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CLIMATE CHANGE, ENERGY SOURCES, AND ENVIRONMENTAL POLICY
and the numbers that govern them

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ABSTRACT

Green development is easier conceived than done. While ideas, technologies, and motivations exist to move away from extensive use of carbon-based fuels, it is imperative that we look into the actual viability of our policies, availability of green energy sources and sustainable materials, and individual human motivations that govern our behavior.

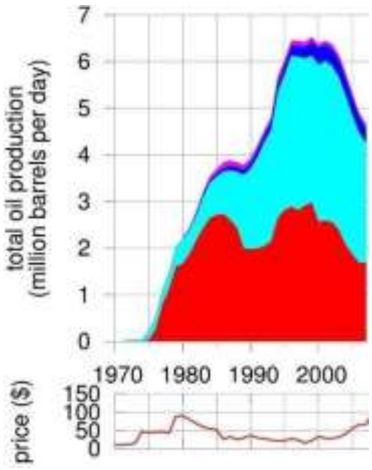
There is a pattern of disproportionate per capita energy consumption of conventional energy resources by the West; the need for developed economies to voluntarily cut down their CO2 emissions to prevent further rising of global temperature is substantiated by data and is the imminent need of the hour. This paper establishes a statistical correlation between the energy consumption data across different countries and environmental policies and practices and further evaluates how excessive dependency on fossil fuels can help address climate change. An argument for renewable energy resources and zero emission energy alternatives, such as nuclear energy, through technological innovations is made with statistical backing. I also explore the potential of encouraging innovations in sustainable materials and the role of individual action to build a greener future.

KEYWORDS: Fossil fuels, climate change, green policies, sustainability.

WHY DO WE DISCUSS ENERGY POLICY?

First, fossil fuels are not an infinite resource. It seems likely that oil and gas will run out in our lifespan. Hence, alternative energy sources are seeked.

Second, we're interested in the security aspect of energy resources. Even if fossil fuels are accessible, dependency on them results in geopolitical vulnerability. By the figure, it looks as if "our" fossil-based fuels have reached limits. The security-of-supply is a matter of resource availability, management and diplomacy depending on how each country deals with it's access.

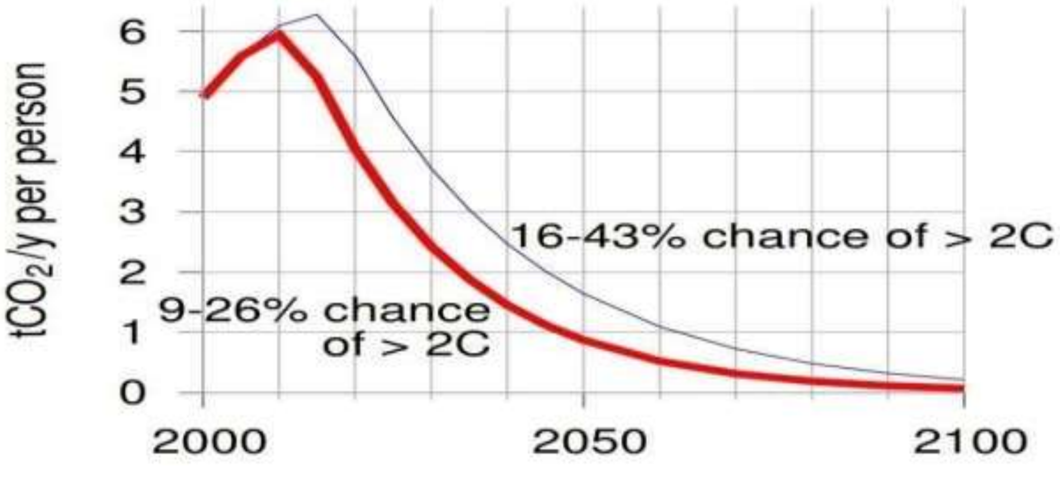


Third, it's likely that using fossil fuels changes the climate. Climate change is blamed on a multitude of human activities, leading to a greenhouse effect on the planet. Most of these emissions come from burning away these fossil fuels for energy. The climate problem is therefore clearly an energy problem.

Whichever of these three concerns encourages oneself, we need energy numbers, and policies that mathematically correlate and not simply make sense from a political perspective. The first two concerns are direct and perhaps even selfish motivations for quickly reducing fossil fuel burns. The third concern, climate change, is comparatively more thoughtful – the impact of climate change will be felt by future generations, over the coming centuries. Some people say, "What's the point of anything? China isn't going to care!" Let's discuss a bit of history then.

History, Country, Policy and blame – all at once!

Let's assume climate change is the damage caused by human activity. That means someone needs to fix it, who should pay? It is not the rate of CO2 pollution that is important, it's the total damage that matters here; this is much of the emitted carbon dioxide will hang around in the atmosphere for at least a large part of a century. If we agree with the ethical notion that "the polluter pays" then we should ask how large is each country's historical climatic footprint. The graphic below shows each country's total emissions of CO2, expressed as an average rate from 1880–2004. Congratulations, Britain! The UK may be an average European nation presently, but in the table of historical polluters, per capita, they are second to the USA.

