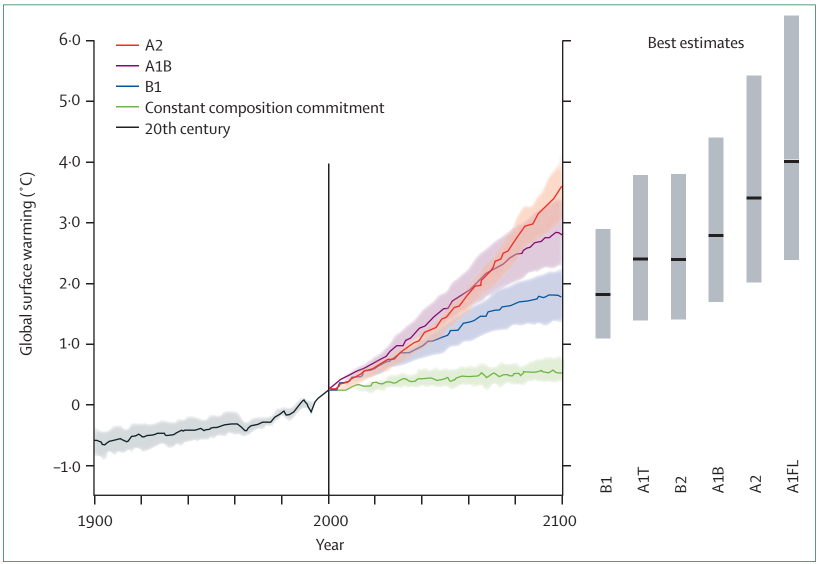

Figure 4: **Projected change in global mean temperatures in selected IPCC scenarios**[18]
Lines beyond 2000 are multimodel global averages of surface warming, relative to 1980–99, for SRES scenarios A2, A1B, and B1 (webpanel), shown as continuations of the 20th century simulations. Shading=SD of individual model yearly averages. Year 2000 constant concentrations are experimental values whereby greenhouse-gas concentrations were held constant at year 2000 values. Best estimates (black lines) and probable ranges (grey bars) assessed for SRES marker scenarios are shown on the right.

	Rate of sea level rise (mm per year)	
	1961–2003	1993–2003
Thermal expansion	0·42 (0·12)	1·60 (0·50)
Glaciers and ice caps	0·50 (0·18)	0·77 (0·22)
Greenland ice sheet	0·05 (0·12)	0·21 (0·07)
Antarctic ice sheet	0·14 (0·41)	0·21 (0·35)
Sum of individual climate contributions to sea level rise	1·10 (0·50)	2·80 (0·70)
Observed total sea level rise*	1·80 (0·12)	3·10 (0·70)
Difference (observed minus sum of estimated climate conributions)	0·70 (0·70)	0·30 (1·00)

*Data before 1993 are from tide gauges and after 1993 are from satellite alitimetry.

Table 2: Sources of sea level rise

combustion, whereas methane and nitrous oxide (N_2O) are rising mainly as the result of agriculture and land use change. Concentrations of CO_2 are now at their highest for 650 000 years, and possibly 30 million years, and are continuing to rise by about two parts per million by volume per year (figure 3);[12–14] numbers are projected to rise substantially over the course of this century (panel 1, figure 4, table 2).[15–21]

The consequences of climate change for ecological systems and human populations are only partly predictable and could be profound, with potential environmental,[18] economic,[19] social, and health effects.[20,21] Among them are adverse effects on water resources, vector-borne diseases, food production, and coastal flooding consequent to sea level rise (figure 4).[18] Panel 2[20] summarises the types of health effects expected.

WHO CRA estimated that the total effect of climate change had reached about 0·4% of the global burden of disease by 2000,[22] which was broken down as: 2·4% of the global burden of diarrhoea; 2% of malaria (6% in some regions); 17% of protein-energy malnutrition; and 7% of dengue fever in some rich countries, which amounts to 150 000 deaths, 99% in poor countries (46% in south Asia). Most of the burden attributable to climate change (88%) affected children under age 5 years.

Although the effect by 2000 was not large by comparison with other risk factors, the degree of human-induced climate change by then was also small by comparison with what is expected. The worry about climate change is not about what has already occurred, but what is likely to occur. In risk assessment terms, the avoidable risk (amount of avoidable ill health if action is taken soon) is much larger than the attributable risk (the current amount that is due to past exposures).

Beyond pollution

All countries, rich and poor, have problems created in poorer parts of society by the lack of affordability of fuel in view of rising energy prices, poor thermal insulation of the home, and inefficient heating and cooking appliances. This so-called fuel poverty in developed countries has been exacerbated by the recent sudden rise in energy prices, as has also occurred in developing countries.[23,24]

Beyond these direct effects are the wider influences of energy use on modern lifestyles, which encourage sedentary living,[25] over-consumption of high-energy foods (produced and distributed by energy-intensive means), and exposure to injury and other environmental risks.

What can be done?

Society does not face a failing energy supply at a global level in the near future, but prices will probably rise. Volatility in markets will occur from time to time consequent on international tensions and temporary imbalances of supply and demand. Strategic planning by governments is therefore needed to ensure continuity of energy provision. But globally, major energy resources seem to be more than adequate to meet even the highest projected demands. Fossil fuels could sustain continued use as a major part of the global economy far beyond this century because, as commodity prices rise and technology improves, unconventional forms of oil and gas will become more economically viable, including those derived from the far more abundant coal resources (table 3).[26,27] These unconventional sources could include coal-bed methane, tight formation gas (gas trapped in low permeability rocks), and geopressurised gas and gas hydrates, as well as oil sands, ultraheavy oil, and oil shale.[27,28] The potential for enormous impact on environmental and human health effect from these

Panel 2: Climate change and health

Climate change has been a constant feature throughout Earth's history. Over different timescales, these changes have been driven by various natural processes—eg, plate tectonics; volcanic eruptions; changes in ocean-atmosphere circulation; variations in Earth's orbit, and Earth's obliquity and precession of spin; and variations in solar output. Life itself has a crucial, through its acceleration of rock weathering and the capture of carbon in plant biomass and marine sediments that are central to the long-term carbon cycle.

