hypothetical scenarios for most of Asia and for the top three seafood exporters, probably because of the high current consumption of seafood in these countries.

The results do not indicate any reductions in vitamin A deficiency in populations with increased seafood supply in their particular country, but instead a general tendency towards adverse effects owing to a lowering of vitamin A intake, especially in Indonesia, Japan, Iran and Norway. The authors suggest that this is due to seafood replacing other vitamin A-rich foods, although fish is one of the best sources of vitamin A, especially oily fish and fish livers. Another point to consider is that the authors base their analysis on the nutritional content of seafood muscle tissue, and do not consider bones, internal organs and adipose tissue, including those currently eaten. Omitting the supply of vitamin A (or other micronutrients) from these tissues runs the risk of underestimating seafood's potential benefits.

Diet is not usually considered to be the main contributor to vitamin D deficiency, which is attributed mainly to inadequate sun exposure at high latitude or to skin being covered[5]. Optimal vitamin D status is, however, achievable through an intake of fatty fish in accordance with recommendations[6]. This indicates that an increase in seafood intake could improve bone health as a consequence of adequate vitamin D intake. Better seafood availability might also aid children's growth, especially in low-income countries where seafood would offer an important supply of high-quality protein.

The estimated benefits of marine omega-3 fatty acids are tied to the authors' chosen cut-off value of 0.4 grams consumed per day, irrespective of sex and age. This value is based on an observed association with a reduction in ischaemic heart disease in adults. However, there is no consensus on the optimal level of intake, and recommendations vary widely from no specific recommended intake to 1 g per day (for people with cardiovascular disease)[7]. The essential role of omega-3 fatty acids began to be recognized in the 1970s and 1980s, and on the basis of accumulating evidence, the total amount and the specific requirements recommended are still being increased. Current evidence indicates that boosting the supply of marine omega-3 fatty acids might have extra benefits, for example to child development or for people with arthritis[8].

Golden and colleagues' work provides a range of methodological advances and some interesting results. Considering the big picture, overall global health would probably improve if seafood availability were to increase, and the authors' models predict that the maximal gains would be in sub-Saharan Africa and southern parts of Asia. The authors' consideration of malnutrition and cardiac diseases associated with diet and other lifestyle factors is a notable approach that is highly relevant for a global-health study. It is a strength of this work that the authors model and assess future changes to the whole diet, instead of just focusing on the effects of an increase in seafood, because their analysis indicates the need to consider potential negative effects of food replacements. This research also provides a proof of concept that such models might be a valuable asset when planning public-health policies — if the models are based on in-depth knowledge about the specific setting in order to make realistic projections.

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Climate science

The energy costs of climate change

Katrina Jessoe & Frances C. Moore

How will global energy usage change as Earth warms? Modelling now suggests that there will be a modest net decrease in energy consumption — but probably at the expense of human well-being in many regions. **See p.308**

Climate change affects many things: the food we grow, human health, the productivity of workers, migration decisions, conflicts and violence, ecosystem services and the amount of energy we consume[1,2]. These disparate and diverse effects are difficult to quantify, particularly in economic terms. Nevertheless, such an evaluation is crucial for analyses of climate and energy policies. US federal agencies, for instance, are required to perform a cost–benefit analysis of all their regulations. For climate and energy policies, this requires them to put a price on carbon dioxide emissions. One measure of this is the social cost of carbon (SCC) — an evaluation of the future costs of emitting one extra tonne of CO_2 into the atmosphere, taking into account all the effects of climate change.

Calculating the SCC is a Herculean task. Researchers have used a set of integrated assessment models (IAMs), which pair simple computational models of socio-economic and climate systems. One essential component of IAMs is the damage function, which relates the level of global warming to resulting changes in human welfare. But a considerable problem in all currently used models is that the science supporting damage functions is based on limited data that are decades out of date[3–5]. With the administration of US President Joe Biden now working on a major update to the country's SCC, incorporating better science and economics into the damage functions of IAMs is a high priority[5]. On page 308, Rode *et al.*[6] provide new estimates of how climate change will affect global energy consumption and a price for the portion of the SCC that is attributable to energy expenditure.

The net global effect of future higher temperatures on energy use has been unclear. Higher temperatures are likely to reduce energy demand for heating, but might increase demand for cooling, with the effects differing between regions. The effect of temperature increases on energy consumption will also vary according to people's income. For example, demand for electricity in high-income locations is likely to be more responsive to temperature increases, because people are much more likely to have (or be able to purchase) air conditioners than are people in low-income areas. Projections of the effects of climate change on energy consumption therefore need to take into account geographical differences and income dynamics. Rode and colleagues address both of these dimensions in their study.