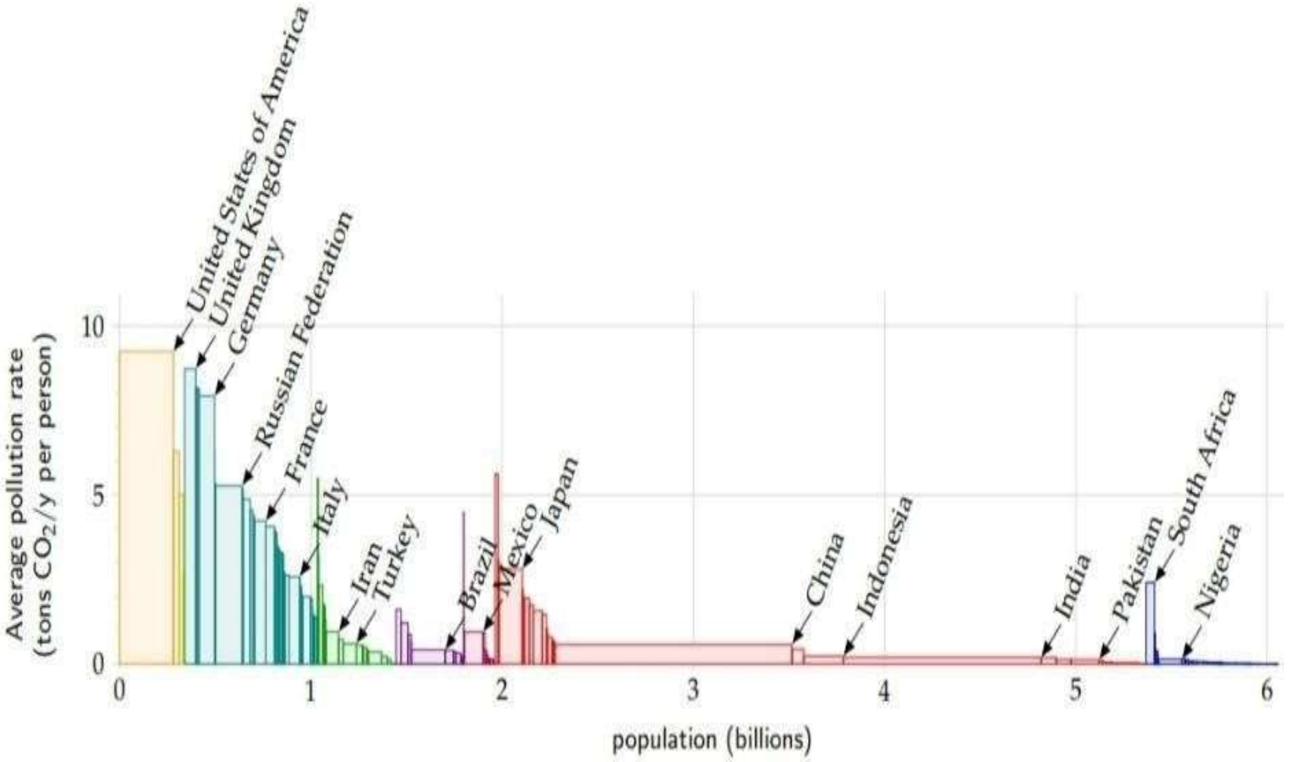


What do scientists believe that needs to be done, to avoid a 2 ◦C temperature rise? The data is clear. We must reduce dependency on fossil fuels. Some countries, including Britain, have committed to at least a 60% reduction in emissions by 2050. However, that really isn't enough at all.

The level of cuts we need to have an impact are shown in figure 1.2. It shows two emissions scenarios presented by Baer and Mastrandrea (2006) from the Institute for Public Policy Research. The bottom curve shows that the reduction in emissions began in 2007, at roughly 5% each year. The top curve assumes a brief delay in the beginning of the decline, and a 4% drop each year. Both cases are thought to offer a reasonable chance of avoiding a 2 ◦C temperature rise above the pre-industrial level. In the bottom scenario, the probability that the temperature rise will exceed 2 ◦C is seen to be 9–26%. In the top scenario, the chance of exceeding 2 ◦C is calculated to be 16–43%. These emissions curves, by the way, include significantly sharper reductions in emissions than any of the case policies presented by the Intergovernmental Panel on Climate Change (IPCC), or by the Stern Review (2007). These trajectories require global emissions to fall by 70% or 85% by 2050.

What would this mean for a country like Britain - it should reduce from its current 11 tons of CO2 per year per person to roughly 1 ton per year per person by 2050. That is harsh! It really means saying goodbye to fossil fuels by the middle of the century.

The Real Numbers behind the energy-ecology relation:



Better Transport

One third of today's energy goes into transportation. Can technology deliver a reduction in utilization of fossil fuels? We deal with two ideas here: to deliver the biggest possible reduction in transport's energy use, and to remove fossil fuel use in transport. There are two types of transport to address: passenger transport, and trade freight. For now, let's take the unit of passenger transport as the passenger-kilometre (p-km), the unit of freight transport is the ton-km (t-km), energy use of passenger transport in “kWh per 100 passenger-kilometres,” and the energy consumption of trade freight in “kWh per ton-km.”

We need to understand where the energy is going in terrestrial transport.

1. In short-range transport needs with plenty of starts and stops, the energy is mainly spent in speeding up the vehicle. This posits that we need to devise a way to weigh less, spend less energy in moving mass and travelling more between different stopping points. Regenerative braking, which captures energy when slowing down, may help too. In addition, it helps to move slower, and to move less.

2. In long-distance travel at steady speed, by train or automobile, most of the energy is spent in breaking through the air, because you only have to accelerate the vehicle once. The key strategies for consuming less in this kind of transport are, hence, to move slower, and to move less with more aerodynamic designs.

Make electricity use efficient

Can we reduce electricity use? Some gadgets are not important, but some are astonishing fuel guzzlers. A laser-printer in an office, sitting and doing nothing, slurps 17 W – that’s almost 0.5 kWh per day! A common lamp can have an adaptor adaptor which guzzles 10 W (0.25 kWh per day) even when switched off. According to the report by the International Energy Agency, standby power consumption results in roughly 8% of residential electricity demand. The issue isn’t standby itself – it’s the problematic way in which standby is caused. It’s perfectly plausible to make standby systems that use less than 0.01 W. However, manufacturers, saving themselves in costs, are saddling the consumers.

The anti-argument: Sustainable Fossil Fuels

Let’s discuss non-renewable options for power production. Let’s take the available reserves of fossil fuels, say coal and share them equally between six billion people, burn them in a sustainable way. What does it mean to say that we burn a non-renewable resource in a sustainable fashion? Here, it means that the burn-rate is “sustainable”. A metric ton of coal produces 8000 kWh of chemical energy, so 1600 Gt of coal (the known minable amount) shared between 6 billion people over 1000 years turns out to be a power of 6 kWh per day per person. A standard coal power station would be about 2.2 kWh(e) per day per person. If we are careful about the climate, however, then presumably we would use a better power plant. “Coal with carbon capture and storage” – a technology that removes most of the CO2 out of the chimney gases and then pushes it down a hole in the soil. However, this act would reduce the delivered electricity by about 25%. So, a “sustainable” utilization of known coal reserves would deliver only about 1.6 kWh(e) per day per person. We can compare this rate of 1.6 Gt per year with the current global rate of 6.3 Gt per year.

Our conclusion is clear:
Clean coal is only a very short-term solution
Coal-mining tends to release methane, carbon monoxide, and carbon dioxide, both directly from the coal, and subsequently from waste shales and mudstones; these coal mining emissions raise the greenhouse gas damage by about 2%.

Solutions that the numbers direct:
Plan ahead
What we do depends largely on our motivation: the end of cheap fossil fuels, national security and climate change. Assuming first that we have such a motivation, that we want to reduce carbon emissions rapidly, what can we exactly do?