At times Earth has been much warmer and colder than now, and fluctuations in global temperatures, sometimes abrupt, are certain to continue in future. However, over the past 10 000 years (known to geologists as the Holocene), the climate has been unusually stable, which could have been important in the development of agriculture and flourishing of human civilization. It is largely because the human species has been so successful that the prospect now of rapid climate change induced by anthropogenic emissions of greenhouse gases is so alarming. Scientists cannot be precise about the course of climate change, but the scenarios of possible temperature change over this century suggest rapid and large increases in global mean temperatures. The range of scenario estimates in the most recent IPCC report suggest several °C warming compared with about a 5°C increase in temperatures since the depth of the last glacial maximum around 18 000 years ago. Such changes are of concern for several reasons: they are likely to disrupt natural ecosystems on which society depends, and they will have direct and indirect effects on health:[21]

- Health effects of temperature extremes, specifically of heat waves. In the UK, for example, under credible climate change scenarios, the type of heatwave seen in Paris in 2003 is likely to become a once-in-2-years event by around the middle of this century. Although there could be some compensation of heat deaths with lower burdens of cold-related mortality in some temperate countries, the net effect is likely to be detrimental, especially in low-income countries that have restricted capacity to adapt
- Increased frequency of extreme weather events, including severe storms, floods, and droughts are again likely
- Sea level rise that will threaten many low-lying areas with inundation
- Increased occurrence of food-borne and water-borne diseases
- Potential for climate change to alter the distribution of vector-borne disease
- Interactions with air pollution and effects on the seasonality and duration of aeroallergens
- Effects on water resources and agricultural productivity—with potential for socioeconomic dislocation and mass migration of environmental refugees

The most predictable effects on health might not be the most important, with much uncertainty about the potential effects of rapid climate change on ecosystems that could already be under pressure from human activity. Regional effects are particularly difficult to predict. Local changes in precipitation and temperature could make some forms of habitation unsustainable for human beings and other species, and the effects could follow a non-linear trajectory. Never before in recent human history—and certainly not when human beings have been using Earth's resources with such intensity as they are currently—has there been the prospect of such rapid global climate change. The consequences are thus unclear and potentially dangerous.

	Production in year 2000 (EJ)	Total reserves* (EJ)	Total resource† (EJ)	Years of reserve at year 2000‡ (EJ)	Years of resource at year 2000* (EJ)	Years of resource with assumption of growing rate of production§ (EJ)
Coal	100	21 000	200 000	210	2000	<400
Oil	163	11 000	32 000	67	196	<150
Conventional		6000	12 000			
Unconventional¶		5000	20 000			
Natural gas	95	15 000	49 500	158	521	<300
Conventional		5500	16 500			
Unconventional||		9500	33 000			
Total	358	47 000	281 500	131	786	..

Table adapted from reference 27. EJ=exajoules (10^{18} joules). *Subset of resource that is available for current exploitation. †Estimated natural occurrence of particular form of energy. ‡At year 2000 rate of production. §Coal growing to 650 EJ in 2100 (1·9% yearly rate) and at 0·5% thereafter; oil growing from 2000 at 0·5% yearly rate; and natural gas growing to typical business level of 160 EJ in 2100 and at 0·5% yearly rate thereafter. ¶Includes oil sands, ultraheavy oil, and oil shale. ||Includes coalbed methane and tight formation gas (gas trapped in low-permeability rocks) but not geopressurised gas and gas hydrates.

Table 3: Estimates of fossil-fuel resources

technologies, however, is high, particularly if they are used in ways that release their carbon as greenhouse gases.

Energy security is also a concern as a result of being dependent on few countries for particular sources of energy (eg, oil and gas supplies), which could therefore be vulnerable to political instability. Actions taken to reduce or take advantage of this insecurity through wars, terrorist acts, and civil strife could have important effects on health in some regions, but are not part of our analysis here.

Renewable sources of energy are theoretically attractive; for example, solar and wind energy offer the prospect of satisfying energy demands in some locations without contributing appreciably to air pollution or climate change. Less than 2% of the USA's land area could provide all the country's primary energy requirements from solar sources at current levels of consumption but at currently unacceptable costs.[29]

Every potential energy future is made safer from a health standpoint by placing emphasis on energy efficiency as well as the development of cleaner, more renewable sources. Society generally uses energy services far less efficiently than is technically feasible or economically beneficial if environmental, health, and other external factors are considered. In essentially every sector—households, transport, industry, power—major improvements worldwide are possible in reducing energy use per unit of societal benefit.

Public-health implications of policy

Human ability to harness inanimate energy sources has been fundamental to advance prosperity. Historically it has freed men and women from toil and permitted unprecedented social development and growth in productivity through the division of labour and mechanisation. The relation between prosperity and health is complex, but international comparisons (figure 5)[30,31] and trends over time do broadly indicate the benefits achieved through energy services, at least up to a certain level of energy consumption.

By most objective variables (life expectancy, anthropometry, literacy, fulfilment of human potential), the profound technological, social, and cultural development of the 250 years since the beginning of the industrial revolution has been a major benefit to health and wellbeing worldwide. Before 1800, life expectancy exceeding 40 years was rare. Since 1800, however, global life expectancy has roughly doubled to 67 years, and average body size has increased by 50%.[19,23] The factors that have been crucial for those health gains are debated, but the exploitation of fossil fuels, which are convenient and inexpensive forms of fuel, has at least accelerated the rate of technological and social advances in the developed parts of the world.

