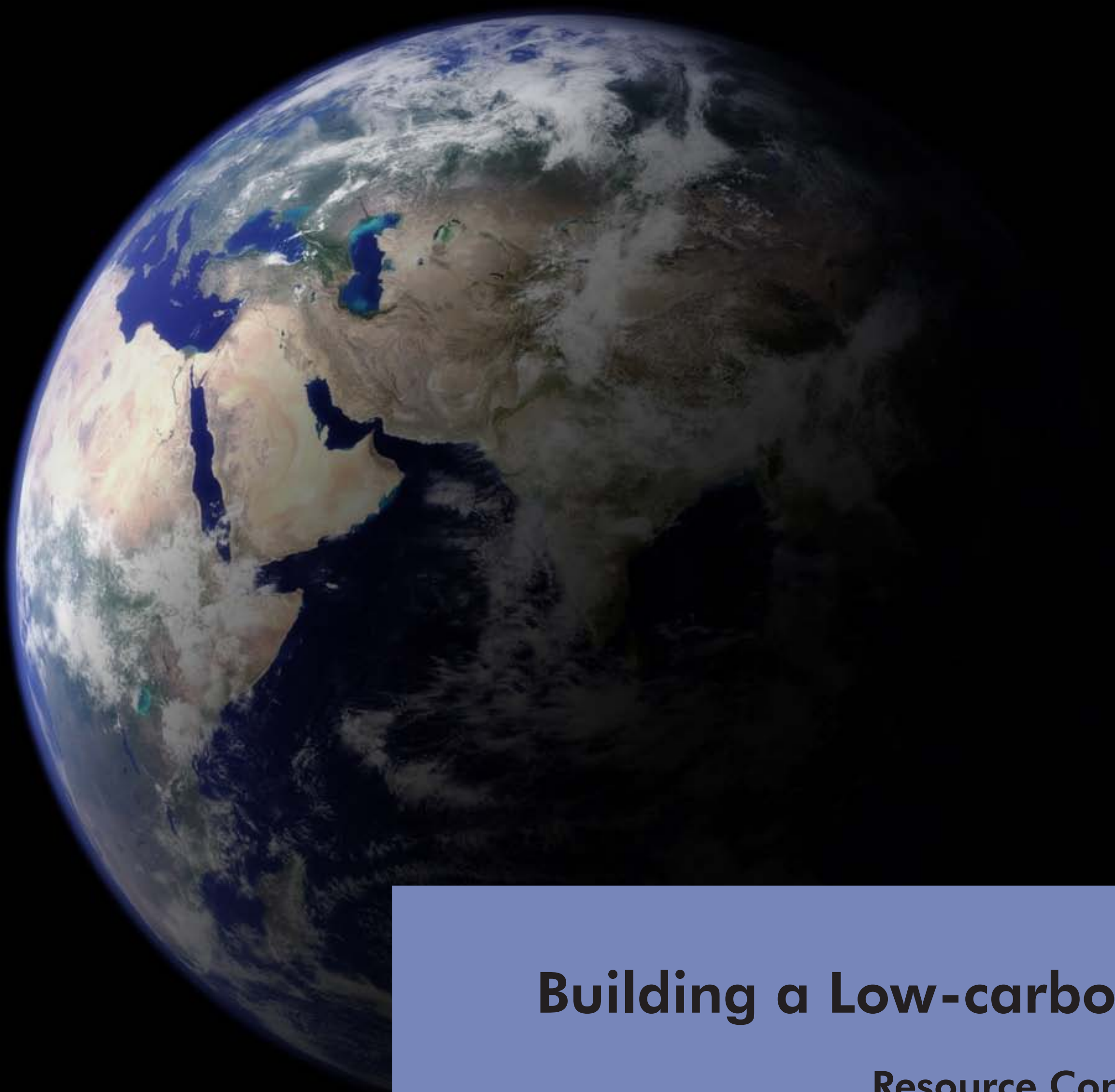


Building a Low-carbon Future

Resource Constraints and Key Strategies to Overcome Them

COMBAT CLIMATE CHANGE
A Business Leaders' Initiative

THE CHALLENGE OF THE GREEN ECONOMY

Building a 'green' economy – with a special focus on energy – is seen as a key strategy to reduce greenhouse gas emissions and prevent dangerous climate change. For countries without vast fossil-fuel reserves, it is also a way to gain energy independence and security.

Yet it is also becoming clear that resource constraints could hinder this endeavour. Low-carbon technologies such as photovoltaics, wind turbines, and electric and hybrid cars, for example, use metals that are mined only in a handful of countries, which can limit their availability. Biofuels development, meanwhile, has raised concerns that fuel crops will displace food crops – or displace forests and vitally important ecosystems. In addition, these crops compete for what are often limited water resources.