We are not headed towards anything that looks like a zero-carbon future. Long-term investment in the field is eyeshadow. Carbon sequestration companies are not living, let alone thriving, even though the advice from climatic and economic experts is that removing carbon dioxide from air will soon become reality.

The bleakness of presence is in the fact that carbon is not even being trapped at any coal power plants (except for one unreal German prototype). The main issue is Price. And there is zero confidence that carbon pollution will have a reasonable price in the future. That means making it big enough so that every power plant out there fits itself with a carbon entrapment system.

Solving climate change is shrouded in complexity, but in a crude move, there is a way: the price is such that nobody buys energy produced through coal without capture. So what do politicians/policymakers do? They make sure that all coal power plants have carbon capture fitted, by force or by economics. That includes sorting out the technology for it, before forcing on a pure price elevation.

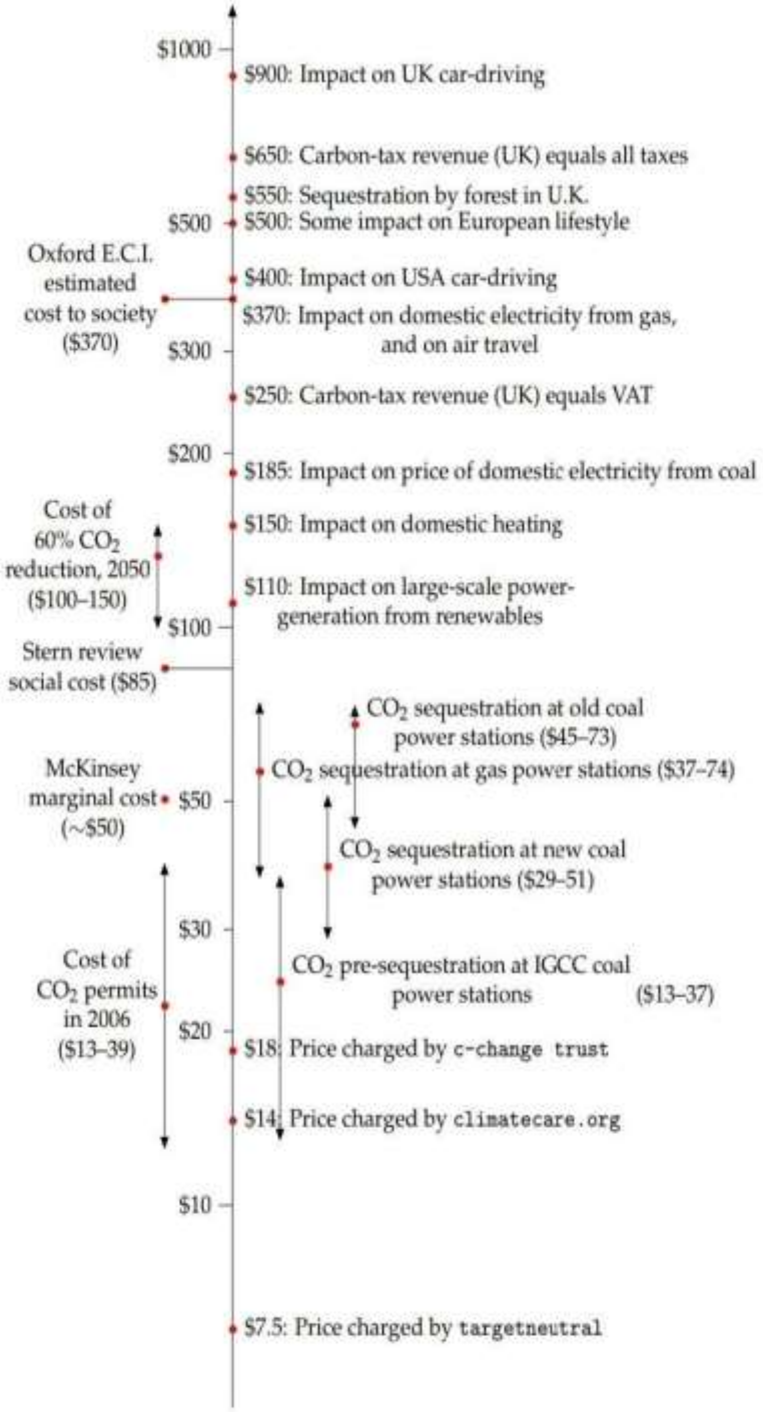
The policy should also ensure to change the long-term regulations for power plants so that the technology is adopted universally.

If we conform to the idea that climate change should be solved through economic forces, how does that work out? Well, carbon trading sounds like a plan– trading permits to produce unwanted carbon and certificates of carbon-capture, with unit carbon-capture certificates being changeable into one-tonne carbon emission permits. This again only works if the change in price is convincing enough to lead to a change in attitude. Alternatively, carbon pollution permits could be sold in an auction with a reasonable base price. Another way would be for governments to become underwriters to investment in carbon capture by guaranteeing that they will redeem the said certificates, whatever happens to the relevant markets.

About Energy Supply

To expand motivations, let’s assume we want to get rid of a dependency on fossil fuels to ensure national or geopolitical security. How do we make that work? Leaving it to the markets can be a challenging proposition. It is odd that politicians have such faith in markets which are known to be shockers with a purpose.

Markets are a good policy tool in the short run – ten years or so – but it is absurd to let markets determine the fate for centuries and generations and even ecological units. If the free market is allowed to construct houses, we will probably end up with poorly insulated houses. The market is not for building roads or railways despite how significant they are in determining transport choices. Similarly, laws which decide where homes may be built and how densely they may be put together in the modern metropolis, have an overwhelming impact on society. So, while markets play a larger than life role, it’s absurd to let it handle it all.



What price would CO_2 need to have in order to drive society to make significant changes in CO_2 pollution?

The diagram shows carbon dioxide costs (per tonne) at which particular investments will become economical, or particular behaviours will be significantly impacted, assuming that a major behavioural impact on activities like flying and driving results if the carbon cost doubles the cost of the activity.

As the cost rises through $20–70 per tonne, CO_2 would become sufficiently costly that it would be economical to add carbon sequestration to new and old power stations.

A price of $110 per tonne would transform large-scale renewable electricity-generation projects that currently cost 3p per kWh more than gas from pipedreams into financially viable ventures. For example, the proposed Severn barrage would produce tidal power with a cost of 6p per kWh, which is 3.3p above a typical selling price of 2.7p per kWh; if each 1000 kWh from the barrage avoided one ton of CO_2 pollution at a value of £60 per ton, the Severn barrage would more than pay for itself.

