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SUSTAINABILITY

Australia at the crossroads

A modelling study argues that comprehensive policy change could limit Australia's environmental pollution while maintaining a materials-intensive path to economic growth. But other paths are worth considering. SEE ARTICLE P.49

BENJAMIN L. BODIRSKY & ALEXANDER POPP

Despite Australia's vastness and its swathes of untouched nature, its per-capita environmental footprint is one of the biggest worldwide. Because it is a major exporter of agricultural products, coal and other emissions-intensive commodities, there is great concern that binding climate agreements could harm the country's economy. In 2014, under then prime minister Tony Abbott, the current conservative government replaced a carbon-tax policy with inefficient mitigation subsidies[1]. Abbott was toppled from the party leadership in September 2015. His successor, Malcolm Turnbull, was once a strong proponent of a carbon-trading scheme, but it remains uncertain whether environmental policies will be reformed under his leadership.

On page 49 of this issue, Hatfield-Dodds *et al.*[2] argue that Australia can stick to its materials-intensive industries and enjoy continued high economic growth while reducing its impacts on climate, water and biodiversity. The authors show that greenhouse-gas emissions can be mitigated through efficiency improvements in production processes, and even more through carbon removal by planting forests (afforestation) and carbon capture and storage. The premise in any case is a comprehensive pricing of emissions.

Hatfield-Dodds and colleagues' assessment, the most comprehensive conducted for Australia so far, is based on the Australian National Outlook 2015, a report[3] prepared by the country's Commonwealth Scientific and Industrial Research Organisation. The authors used nine linked simulation models to estimate the performance of Australia's economy in a global market, with a particular focus on the agriculture, energy and transport sectors, which exert the largest environmental pressures on land, water and climate. The modelling framework is exemplary in bridging scales between global, national and sub-national dynamics. This cross-scale approach could, and should, become seminal for future regional assessments.

The study produces 20 scenarios for Australia's future, exploring possible domestic developments in regard to lifestyle, policy and technological progress. All scenarios are embedded in one of four possible settings for global change, characterized by different population trajectories and by different global carbon prices, leading to 2, 3 or 6 °C of global warming above pre-industrial levels in the year 2100. The authors' models then provide projections, under each scenario, for rates of technology adoption in the energy, transport and agricultural sectors; for production, income, and trade; and for environmental indicators such as water usage, land clearing and greenhouse-gas emissions.

The findings indicate that Australia's gross domestic product will more than double by 2050 in all scenarios. However, without carbon pricing, greenhouse-gas emissions would increase by up to 90% in the same period. Even with a carbon tax at a similar level to that in force in 2012–14, Australia's emissions are projected to rise by about 25% by 2050. Complying with a 2 °C global-warming target will require higher taxes, which Hatfield-Dodds *et al.* show can be reached most cost-effectively

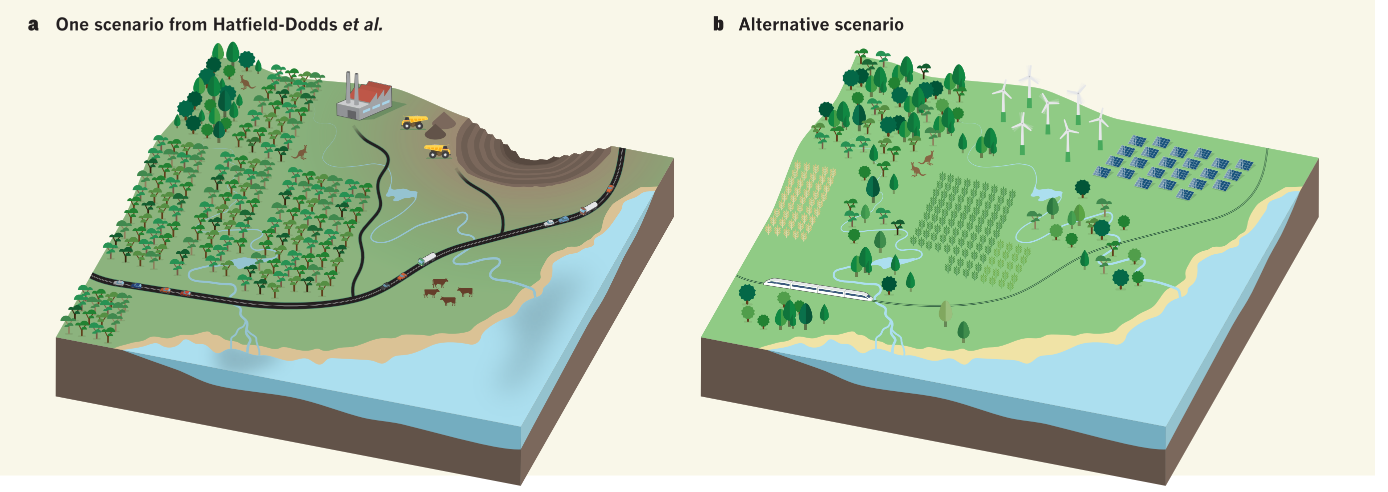

Figure 1 | Possible paths. **a**, Scenario modelling presented by Hatfield-Dodds *et al.*[2] suggests that Australia could maintain its economic growth and its typically materials-intensive lifestyles, while reducing its environmental impacts. Under this scenario, fossil fuels continue to be burned, but in combination with carbon capture and storage. The transport sector switches to electric and hybrid cars. Agriculture is intensified and dominated by forest plantations to sequester carbon, while biodiversity reserves and seawater desalination produce ecosystem services. **b**, An alternative pathway, not simulated by the authors, is a structural change towards a labour- and technology-intensive economy, with dematerialized lifestyles. Energy is obtained from renewable sources and public transport is expanded. Agriculture gradually shifts from resource-intensive livestock and feed production towards diverse high-value horticulture, and natural and agricultural systems are integrated. We suggest that this pathway would be more resilient to technological or institutional failure.

in Australia through large-scale afforestation and renaturation programmes. In an international carbon market, such greening programmes can become a profitable export industry through the sale of carbon credits.