We cannot predict the health benefits of future prosperity increases in rich populations, but much benefit is clearly to be gained from improvements in income among the world's poor populations. The link between energy use and the economy is neither simple nor fixed, but continuing technological and economic advancement is important for health. Energy poverty is also important in overall poverty in nearly all poor populations. Examination of past trends has shown that, largely because of the deployment of improved technology, rich populations tend to have reduced exposure to energy-related pollution, and over time the dissemination of technology means that pollution for a specific level of wealth and industrial production is also reduced.[25] However, the intensity of energy use is also increased, which, under current technology, still equates to intensity of greenhouse emissions. Heavy consumers are the principal contributors to climate change. In view of this background, three major goals in relation to energy use have been proposed that could have substantial public-health benefits through direct and indirect mechanisms.

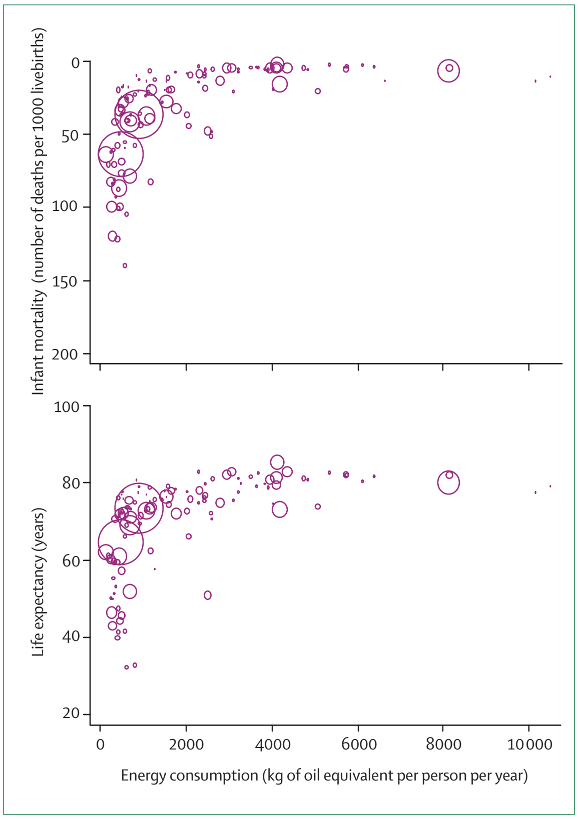

Figure 5: **Scatter plot of (A) infant mortality and (B) life expectancy *vs* consumption per person**

Drawn from data compiled in references 30 and 31. Symbol sizes are proportional to country populations. Kg of oil equivalent=energy equivalent to that produced by combustion of kg of oil.

(1) Improvement of access to affordable, clean energy for poor countries

The large differences between rich and poor countries in access to clean energy show a fundamental injustice in energy. The richest populations use up to 20 times more energy per person than those from the poorest countries (figure 5),[30,31] and enjoy many benefits but few adverse effects. The 2·4 billion people who continue to depend on biomass fuels suffer adverse health effects, not only from indoor air pollution, but also because of the opportunity cost of time spent collecting fuel, and the lack of access to all services—in education, health care, and household resources—that modern energy provides. Very low-income households (especially women and girls in them) spend about 100 h/year more collecting biomass fuels than rich households in Pakistan,[32] often walking large distances and increasing their exposure to dangers of being outside their own communities (eg, violent assault). Time spent on collection of fuel also means less time is available for agricultural or other domestic work. Expenditure on fuel as a proportion of total household expenditure could be four or five times larger in poorer socioeconomic groups than in richer groups in the same country. Although difficult to quantify, such stressors clearly affect health.

In some areas, use of biomass fuel contributes to deforestation or land degradation, but places with renewable harvesting can be a long-term, if low-quality, source of energy for local populations. Unfortunately, however, even when harvested renewably, and thus ostensibly carbon-neutral with regard to yearly emissions, traditional biomass combustion technologies, such as simple household stoves, operate at very low combustion efficiencies.[9] Thus, a large fraction of fuel carbon is diverted to products of incomplete combustion, such as carbon monoxide, methane, volatile organics, and black carbon, all of which are substantially stronger greenhouse pollutants than CO_2. Thus, surprisingly, simple biomass stoves using renewable fuel could also contribute to global warming. Health-damaging pollutants from biomass are also mainly caused by this poor combustion. Even though not large globally, compared with the climate effect of fossil fuels, improvement of the combustion of such devices allows for cost-effective benefits in both climate and health protection for some of the most disadvantaged of the world's populations.

Lack of access to modern energy affects every aspect of life, including transport, agriculture, and health care. Thus, disadvantaged groups tend to walk or cycle whereas affluent populations use energy-consuming vehicles such as cars. Farming in high-income settings is far more energy-intensive than in low-income countries with consequent differences in crop yield. Health-care facilities in poor countries often have an unreliable electricity supply, causing difficulties in the running of laboratories, use of diagnostic technology (eg, ultrasonography and radiography), undertaking of surgical procedures at night, sterilisation of equipment, and maintenance of the cold-chain for the distribution of vaccinations.

Access to clean energy would also bring benefits other than reduction in indoor air pollution and environmental degradation, which are difficult to quantify but still important, such as increased light for security, social interaction and study, reduced burns from household fires, and the provision of energy to pump and purify water. Economic analyses of the implications of clean-energy technologies therefore need to account for the range of potential benefits that encompass health and nutrition, the environment, and poverty reduction.