At $150 per tonne, domestic users of gas would notice the cost of carbon in their heating bills.

A price of $250 per tonne would increase the effective cost of a barrel of oil by $100.

At $370, carbon pollution would cost enough to significantly reduce people's inclination to fly.

At $500 per tonne, average Europeans who didn't change their lifestyle might spend 12% of income on the carbon costs of driving, flying, and heating their homes with gas.

And at $900 per tonne, the carbon cost of driving would be noticeable.

The possibility of individual action

It's particularly simple to say it all on policy and parliament. The changes we speak of require strong, very strong rather, politics and determination. Yet, it's only fair to lay it out on the common person to take a few harder calls. What should we do to do our part, in such a way that the math and the numbers align?

This is comparable to the rather simple policy calls we've discussed. To push the limits further and actually achieve the goals we set out for, the following rather hard steps should make the cut. The math still adds up, if you check.

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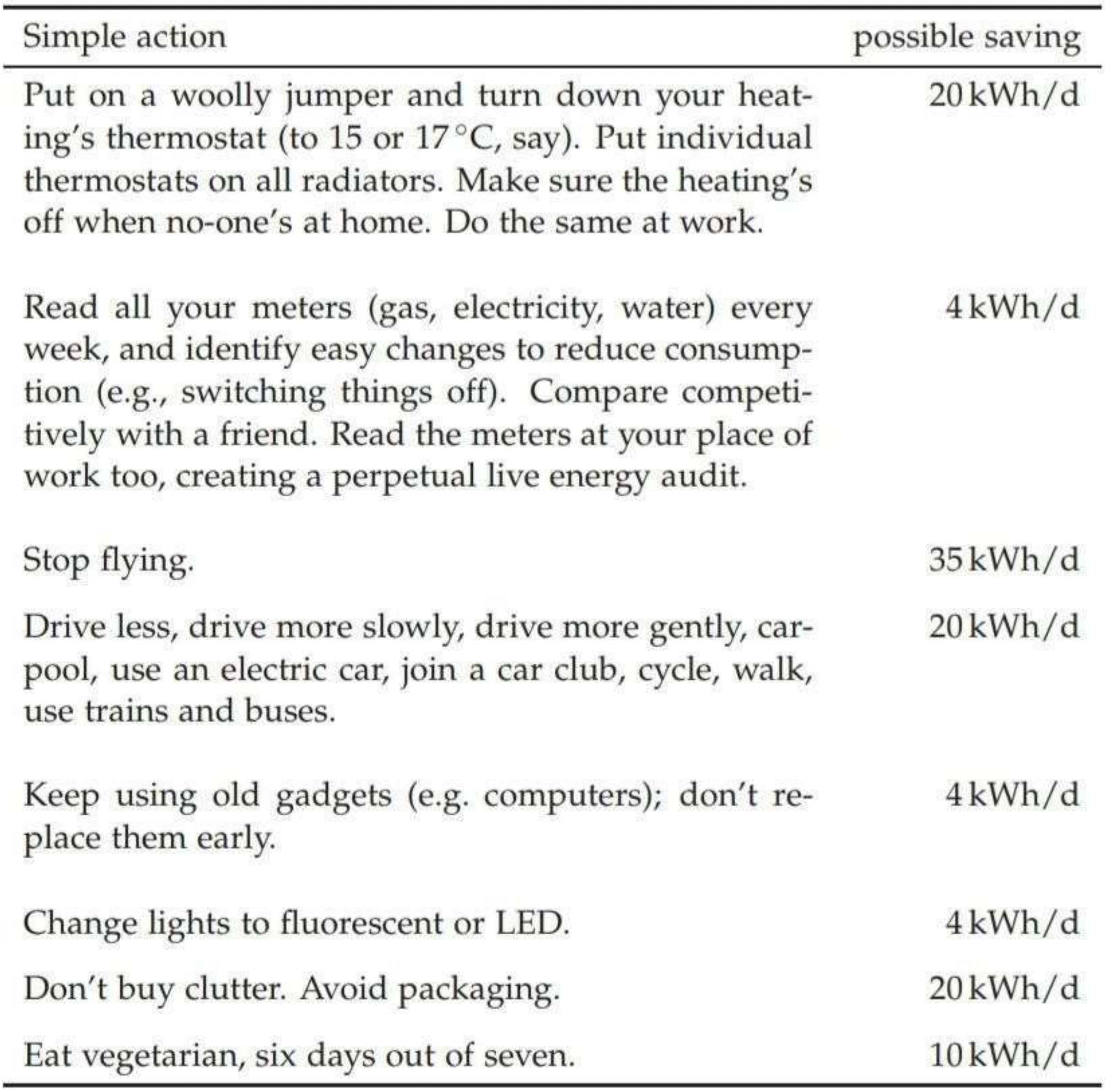
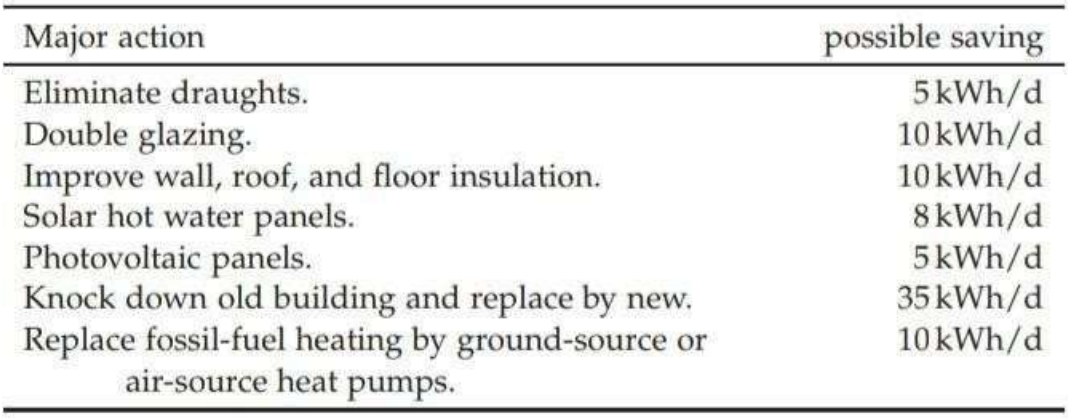