The authors combine historical annual income and energy-consumption data from 146 countries with daily temperature and rainfall data at 0.25° × 0.25° resolution, to estimate

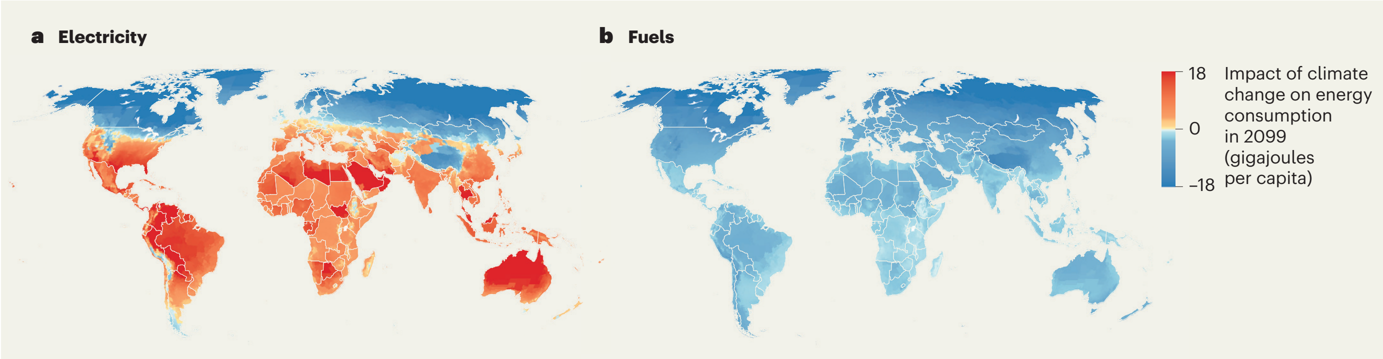

Figure 1 | Estimated changes in energy consumption in 2099. Rode *et al.*[6] used statistical models to estimate how global warming will affect energy demand across the world by 2099, taking into account local weather conditions and country-level per capita income, and assuming that carbon dioxide emissions will be very high. **a**, The authors report that electricity consumption will increase in wealthier countries that become warmer, as a result of increased use of air conditioning. **b**, However, consumption of fuels is projected to decline across most of the world, because of lower heating requirements – offsetting the increased electricity use shown in **a**. There will therefore be a modest net decrease in energy use globally.

how global energy consumption will change in response to temperature and income variation. A key advance is the application of econometric tools – statistical methods commonly used in economics to estimate causal influences – to isolate the effects of temperature, income and climate on energy expenditure from the effects of other factors. Specifically, Rode and co-workers control for difficult-to-observe factors such as global energy-supply shocks that lead to differences in energy demand between countries and over time.

The resulting estimates show that the relationship between energy expenditure and temperature depends strongly on per capita income: energy use will increase substantially on very hot or very cold days in the wealthiest places, but not in most low-income locations. This supports findings from previous work showing that the uptake of air conditioning in warm countries is rapid once household incomes exceed approximately US$10,000 per year[7,8].

Rode *et al.* combined their temperature–energy-expenditure relationships with projections from climate and socio-economic models to estimate the effects of climate change on energy consumption throughout the twenty-first century (Fig. 1). They conclude that, globally, increased demand for electricity for cooling will be largely offset by the reduction in use of fuels for heating. The result is a modest net decrease in energy use, and therefore a negative SCC for energy consumption. This finding alone highlights the importance of updating the currently used models to estimate the SCC. Only one of these explicitly models energy use, and it assumes that increased energy demand will be the largest source of damage due to climate-change[9,10]. However, as with most of the effects of climate change, the SCC is not evenly distributed: hotter middle-income and high-income countries will incur net costs as a result of increased electricity use, whereas cooler countries and those with the lowest incomes will receive net benefits.

It would be premature to interpret a small, negative global SCC from end-use energy consumption as good news, given that income inequities largely explain this result. Many areas that experience warming will not be able to afford cooling, even taking into account the income growth expected by the end of this century. These areas include densely populated regions that already have dangerous levels of heat and humidity, such as parts of South Asia and West Africa. Given the dangers of moist-heat stress[11,12], the implication that large numbers of people in these areas will be unable to access air conditioning is sobering. Programmes to expand access could be an important strategy for adaptation to climate change in these regions.

One caveat of Rode and colleagues' findings is that they do not account for potential future decreases in the price of cooling (or heating) technologies. If the price of air conditioning falls over time, and if poorer countries expand their electricity grids, then air conditioning might be adopted sooner than projected. For example, price decreases were key to the adoption of air conditioning in the United States in the mid-twentieth century[13].

Another caveat relates to the authors' projections of energy-system costs. Climate change will cause events, such as wildfires and hurricanes, that will affect energy systems and probably increase the cost of supplying electricity. Growth in peak demand from warming temperatures is also likely to increase the costs of energy generation[14]. Rode and co-workers use projections of fuel and electricity prices from energy-system models, but if these models miss some of the effects of warming on energy infrastructure, the costs might be under-valued. Quantifying how warming will affect energy infrastructure and the cost of supplying energy is the next crucial step towards understanding climate-change impacts in the energy sector.

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