Inequalities of energy use in other sectors also greatly affect health, such as high injury rates, low crop yields, and poor-quality health care. During the 20th century, the world population grew about four-fold, but CO_2 emissions from fossil-fuel combustion have increased 12-fold. With a growing world population of perhaps 9 billion by 2050, current patterns of fossil-fuel-dependent consumption of North America or even Europe would have catastrophic consequences if they were enjoyed by the entire world population over extended periods; four planet Earths have been estimated to be needed to sustain life if all the world's population had consumption patterns equal to those in North America.[33]

(2) Reduced exposure to outdoor pollution

Globally, the health effects of outdoor air pollution are among the largest of all environmental hazards (table 1).[8] Published work underpinning our understanding of those effects is extensive.[8,34] Increasingly, outdoor pollution is becoming an international problem, as transboundary transport of air masses carry pollutants across continents and oceans.[34] Only part of the background particle concentrations in most cities come from local sources. Although regional emissions of pollutants and precursor species in high-income countries could in future be controlled with stricter air quality standards, the global background will probably continue to increase because of population growth and rapid industralisation in developing nations. There is also potential interaction with climate change through, for example, the influence of meteorology on the formation and dispersion of secondary pollutants such as ozone.[35]

Improved technology has much to contribute to the efficiency and cleanliness of combustion processes. However, the highest exposures tend to occur in low-income and middle-income countries, where industrial development is driving rapid growth in emissions without the most advanced technology and legislation for emissions control. Even in high-income countries, pollution in most urban environments is still undesirably high. Substantial reduction in those levels could require a switch away from fossil fuels towards cleaner, perhaps even so-called zero-emissions, primary and secondary fuels. At present, this goal seems distant, but the potential health dividends are substantial.

(3) Reduced greenhouse-gas emissions

The current status of climate change projections and the health implications have been described (panels 1, and 2).[15–21] The world energy system, including transport, mainly through fossil fuels, is responsible for about two-thirds of greenhouse-gas emissions. There are three important ways that human emissions of greenhouse gases, the resulting effect on climate and human-health interactions, should engage the health community:[36]

First, climate change is expected to have important, although still somewhat uncertain, effects on health through heat stress, changes in the intensity and

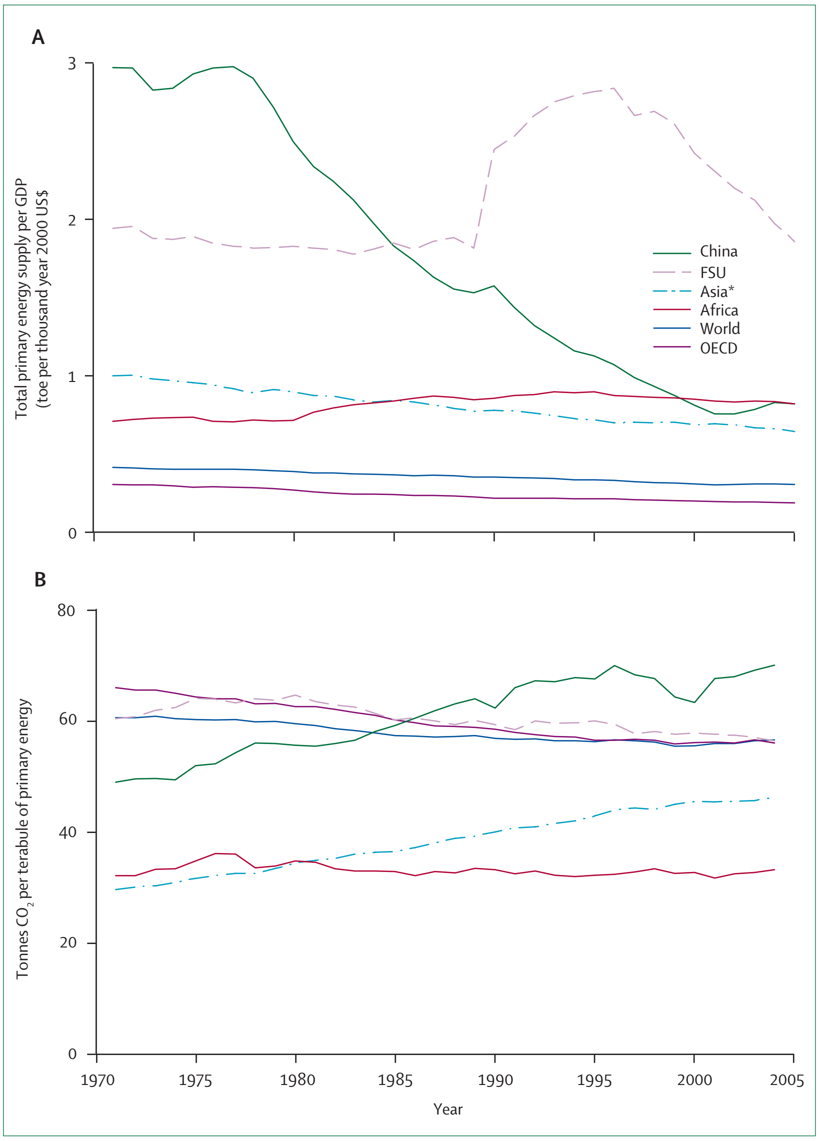

Figure 6: **Trends for selected countries and regional groups in (A) energy intensity and (B) carbon intensity of the energy system**

Based on data from reference 42. toe=tonnes of oil equivalent. OECD=countries of the Organisation for Economic Co-operation and Development. FSU=former Soviet Union. *Apart from China. Note large rate of improvement in energy intensity in China in recent decades, and possible flattening or reversal in world trend of decarbonisation.

frequency of extreme weather events, shifts in disease vectors such as mosquitoes, increased stress on vulnerable coastal populations through sea level rise, enhanced malnutrition through loss of agricultural production, and other avenues.[20,21] Prevention or mitigation of climate change is therefore essential from a health viewpoint.

Second, if properly designed, changes in energy systems can achieve both short-term and long-term co-benefits of health protection through simultaneous reduction of greenhouse and health-damaging pollutants, and by promoting physical activity in currently inactive populations. However, reduced fossil-fuel dependence and raised fuel prices could force some people to resort to the use of highly polluting fuels to replace unaffordable mainstream sources.[37] In addition, a switch of agricultural land use to biofuels will raise food prices, with serious implications for the health of low-income consumers.