Simple action	possible saving
Put on a woolly jumper and turn down your heating's thermostat (to 15 or 17 °C, say). Put individual thermostats on all radiators. Make sure the heating's off when no-one's at home. Do the same at work.	20 kWh/d
Read all your meters (gas, electricity, water) every week, and identify easy changes to reduce consumption (e.g., switching things off). Compare competitively with a friend. Read the meters at your place of work too, creating a perpetual live energy audit.	4 kWh/d
Stop flying.	35 kWh/d
Drive less, drive more slowly, drive more gently, carpool, use an electric car, join a car club, cycle, walk, use trains and buses.	20 kWh/d
Keep using old gadgets (e.g. computers); don't replace them early.	4 kWh/d
Change lights to fluorescent or LED.	4 kWh/d
Don't buy clutter. Avoid packaging.	20 kWh/d
Eat vegetarian, six days out of seven.	10 kWh/d



Major action	possible saving
Eliminate draughts.	5 kWh/d
Double glazing.	10 kWh/d
Improve wall, roof, and floor insulation.	10 kWh/d
Solar hot water panels.	8 kWh/d
Photovoltaic panels.	5 kWh/d
Knock down old building and replace by new.	35 kWh/d
Replace fossil-fuel heating by ground-source or air-source heat pumps.	10 kWh/d

Sustainable Materials is the answer…

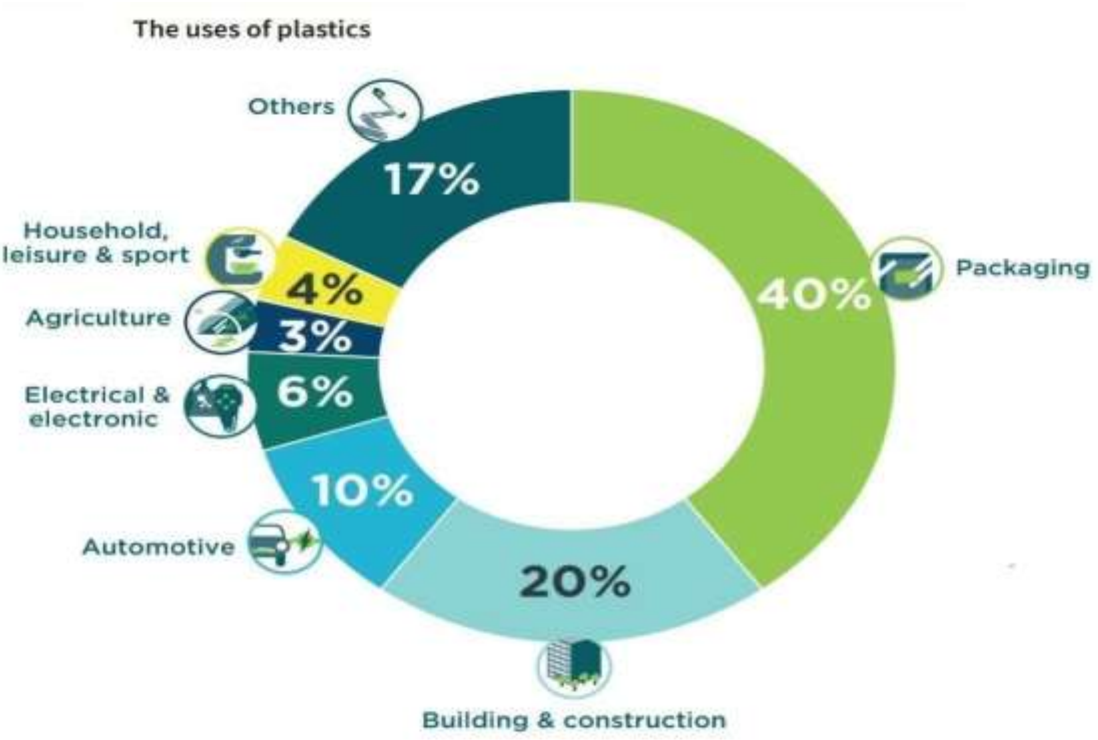
A step further with energy: Plastics

The plastics on the market today are sourced from petrochemicals, which are derived from oil and gas. Controlling the use of these materials will require a reduction in both energy use and carbon emissions associated with the manufacturing processes.

In the longer term, the world will shift from a manufacturing system that is based mainly on fossil fuels. Chemistry can help to develop routes to create plastics that actually recycle waste CO2 as a co-monomer and lock it into a synthesized polymer backbone. Common petrochemical-derived polymers such as polyethylene and polypropylene take several years to break down in the environment. Their carbon chains typically do not contain chemical groups that could act as usual ‘break points’ for chemical or biological decomposition, and in many cases are water resistant. The polymer chains can come together to form crystalline blocks that allow excellent thermal and mechanical properties, making the material durable but also less amenable to degradation after use.

Only a few polymers have been designed to be easily degradable – for example the polyester polybutylene adipate terephthalate (PBAT), is used as a compostable packaging material because it is similar in properties to low-density polyethylene (LDPE) but reacts with water to completely degrade. Plastics need to be designed for recycling and the field of depolymerization chemistry needs fundamental depth-based research, theoretical understanding and use.

Biologically sourced monomers tend to be more oxygen rich than hydrocarbons. To use these oxygen-bearing chemical groups and to provide ‘break points’ for degradation, is a plausible exploratory set. The other option is to use non-permanent interactions between chains to produce polymers that can disassemble, or crystallites that can be intervened with at reasonably low energy costs.



Scientific Deep Dive: Polymers from Renewable Sources

Bio-polymers currently make up a small proportion of the plastics market. Polylactic acid (PLA, o polylactide) is a widely used bio-based synthetic polymer, found in things like disposable cutlery and plastic cups. Thanks to the aliphatic ester chemical groups in these polymer chains, PLA can be completely decomposed by industrial composting processes. Life cycle assessment testings suggest that PLA has lower overall CO2 emissions compared to conventional petrochemical plastics such as polyethylene and polypropylene (J. Polym. Environ. 2019, DOI: 10.1007/ s10924-019-01525-9).

PLA is most commonly produced through a ring-opening polymerization of lactide, a cyclic diester made from lactic acid. This starting material is manufactured by the fermentation of plant sugars taken from crops such as sugarcane. Other lactones and cyclic monomers can be polymerized either to make types of PLA or other aliphatic polyesters. These approaches allow for a certain element of control over the polymers' chemical, physical, thermal and mechanical properties (Chem. Rev. 2018, DOI: 10.1021/acs.chemrev.7b00329).

Other bio-based polymers can be made utilizing monomers such as terpenes, including but not limited to pinene (derived from pine tree oil (Polym. Chem. 2014, DOI: 10.1039/C3PY01320K; Angew. Chem., Int. Ed. 2016, DOI: 10.1002/anie.201509379), limonene oxide made from waste citrus fruit peel, and succinic anhydride (Angew. Chem., Int. Ed. 2018, DOI:10.1002/anie.201801400).