As low-carbon power production increases, it too often competes for water supplies that, in many regions, are already being tapped at unsustainable levels. With population growth, rapid urbanization, and the projected impacts of climate change, there is concern about the viability of not just hydropower, but also solar thermal, geothermal and other renewable technologies that require water for cooling.

If low-carbon energy is to be produced on a large scale – a must in order to keep global temperature increases under 2°C – it is crucial to ensure that there are the necessary resources.

That is the focus of this document, which summarises the findings of three studies on resource scarcity and the green economy carried out within the partnership programme between the business leaders' initiative Combat Climate Change (3C) and the Stockholm Environment Institute.

THE STUDIES

The work summarised here pursued two goals: first, to quantify the potential problems, and second, to identify potential solutions – including both existing technologies and policies, and new options to explore.

Resource scarcity is a concern in many areas of business and policy. These studies focused on three that seem particularly pressing in the context of low-carbon energy:

Biomass

Biomass is a promising source of renewable low-carbon energy and a potential source of 'bio-based' industrial materials as well, but it is constrained by land and water availability, by soils' ability to produce biomass, and by the need to return some biomass to the land to retain nutrients and soil moisture. There are also competing uses for biomass, and the need to reduce emissions also constrains land conversion and agricultural practices. This study explores the potential for biomass use under four different scenarios.

Metals

Low-carbon technologies such as photovoltaics, wind power, and electric and hybrid vehicles depend on metals which are becoming scarce, and this could hinder large-scale deployment. This study evaluates the prospects for five metals in particular – cobalt, lithium, neodymium, indium and tellurium – under different energy and global trade scenarios, and examines how governments and businesses are addressing metals supply scarcity, and how they might do better.

Water

Low-carbon electricity generation is crucial not only to mitigate climate change, but also to support development and allow more countries to produce their own energy. There is vast untapped potential around the world, but successfully exploiting it requires understanding how different technologies use water, and plan accordingly. This study compares the water needs of fossil-fuel and renewable technologies, identifies water-saving options, and uses a case study in California to show the trade-offs that may have to be made.

BIOMASS IN A LOW-CARBON ECONOMY

A 'bio-based' economy?

Biomass has a role to play in energy, although electrification and new technologies could reduce this in the long run. Yet as innovators in Brazil, the United States and other countries are already demonstrating, biomass could also become an important renewable resource for industry. In a future 'bio-based' economy, products now derived from petroleum, such as plastics and conductors, could be replaced by materials derived from biomass.

Renewable, but not unlimited

Biomass regenerates naturally, but at any given time, only so much is available, and resources can be degraded through human action and lose their regenerative capacity.

There are also many competing uses for biomass: it is needed for food, animal feed, materials, etc., and in nature, for habitats and ecosystem services. Biomass use is also not always carbon-neutral. When a forest is cleared for agricultural land, for example, a significant amount of carbon is released. In addition, some agricultural inputs emit greenhouse gases during production, and some agricultural practices produce nitrous oxide or methane emissions.

Thus biomass is hardly a 'silver bullet' solution to the low-carbon energy challenge – but it can be part of the answer.

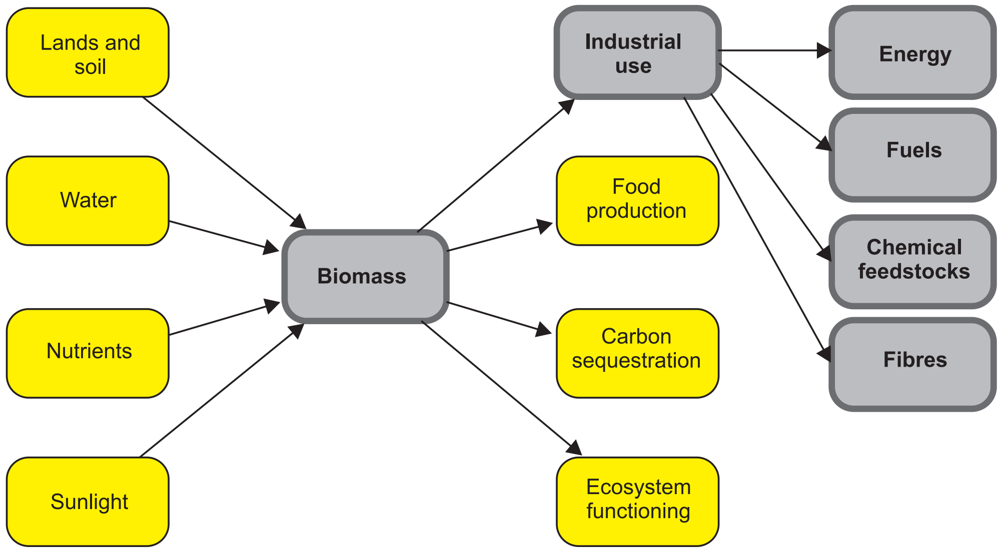


Figure 1: Biomass in nature and in a low-carbon economy

What is biomass?