The general outcome of this Australian assessment is in line with the findings of the *Special Report on Emissions Scenarios* produced by the Intergovernmental Panel on Climate Change (IPCC)[4], which concluded that immediate and global action to limit warming to 2 °C by 2100, in combination with the full availability of key technologies, would entail losses in global consumption of 2–6% (median 3.4%) in 2050 and 3–11% (median 4.8%) in 2100. But Hatfield-Dodds and colleagues' regional study argues that even Australia, with its high dependence on fossil-fuel and agricultural exports, and with high per-capita emissions, does not need to fear increased mitigation costs, because it can remain one of the most cost-efficient producers.

However, although the study shows that Australia can reduce emissions and environmental impact while sticking to its materials-intensive production and consumption patterns, the authors assess only a selection of potential pathways (Fig. 1). Within the literature on future scenarios[4–6], the possibilities considered by Hatfield-Dodds *et al.* describe a rather optimistic future in terms of political institutions and technological performance, and envisage a society open to trade and migration and with materialistic lifestyles. Ecosystem services are valued, but with a curative rather than a preventive approach to environmental damage. Focusing on this strand of scenarios might mask certain risks and opportunities.

One such risk is that future technologies will perform less well than we expect them to. For example, the performance of carbon-capture-and-storage technologies and of large-scale afforestation enormously influence the challenges and mitigation costs of reaching ambitious climate targets[7]. In a world that relies on resource-intensive growth, if such mitigation options fail, this could escalate abatement costs or render climate targets unachievable.

Society might also fail to establish the institutional framework required to embed a materials- and energy-intensive economy into environmental systems. Such a framework requires not only a timely international agreement on global carbon pricing, but also the regulation of other indirect environmental costs that are not reflected by market prices (externalities), such as groundwater use or nutrient pollution. Hatfield-Dodds and colleagues' study clearly shows that, without such policy frameworks, problems rapidly emerge — for example, fast-growing forests planted for carbon sequestration can lead to extreme water scarcity in certain catchment areas. Other side effects could include the increased use of pesticides and fertilizers when afforestation reduces the areas available for crops[8], or the disruption of marine ecosystems as a result of water desalination[9].

The study convincingly argues that lifestyle changes, such as reduced working time, are not sufficient to solve environmental problems. But such changes do help to relieve pressure in the water–energy–food–climate–biodiversity nexus[10] and might lessen the grave consequences of technological or institutional failure. Even in high-abatement scenarios, Hatfield-Dodds and colleagues estimate that per-capita energy demand will not fall below current levels, and that the global demand for animal products will double. Here, they may underestimate the potential for behavioural change, which was also highlighted in the IPCC's Fifth Assessment Report[7].

This work reinforces the appraisal that global pricing of greenhouse gases is essential to mitigate climate change effectively and efficiently[7], and that it should be supported by a general regulation of environmental externalities to avoid unwanted effects. Anchoring mitigation commitments in a global climate treaty has the capacity to protect Australia's economy from unfair competition and to allow continued growth.

Beyond this, this paper and other findings of the Australian National Outlook[3] should trigger debate on how to shape Australia's future. Continuous, resource-intensive growth is one possible pathway, but it will require powerful institutions to restrain the pressure on environmental systems. Another pathway could be an economy shaped by technology and labour instead of energy and resources, allowing less-strict regulation to keep the economy within environmental boundaries. The structural change needed for the latter pathway could be initiated by investing carbon-tax revenues in education and science, establishing markets for flexible electricity consumption, providing bicycle and public-transport infrastructure and promoting healthy and sustainable diets. Australia is free to choose which path to follow. ■

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MATERIALS SCIENCE

Droplets leap into action

What could cause a water droplet to start bouncing on a surface? It seems that a combination of evaporation and a highly water-repellent surface induces droplet bouncing when ambient pressure is reduced. **SEE LETTER P.82**

DORIS VOLLMER & HANS-JÜRGEN BUTT

On page 82 of this issue, Schutzius *et al.*[1] report a remarkable phenomenon: at low pressure, droplets of water resting on an extremely water-repellent surface spontaneously jump and bounce. In some cases, the height of each bounce increases, like a gymnast jumping on a trampoline. The findings add to our understanding of how droplet–surface interactions can prevent the accumulation of water or ice on surfaces.

Ice accretion on surfaces is a big problem in cold regions, particularly for aviation, shipping or offshore industries[2]. Strategies to minimize ice adhesion include using either smooth or highly water-repellent (superhydrophobic) surfaces. Superhydrophobic surfaces are covered with tiny protrusions that have low interfacial energy, which minimizes their attraction to liquids.

A water or ice droplet resting on a superhydrophobic surface sits on top of the protrusions, so that the main part of the droplet's underside is separated from the surface's substrate by a thin layer of air[3] (Fig. 1). The small contact area between the water or ice and the protrusions ensures low ice adhesion. However, the remaining adhesion is usually still sufficiently strong to keep ice in place.