Researchers have developed very active and selective catalysts for these co-polymerization reactions. However, further improvements are needed to translate these to viable industrial processes that make plastics with better or desirable characteristics such as higher mechanical strength and improved barrier properties.

It is good to stress that the material properties of a polymer decide its final applications. The thermal and mechanical properties of PLA, for example, decide its viable applications, and exclude a multitude of others.

Rerouting towards using waste molecules for sustainable materials

Better reuse of waste molecules, from industrial and agricultural processes, will be important in reducing the carbon emissions. But CO2 can also be used, of course with a co-monomer, as a building block for plastics. In many ways, it proves as an ideal feedstock – cheap, abundant, and the waste product from many industrial processes.

For example, polycarbonates can be made by reacting epoxides with CO2. This process operates at commercial scale; life cycle assessments have quantified the reductions to overall greenhouse gas emissions (Green Chem. 2014, DOI: 10.1039/c4gc00513a). The CO2 co-polymerization process is heavily dependent upon the catalyst, and recent research has uncovered the ability to increase performance using mixed-metal catalysts, like of magnesium and zinc (Chem. Sci. 2019, DOI: 10.1039/C9SC00385A). As chemists frame a better understanding of how these metals work together, it should help to develop better catalysts which can make the process further more efficient, reducing manufacturing costs and prompting wider adoption of these sustainable materials.

In the longer run, chemistry has a major role to play in generating new, disruptive technologies for plastics. For example, sulfur is a large scale waste from the petrochemical industry and finding ways to recycle it into polymers is useful. Polythioesters exploit sulfur by introducing convenient break points in the polymer structure which could be targeted by future recycling mechanisms.

Natural polymers like cellulose, chitin and starch are renewable and environmentally degradable resources, which can be used to make monomers. Cellulose is a major component of natural plant fibres, and the most abundant natural polymer in the world. It is already used to make a variety of products including cellophane film, textiles and packaging materials.

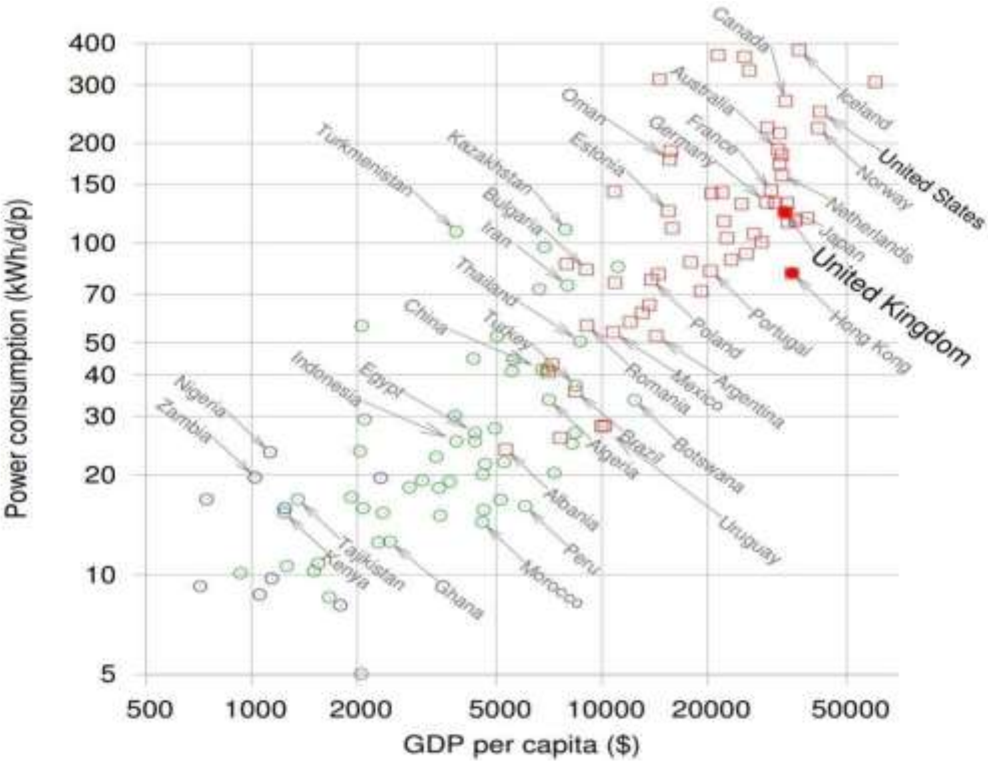
But processing cellulose is a lasting challenge. Cellulose molecules are held together by few networks of hydrogen bonds, meaning cellulose does not melt and doesn't simply dissolve in diurnal solvents. Finding new ways to fine-tune the physical properties of cellulose derivatives can possibly help in opening up applications such as low-cost packaging, or to avoid the use of plasticizer-gade additives.

Significant research is trained towards the efficient transformation of lignocellulosic wastes into monomers for plastic production: from heterogeneous catalysis to engineering, bio-processing and synthetic biology. It also allows for the manufacture of polymer-natural-fibre composites for the improvement of natural materials like paper.

A view of the status quo, and how it may shift

Adding the numbers up for Energy Plans, and redoing the numbers

The figure below portrays the energy consumptions of various regions, against their gross domestic products (GDPs). It's not established what consumption is good to plan for, but the average European level (125 kWh per day per person) seems more than fair.



Mathematics of Europe

Europe's average population density is roughly half of the UK's, so there is more land to work with. . The area of the European Union is roughly 9000 m2 per person.

Let's calculate some rough numbers.

Wind

Continental Europe has lower wind speeds than the UK – much of Italian wind speeds are below 4 m/s. Let's assume that one fifth of Europe has sufficient wind-speeds for plausible wind-farms, with

power densities of 2 W/m2. Let's then assume that we can manage to boldly fill them up with 10% land area allocated to wind farms. The area of the European Union is roughly 9000 m2 per person. So wind provides
1/5 × 10% × 9000 m2 × 2 W/m2 = 360 W or 9 kWh/d per person. Hydroelectricity
Hydroelectric production in Europe totals around 67 GW; shared between 500 million people, that's 3.2 kWh/d per person. If every country doubled its hydroelectric production in Europe and wasn't dominated entirely by the Nordic region – which would surely be challenging – then hydro would generate 6.4 kWh/d per person.

Mathematics of North America
The average American consumes 250 kWh/d per day. That's double of that of the average Japanese or European citizen. The numbers could show a glimmer of hope then.