Third, the climate change already committed by past and present energy patterns has implications for altering priorities, training needs, and resource requirements for both public-health researchers and practitioners—eg, anticipating and blunting the changing pattern of diseases—that are already expected. An important part of this effort will be to put even more effort into the reduction of vulnerability in poor populations.[38]

Mitigation and the *IPA*(*E*)*T* equation

In the 1970s, the *IPAT* equation was suggested as a simple way to discuss the first-order issues related to environmental effects such as pollution or resource depletion due to human activities:[39]

$I = P \times A \times T$ (where I=impact, P=population size, A=affluence [per-person income], and T=technology [effect per unit income]).

This simple formulation has been criticised because of its lack of interaction terms.[40] Nevertheless, simple models are often useful as starting points and often sufficiently accurate for many purposes even if not including non-linear effects.[41]

For greenhouse gases and energy discussions, a more useful variant is the *IPA*(*E*)*T* equation:[2]

$I = P \times A \times E \times T$ (where I=total greenhouse-gas emissions, E=energy [per unit of affluence], and T=technology for energy [carbon/greenhouse-gas emissions per unit energy]).

This equation allows the energy needed per unit affluence to be calculated separately from greenhouse-gas emissions per unit energy. For example, world figures in 2000 were calculated as: $6 \cdot 1 \times 10^9$ people×US$7400/person×0·01 gigajoule (GJ)/$×14 kg carbon/GJ. This calculation equated to $6 \cdot 4 \times 10^{12}$ kg of carbon, or 6·4 billion tonnes of carbon as CO_2 (there is 1 tonne of carbon in 3·67 tonnes of CO_2).

With *IPA*(*E*)*T*, most discussions to reduce greenhouse-gas emissions (*I* in the equation) focus on combinations of efforts to reduce *E* (energy) by improving energy efficiency for specific affluence-generating activities and *T* (technology) by capturing carbon from fossil-fuel combustion and switching to low-emitting or non-greenhouse-gas-emitting sources, such as renewable sources. Indeed, the world is making slow progress with year-on-year reductions in energy intensity (energy per US$GDP) and carbon intensity (carbon emissions per J, figure 6).[42]

To overcome the concomitant increases in *P* (population) and *A* (affluence), however, the rate of these reductions will have to increase. Also, without major pushes to develop alternative energy supplies and carbon capture, carbon intensity might actually start to increase as coal becomes increasingly important for power and, perhaps, even as a feedstock to replace petroleum fuels.

As shown in the $IPA(E)T$ equation, population policy can also be important because reduction or even reversal of population growth will also reduce emissions over time. Additionally, although politically difficult to even discuss, reduction or reversal of growth in average affluence (A) will also reduce greenhouse-gas emissions (I). From a health standpoint, the negative effects of reduction in income growth in the poorest populations will probably overwhelm any advantage in terms of lowered greenhouse-gas emissions. In rich populations, however, reduced income growth per head (as usually measured) might promote health—eg, by encouraging healthy diets and increased physical activity.

Since the bulk of greenhouse-gas emissions come from rich populations, therefore, options to restructure the economy into less energy-intensive forms as greenhouse-gas control measures should be considered, with potentially substantial benefits. In terms of the equation, this aim amounts to working simultaneously on affluence per head and energy per unit affluence to both increase the energy efficiency of current activities and to shift to less energy-intensive activities. Indeed, the revolution in information technology and the freedom it gives to interact over space with little energy use is the archetypal change in this regard.

Finally, several health effects apart from those mediated through climate change are due to the energy system. Thus, reduced dirty combustion of fuels also has a range of other environmental health benefits.

Institutional responses

Meeting the climate change challenge should be based on principles of shared responsibility. These principles are that (1) global CO_2 emissions should be reduced to an internationally agreed level (contraction); and (2) global governance should be based on justice and fairness with convergence towards equitable shares of per person carbon emission. The most direct statement of this goal was enshrined in the principle of contraction and convergence, as proposed by the Global Commons Institute.[43] Variations on this aim could allow for differences in national circumstances, income, the feasibility of reaching specified targets, and growth needs.[19] But enormous inequality exists in consumption of energy resources between rich and poor countries (figure 7),[44] and under any reasonable version of shared responsibility, the largest absolute reductions in energy use will have to fall on the most developed countries.

To contain temperature increases to a tolerable level will require substantial reduction. The worst effects of climate change will require stabilisation of greenhouse gases at 450–550 ppm CO_2-equivalent (a combined and weighted overall index of warming contributions of the various greenhouse gases) from a level currently at the bottom of this range. Emission reductions would have to be far beyond those of the Kyoto protocol, by a global average of at least 25% by 2050 (60–80% reduction for the highest-income countries) and ultimately by more than 80% worldwide. Although a major challenge, yearly costs to achieve such reduction are probably modest (probably around the same size as the world military budget of about 2·5% of global GDP), and "low in comparison to the risks of inaction".[19]

The imperatives and opportunities of responding to climate change are increasingly recognised by national governments and international agencies such as WHO, which has led debate on the links between climate change and health and the needed policy responses.[46] It is gratifying also that the World Bank has publicly recognised that "increased variability and volatility in weather patterns are expected to have a significant and disproportionate impact in the developing world, where the world's poor remain most susceptible to the potential damages and uncertainties inherent in a changing climate".[47] As a result, the World Bank is incorporating climate-change considerations into its development operations and