Biomass is material that comes from a living (or recently living) organism: plants, animals, bacteria – whether it's part of the organism itself (say, wood from a tree), or a product or waste matter (manure, e.g.). Most of the biomass use envisioned for a low-carbon future would involve plants.

Plants are remarkable and unique chemical factories. Photosynthesis is the only process known to break the chemical bonds in carbon dioxide at ordinary temperatures and pressures. Once the bonds are broken, plants construct complex carbon compounds with stable, high-energy bonds that can be used for energy, nutrients, and structural materials. Indeed, all of the complex carbon compounds in today's economy, including fossil carbon, are ultimately derived from a product of photosynthesis, whether directly, as with wheat grain, cotton fibre, and palm oil, or indirectly, as with cellophane, gasoline, and synthetic plastics.

Biomass potential

One way to determine how much biomass will be available for a future low-carbon economy is to gauge the share of the earth's biological production that already goes to human use – a measure called 'human appropriation of net primary productivity' (HANPP).

The most recent major HANPP study[1] found that 14 to 26 per cent of global biomass is used by humans, with an intermediate value of 20 per cent. There are huge regional variations: from 6 per cent in South America, to 24 per cent in North America, to 72 per cent in Western Europe, to 80 per cent in South Central Asia (not all biomass used in each region is local, however).

While there is no specific HANPP value that is 'too high', there is evidence that higher HANPP tends to impair ecosystem functioning. Since 20 per cent is clearly already high, a bio-based economy will have to be carefully built to avoid stressing resources beyond their capacity to renew themselves.

1 Imhoff, M. L., Bounoua, L., Ricketts, T., Loucks, C., Harriss, R. and Lawrence, W. T. (2004) 'Global patterns in human consumption of net primary production'. Nature, 429(6994). 870–73. doi:10.1038/nature02619.

Boosting crop yields

The biggest constraint to biomass production for a bio-based economy is land availability – and the biggest chance for growth is to boost crop yields. Improvements could be made on two fronts: increasing yield potential (the yield under ideal conditions), and shrinking the gap between potential and actual yields.

Some countries have very low yields compared with potential. Boosting those yields will require addressing not only biophysical parameters – soil quality, water availability, weather – but also economic, political and cultural factors.

In already high-yielding areas, the potential to improve crop yields may be limited, and yield increases have slowed and plateaued in many countries in recent years. In those countries, light utilization (photosynthesis) is seen as the most promising target for breeding and genetic modification to further increase yield potential. Some have estimated that with an active research programme, plants with up to 20 per cent higher photosynthetic efficiency could be in farmers' fields within 25 years.

Still, soils, climate, and slope may not be ideal for a given crop, and farmers always face economic constraints, so realized yields will never fully match yield potential, even if all other stresses – such as pests and diseases – are effectively controlled. Thus it is likely that in the future, more land will be needed to support biomass production. Given that, according to the UN Food and Agriculture Organization (FAO), most highly productive land is already occupied, lower-quality land may need to be used.

BIOMASS IN A LOW-CARBON ECONOMY: 4 SCENARIOS

The future of biomass use in the global economy is filled with uncertainties, many linked to human choices – specifically, whether to act aggressively to mitigate and adapt to climate impacts, and whether to boost agricultural production to feed a fast-growing population.

To gauge the prospects under these different policy agendas, four scenarios were created, defined by whether the focus is on the climate, on agriculture, on neither, or on both.[2] Assumptions about biomass demand under these scenarios were fed into a model that also considered biomass yields, the share and types of biomass available, biomass uses, waste, and other factors.

Single Bottom Line

A world in which the main focus is on economic growth. There is little attention paid to climate beyond the policies currently in the pipeline, and little interest in making agriculture more productive or sustainable.

Meeting the Climate Challenge

The world adopts strong climate policies, with a prominent role for biofuels. Biofuels markets drive investment and productivity improvements in agriculture, with few policy interventions.

Feeding the Planet

World leaders cannot agree on strong climate policies, but public and private actors do focus intensely on feeding the world and seek to boost agricultural yields without seriously damaging ecosystems.

Sustainability Transition

People worldwide frame their future in terms of sustainability, and see the pursuit of a bio-based economy as one way to achieve this. There is a strong policy push towards limiting human impacts on the climate while also developing a high-yielding but sustainable agriculture. Only the first steps can be taken in the relatively short time of the scenario, but by 2035, it is clear that a sustainability transition is possible.