A study by Elliott et al. (1991) assessed the wind energy potential of the USA. The best locations are in North Dakota, Wyoming, and Montana. They showed that about 435 000 km2 of windy land could be dedicated to energy needs, and that the electricity generated would be placed in the ballpark of 4600 TWh per year, which is 42 kWh per day per person, once shared between 300 million people.
The amount of hardware required (with a load factor of 20%) is about 2600 GW, which raises eyebrows because it leads to a 200-time increase in the country.

Mathematics of the world
How do 6 billion people get the power for a European standard of living – 80 kWh per day per person, say?

Wind
The exceptional spots with strong and steady winds are the central states of the USA (Kansas, Oklahoma); Saskatchewan, Canada; the southern limits of Argentina and Chile; northeast Australia; northeast and northwest China; northwest Sudan; southwest South Africa; Somalia; Iran; and Afghanistan.

And everywhere offshore except for a tropical band 60 degrees wide centred on the equator. For our global estimate, let's use the numbers from Greenpeace and the European Wind Energy Association:

"the total available wind resources worldwide are estimated at 53 000 TWh per year." That's just 24 kWh/d per person, far from the requirements of 80 kWh/d per person.

Hydro
Worldwide, hydroelectricity currently produces about 1.4 kWh/d per person. The International Hydropower Association and the International Energy Agency estimate the total viable hydro-potential at 14 000 TWh/year (about 6.4 kWh/d per person), of which about 8000 TWh/year (3.6 kWh/d per

person) is currently considered economically viable for development. Most of the opportunities for development are in Africa, Asia and Latin America.

Tide

There are several places in the world with tidal resources on the same magnitude as the Severn estuary. In Argentina there are two locations: San Jose and Golfo Nuevo; Australia's the Walcott Inlet; the USA & Canada share the Bay of Fundy; Canada possesses Cobequid; India's Gulf of Khambhat; the USA has Turnagain Arm and Knik Arm; and Russia has Tugur.

And then there is the global tidal whopper, a place called Penzhinsk in Russia with a reserve of 22 GW – ten times as big as the Severn! Kowalik (2004) estimates that worldwide, 40–80 GW of tidal power could be generated. Shared between 6 billion people, that comes to a mere 0.16– 0.32 kWh/d per person.

Wave

The total extractable power from waves can be estimated by multiplying the length of exposed coastlines (roughly 300 000 km) by the normal power per unit length of coastline (10 kW per metre): the raw power is therefore about 3000 GW. Assuming 10% of this raw power is usable by systems that are 50%-efficient at producing electricity, wave power could deliver 0.5 kWh/d per person.

Geothermal

According to D. H. Freeston of the Auckland Geothermal Institute, geothermal power amounted on average of about 4 GW, globally, in 1995 – which is only 0.01 kWh/d per person. However, MIT says that if we assume that the whole world is like America topographically, then geothermal power offers 8 kWh/d per person, which while optimistic, remains untrue.

The non-solar bottom line

The non-solar numbers add up followingly: Wind: 24 kWh/d/p; hydro: 3.6 kWh/d/p; tide: 0.3 kWh/d/p; wave: 0.5 kWh/d/p; geothermal: 8 kWh/d/p – a total of 36 kWh/d/p.

Our target of a post-European consumption of 80 kWh/d per person is far-fetched hence. We have a clear conclusion: the non-solar renewables may be large but they are not quite enough. To complete a plan that adds up, we must rely on one or more forms of solar power. Or use nuclear power. Or both. However, the numbers behind both tend to shift a lot based on the technology being used, meaning any meaningful calculation will require budgetary constraints to be established globally and then peered into.