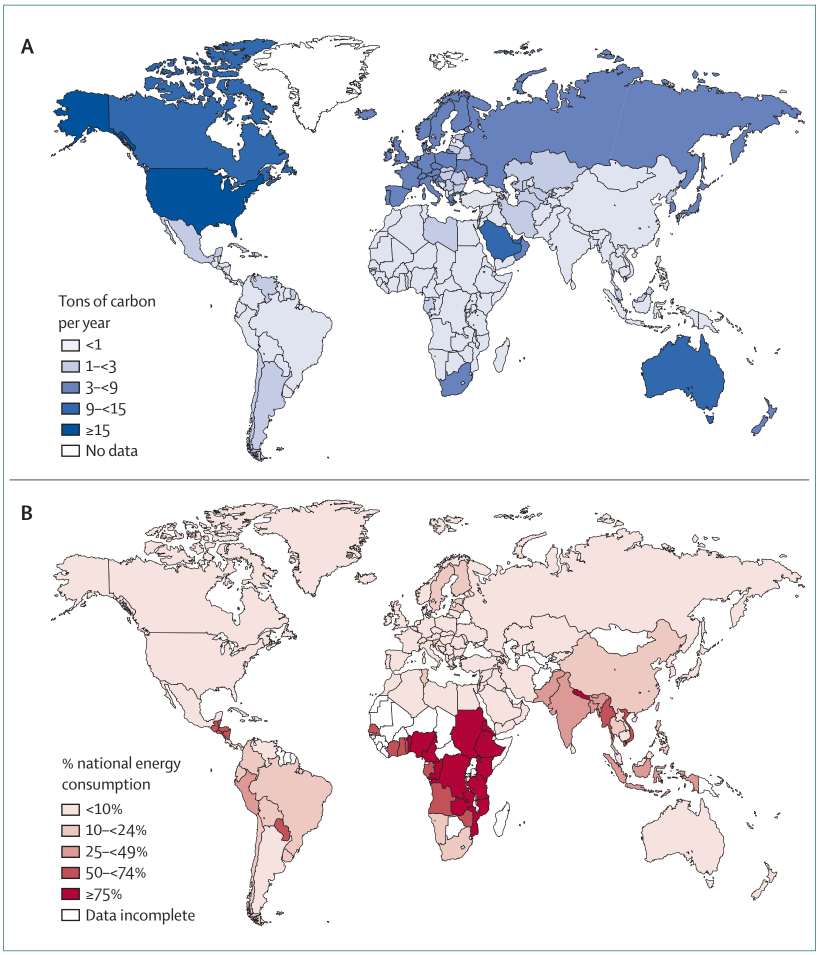

Figure 7: **Geographical comparison of (A) carbon emissions per head and (B) biomass consumption**
Adapted from reference 44. For consumption by households see references 9 and 45.

"seeking sectoral efficiency and clean energy alternatives". Similarly, despite not having a specific mandate on climate change, the Food and Agriculture Organization (FAO) has established an Interdepartmental Working Group on Climate Change (IDWG-CC) for "mainstreaming and coordinating climate change related work among all FAO's technical departments [with the] main objectives to develop normative and methodological approaches integrating forestry, agricultural, cultural, and economic issues in the context of climate change; and to open new channels of financing and other support measures for mitigating and adapting to climate change...".[48] Although such initiatives are welcomed, they are far from sufficient in view of the challenges the world now faces. The required speed and scale of change demand not only that energy issues become fundamental to policy and practice across many sectors, but also that bold strategic goals are set and vigorously pursued with strong, visionary leadership at the highest level within local, national, and international agencies.

Energy security

Energy security encompasses notions of protection of future energy resources, continuity of supply, the level and predictability of energy costs, and reduction of the role of energy as motive in international conflict.

Energy resources are very unevenly distributed in geographical terms, and will probably always remain so.[49] This situation is certainly true of economic oil reserves, and the concentration of resources in the hands of a comparatively small proportion of nations places others in positions of dependence and potential vulnerability. Although the mutual interest of suppliers and consumers seeks to ensure stability of trade, periods of volatility and political tension inevitably raise concerns to safeguard vital energy supplies. For example, France has a well-developed nuclear industry, with 59 reactors, mainly because of its lack of sizeable deposits of fossil fuels, and the realisation by previous French governments of just how vulnerable the country was to interrupted oil imports after the Suez crisis of 1956 and the global oil embargo in 1973.[50] Oil production in countries not in the Organisation of Petroleum Exporting Countries (OPEC) is set to peak in the near future and thus will become concentrated in an increasingly small number of countries; Europe's gas production has already peaked with consequent increasing import dependence.[51]

Those who study the causes of war rarely identify conflict over energy resources as an over-riding motive. In most cases, military objectives to secure oil fields or other energy resources have been part of wider campaigns, motivated by complex political purposes, rather than the primary motive. Even the Gulf War, which outwardly seemed to have clear links to considerations of protecting oil resources, had more complex reasons for coalition countries to wish to contain Iraqi expansion and remove a perceived regional source of terrorist threat. However, humanitarian action might have been taken earlier in Darfur were it not for the status of Sudan as an oil exporter.

But history might not be a good gauge of future patterns. The future is uncertain in the context of dwindling availability of the most economic resources. Investment over the next decade will set up the energy technology that will prevail for perhaps the next half century. If prudent long-term planning and development of alternative energy sources is done by the main consumers, a non-turbulent transition to a new order of energy systems and trading could be envisioned. However, as resources become increasingly scarce and in the hands of a few providers, volatility and political unrest could provoke international disputes and perhaps war.

Additionally, it should be remembered that the capacity for destruction using high-energy explosives and the mobilisation of large armies has been made possible—directly or indirectly—by command of energy systems. With nuclear energy, the link to weapons production is fairly direct. Indeed, military use (with the atomic bomb in 1945, and the hydrogen bomb in 1952) preceded controlled nuclear energy for civilian application; with fusion, civilian application remains unachieved. The stockpiling of the nuclear arsenal by the USA and Soviet Union between 1950 and 1990 accounted for at least 5% of all energy use by those countries over that period, and used up to 50% in some years during the 1960s.[49,52] As we will discuss later in the Series, the connection between weapons development, potential terrorist threats, and civilian energy systems could have increasing bearing on choices in future energy policy.

Perhaps of more immediate concern to people both in developed countries, and more particularly, developing countries are considerations of energy price. Despite recent volatility relating to supply concerns and an apparent problem with refining capacity that has had an adverse effect on prices of oil and other fossil fuels, in real terms current crude-oil prices are below the peaks seen at various points over recent years. However, recent increases in fuel price clearly have had adverse effect on poor populations in both developed and developing countries. In the UK, for example, recent progress to reduce fuel poverty (the proportion of households that have to spend more than 10% of their income on fuel) is being reversed by the recent trends of increasing fuel prices.[53] By 2009, some projections suggest that as many as 2 million households could be defined as fuel-poor. This problem is even more acute in low-income countries, where price rises make energy unaffordable for increasing numbers of households, which therefore are forced to rely on informal energy sources, to the detriment of their health. Equitable access to future energy resources will be of crucial importance for public health.