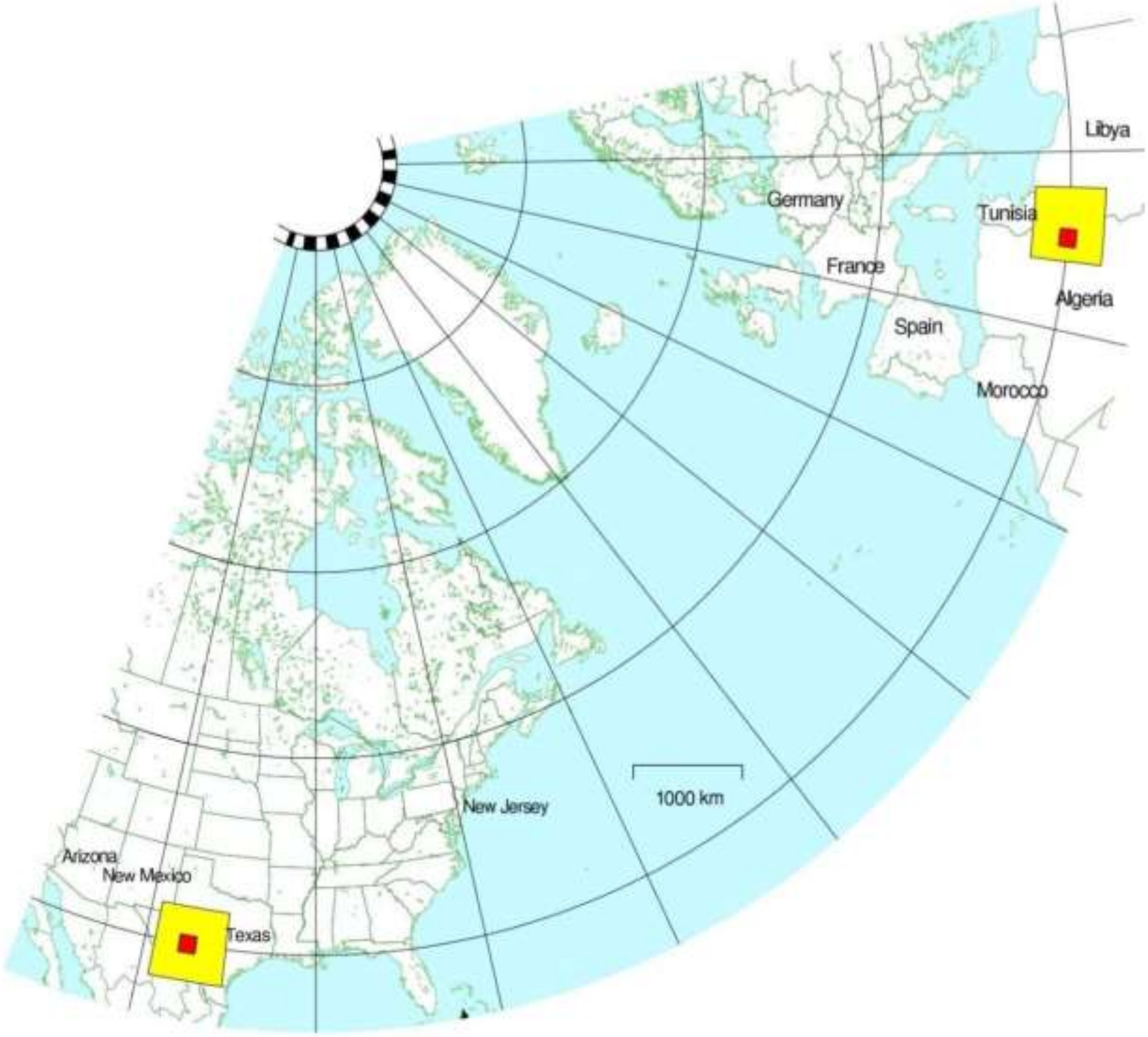


Figure 30.3. The little square strikes again. The 600 km by 600 km square in North America, completely filled with concentrating solar power, would provide enough power to give 500 million people the average American's consumption of 250 kWh/d.

This map also shows the square of size 600 km by 600 km in Africa, which we met earlier. I've assumed a power density of 15 W/m^2, as before.

The area of one yellow square is a little bigger than the area of Arizona, and 16 times the area of New Jersey. Within each big square is a smaller 145 km by 145 km square showing the area required in the desert – one New Jersey – to supply 30 million people with 250 kWh per day per person.

BIBLIOGRAPHY

Aitchison, E. (1996). Methane generation from UK landfill sites and its use as an energy resource. Energy Conversion and Management, 37(6/8):1111–1116. doi: doi:10.1016/0196-8904(95)00306- 1

Amos, W. A. (2004). Updated cost analysis of photobiological hydrogen production from Chlamydomonas reinhardtii green algae – milestone completion report

Anderson, K., Bows, A., Mander, S., Shackley, S., Agnolucci, P., and Ekins, P. (2006). Decarbonising modern societies: Integrated scenarios process and workshops. Technical Report 48, Tyndall Centre.

Archer, M. D. and Barber, J. (2004). Photosynthesis and photoconversion. In M. D. Archer and J. Barber, editors, Molecular to Global Photosynthesis. World Scientific.

Burnham, A., Wang, M., and Wu, Y. (2007). Development and applications of GREET 2.7 — the transportation vehicle-cycle model.

Baker, C., Walbancke, J., and Leach, P. (2006). Tidal lagoon power generation scheme in Swansea Bay. www.dti.gov.uk/files/ file30617.pdf. A report on behalf of the Dept. of Trade and Industry and the Welsh Development Agency.

Church, R. A., Hall, A., and Kanefsky, J. (1986). The history of the British coal industry. Vol. 3, 1830–1913: Victorian pre-eminence

Eckhartt, D. (1995). Nuclear fuels for low-beta fusion reactors: Lithium resources revisited. Journal of Fusion Energy, 14(4):329– 341.

Etheridge, D., Steele, L., Langenfelds, R., Francey, R., Barnola, J.-M., and Morgan, V. (1998). Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA

European Commission. (2007). Concentrating solar power - from research to implementation Denison, R. A. (1997). Life-cycle assessment for paper products. In E. Ellwood, J. Antle, G. Eyring, and P. Schulze, editors, Wood in Our Future: The Role of Life-Cycle Analysis: Proc. a Symposium. National Academy Press

Hansen, J., Sato, M., Kharecha, P., Russell, G., Lea, D., and Siddall, M. (2007). Climate change and trace gases. Phil. Trans. Royal. Soc. A, 365:1925–1954. doi: 10.1098/rsta.2007.2052.

Gellings, C. W. and Parmenter, K. E. (2004). Energy efficiency in fertilizer production and use. In C. W. Gellings and K. Blok, editors, Efficient Use and Conservation of Energy, Encyclopedia of Life Support Systems.

Hird, V., Emerson, C., Noble, E., Longfield, J., Williams, V., Goetz, D., Hoskins, R., Paxton, A., and Dupee, G. (1999). Still on the road to ruin? An assessment of the debate over the unnecessary transport of food, five years on from the food miles report.

Indermuhle, A., Stocker, T., Joos, F., Fischer, H., Smith, H., Wahlen, M., Deck, B., Mastroianni, D., Tschumi, J., Blunier, T., Meyer, R., and Stauffer, B. (1999). Holocene carbon-cycle dynamics based on CO2 trapped in ice at Taylor Dome, Antarctica. Nature, 398:121–126

Grubb, M. and Newbery, D. (2008). Pricing carbon for electricity generation: national and international dimensions. In M. Grubb, T. Jamasb, and M. G. Pollitt, editors, Delivering a Low Carbon Electricity System: Technologies, Economics and Policy. Cambridge Univ. Press, Cambridge.

Lemofouet-Gatsi, S. and Rufer, A. (2005). Hybrid energy systems based on compressed air and supercapacitors with maximum efficiency point tracking.

Le Que´re´, C., Rodenbeck ¨, C., Buitenhuis, E., Conway, T. J., Langenfelds, R., Gomez, A., Labuschagne, C., Ramonet, M., Nakazawa, T., Metzl, N., Gillett, N., and Heimann, M. (2007). Saturation of the southern ocean CO2 sink due to recent climate change. Science, 316:1735–1738. doi: 10.1126/science.1136188.

Marland, G., Boden, T., and Andres, R. J. (2007). Global, regional, and national CO2 emissions. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA

Richards, H. G., Parker, R. H., Green, A. S. P., Jones, R. H., Nicholls, J. D. M., Nicol, D. A. C., Randall, M. M., Richards, S., Stewart, R. C., and Willis-Richards, J. (1994). The performance and characteristics of the experimental hot dry rock geothermal reservoir at Rosemanowes, Cornwall (1985-1988). Geothermics,

Neftel, A., Friedli, H., Moor, E., Ltscher, H., Oeschger, H., Siegenthaler, U., and Stauffer, B. (1994). Historical CO2 record from the Siple station ice core. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA

Rubbia, C., Rubio, J., Buono, S., Carminati, F., Fietier ´ , N., Galvez, J., Geles` , C., Kadi, Y., Klapisch, R., Mandrillon, P., Revol, J., and Roche, C. (1995). Conceptual design of a fast neutron operated high power energy amplifier. Technical Report CERN/AT/95-44 (ET), European Organization for Nuclear Research.