	Link to energy and health
Goal 1: Eradicate extreme poverty and hunger	
• Reduce proportion of people living on <US$1 per day by half • Reduce proportion of people who suffer from hunger by half	• Personal development and economic productivity linked to access to electricity or reliable clean energy • Global burden of hunger as well as economic growth could be worsened by effects of climate change—hence importance of CO_2 reduction targets • Household fuel is important in household expenditures, with consequent advantage to efficiency: Reliable and efficient energy delivery can improve enterprise development Reliable fuel access increases range of staple foods available to households Improved fuel and stove technology can improve food preservation thereby decreasing the proportion lost to spoilage
Goal 2: Achieve universal primary education	
• Ensure that all children complete a full course of primary education	• Opportunities and quality of education improved by access to electricity • Reduced need for harvesting of household fuels increases school attendance
Goal 3: Promote sex equality and empowerment of women	
• Eliminate sex disparity in primary and secondary education by 2005 (preferably), and at all levels by 2015	• Women disproportionately exposed to air pollution from poor household fuels • Availability of cleaner-burning, efficient, and reliable fuel reduces time spent by women to collect fuel, cook, and clean; this time can be spent on leisure or income-generating pursuits, enhancing opportunity
Goal 4: Reduce child mortality	
• Reduce mortality in children under age 5 years by two-thirds	• Children exposed to high levels of indoor air pollution have more pneumonia, low birthweight, and other life-threatening conditions • Health-care services improved by reliable and affordable access to electricity or reliable clean energy: Improved fuel availability can improve water boiling and food preparation practices, leading to increased nutritional health
Goal 5: Improve maternal health	
• Reduce maternal mortality by three-quarters	• Health-care services improved by reliable and affordable access to electricity or reliable clean energy • Household solid-fuel harvesting needs much of women's time and energy • Indoor air pollution linked with risk of adverse pregnancy outcomes, tuberculosis, lung cancer, chronic lung disease, and heart disease in women
Goal 6: Combat HIV/AIDS, malaria and other diseases	
• Halt and begin to reverse spread of HIV/AIDS • Halt and begin to reverse occurrence of malaria and other major diseases	• Decreased fuel-collection responsibilities of women leads to reduced associated risks of rape and infectious disease transmission • Climate change likely to exacerbate health and social problems of populations with highest occurrence of HIV/AIDS, malaria, and other major diseases, and to alter the distribution of malaria and other vector-borne diseases
Goal 7: Ensure environmental sustainability	
• Integrate principles of sustainable development into country policies and programmes; reverse loss of environmental resources • Reduce proportion of people without sustainable access to safe drinking water by half • Achieve substantial improvement in lives of at least 100 million slum dwellers by 2020	• Energy is crucial to sustainable development, and balance is needed to improve access to energy services while restricting local and global effects to environment and health • Energy is needed to service reticulated water supplies • Electricity and energy is important part of services needed for decent housing • Unsustainable harvesting of wood fuel enhances deforestation
Goal 8: Develop global partnership for development	
• Further develop open trading and financial system that is rule-based, predictable, and non-discriminatory; and includes commitment to good governance, development, and poverty reduction—nationally and internationally • Address least developed countries' special needs, including: tariff and quota free access for exports; enhanced debt relief for heavily indebted poor countries; cancellation of official bilateral debt; and more generous development assistance for countries committed to poverty reduction • Address special needs of land-locked and small-island developing states • Deal comprehensively with developing countries' debt problems through national and international measures to make debt sustainable in the long term • In cooperation with the developing countries, develop decent and productive work for youth • In cooperation with pharmaceutical companies, provide access to affordable essential drugs in developing countries • In cooperation with the private sector, make benefits of new technologies available—especially information and communications technology transfer	• Energy costs are central to affordability of essential services for homes and for commerce and industry • Principles of equitable contribution to reduction of fossil-fuel use (the principle of contraction and convergence)[43] implies international trading system that places greatest burden for CO_2 reduction on wealthier nations—a carbon-trading system • Small-island states and those of other nations could be particularly vulnerable to effects of climate change • Debt is a main contributing factor to inability of poorer nations to develop energy infrastructure • Transfer of technology for clean, sustainable development in energy services is essential to development initiatives

Table expanded from reference 48.

Table 4: **Link between UN Millennium Development Goals (MDGs) and energy services**[54]

Conclusions

Dependence on coal, oil, and gas will eventually diminish, but it will do so not for lack of resources in the near term, but rather when the economic, social, health, and environmental costs force shifts to alternative sources. That transition will eventually come irrespective of deliberate actions by policymakers, but could be accompanied by great disruptions and effects unless

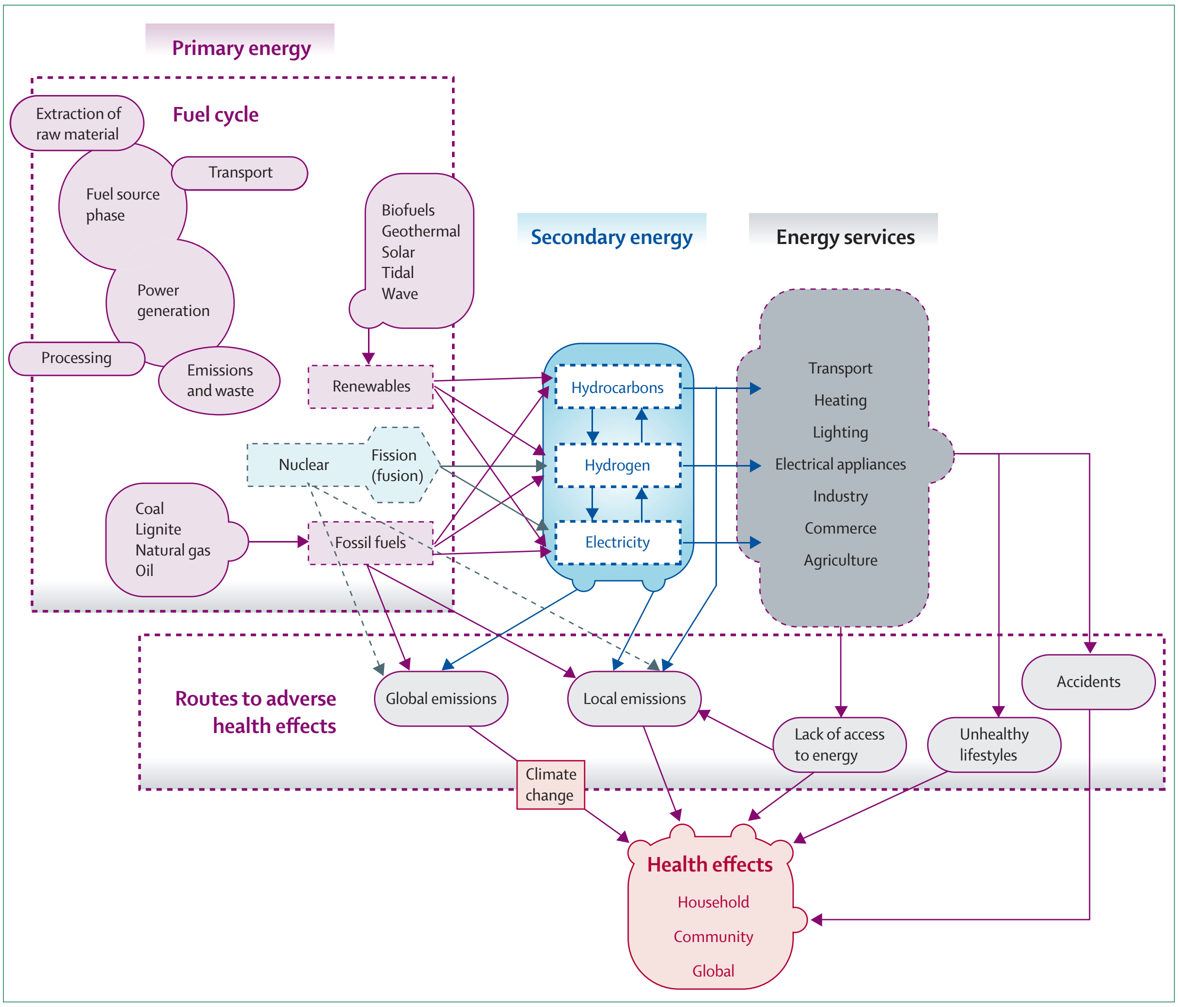

Figure 8: **Connections between energy and health**
Adapted from reference 27.

policy is soon directed toward accelerating and easing the transition to more sustainable energy systems. The inertial barriers to the widespread adoption of cleaner technology are substantial, however, and include existing infrastructure, established patterns of activity, and public expectations and demands. These barriers tend to favour modest, incremental responses that do not adequately respond to the imperatives of climate change and the health burdens of current practices in low-income countries.

The UN's Millennium Development Goals (MDGs) include several indicators relevant to energy use (per US$GDP, CO_2 emissions per head, and proportion of population using solid fuels). Access to energy services is crucial to many aspects of human health and wellbeing (table 4).[54] Energy services are fundamental to personal development and to the reduction in poverty and hunger; have bearing on gender and social inequalities in health; and are important to tackling maternal and child mortality. The adverse health consequences of climate change will also probably fall disproportionately on individuals already disadvantaged by poverty and disease, including HIV/AIDS, and energy is central to issues surrounding global partnerships and governance for development.

Provision of affordable, clean, and efficient energy systems is linked to all the MDGs, and closely to some, including child and maternal health, poverty alleviation, and environmental sustainability (table 4).[54] However, the fact that no specific MDG has been made to reduce the number of people without access to electricity is unfortunate, in view of its proven benefits. Collective action to tackle climate change through reduction of greenhouse-gas emissions is important and other UN mechanisms are in place for this purpose. However, long efforts to meet many of the MDGs will be impaired by growing climate change.

In addition to access to electricity and reduced greenhouse-gas emissions, the most important health-related energy indicator would seem to be reduction in the number of households using highly unhealthy unprocessed solid fuels (biomass and coal) or, equivalently, an increase in the proportion using clean fuels.[45] In this regard, it is parallel to the oldest of the major environmental health indicators; access to clean water. As will be described in more detail in the following Series articles, formidable barriers need to be overcome, but the social, health, and environmental benefits to achieve these goals would be great indeed. The difficult choices we now face in relation to energy use provide an opportunity to affect the health and social circumstances of populations worldwide—just as previous generations have engaged the public-health environmental challenges posed by dirty water, poor sanitation, and unsafe food (though these challenges are by no means solved globally).

In this Series, we consider the specific health implications of energy systems in four key sectors—power generation, transport, the built environment, and food production. Connections with health occur at all stages of the cycle of energy generation, distribution, and use, and arise through emissions to the local and global environment, through influence on health-related behaviours and risks (including those causing injuries), and through influence on access to several social, environmental, and health-care services (figure 8).[27]

Overarching all these factors is the need to reconcile energy needs, particularly for the world's poorest individuals, with the imperative to reduce environmental effects relating to local and increasing global emissions. The major challenges for energy and health policy will be discussed in the final paper of the Series, but the recurring message is that energy-use patterns are of central importance for future health and wellbeing. Despite formidable challenges ahead, a shift towards an equitable distribution of energy based increasingly on renewable resources has the potential for major health dividends. Progress along that path is measurable.

Conflict of interest statement

We declare that we have no conflict of interest.

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