2 Energy demands are adapted from International Energy Agency (2010) World Energy Outlook 2010. Paris, France. http://www.worldenergyoutlook.org/2010.asp. Food demands are adapted from Food and Agriculture Organization of the United Nations (2006) World Agriculture: Towards 2030/2050. FAO Global Perspective Studies Unit, Rome, Italy. http://www.fao.org/economic/esa/esag/en/.

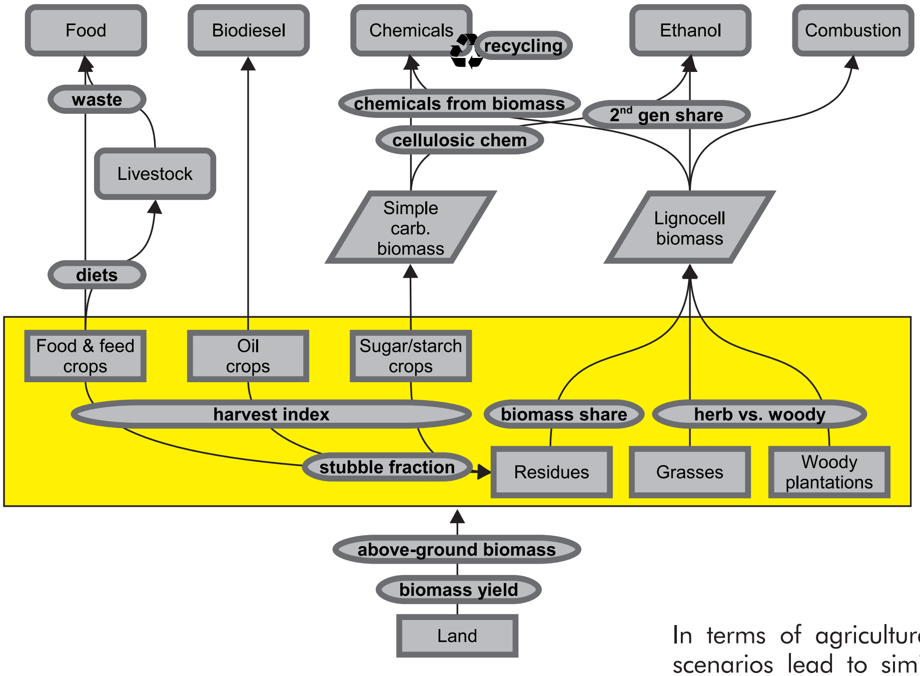


Figure 2: Biomass model schematic

Scenario findings

The Meeting the Climate Challenge scenario keeps cumulative emissions to 1,000 Gt CO_2 by 2035, but requires either zero annual emissions from 2036 onward, or net negative emissions later in the century. In contrast, the Sustainability Transition scenario seeks to meet climate mitigation targets soon, sharply reducing annual emissions by 2020 using more biomass for energy (25 per cent of the total supply in 2035, versus 13 per cent under Meeting the Climate Challenge). Nevertheless, total demand for biomass is not much greater, kept in check by low total energy consumption and lower meat consumption.

In terms of agricultural land use, three of the four scenarios lead to similar increases. However, in the Sustainability Transition, that is partly because some productive agricultural land is given up to restore ecosystems, and some potential yield increases are sacrificed for a smaller environmental impact.

In the Meeting the Climate Challenge scenario, moderate increases in biofuels production and large increases in food production expand the agricultural footprint. In the Feeding the Planet scenario, significant crop yield increases boost agricultural output while shrinking the agricultural footprint – but carbon emissions continue to rise rapidly. In the Single Bottom Line scenario, perhaps the closest to current political realities, emissions and land use both continue to rise, pushing planetary boundaries.

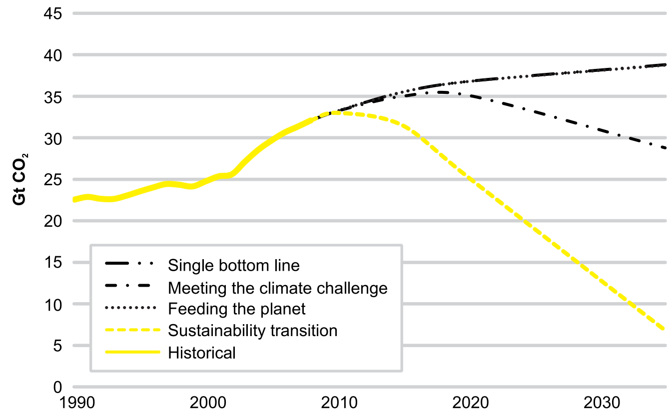


Figure 3: Annual emissions, in gigatonnes of carbon dioxide, under the four scenarios

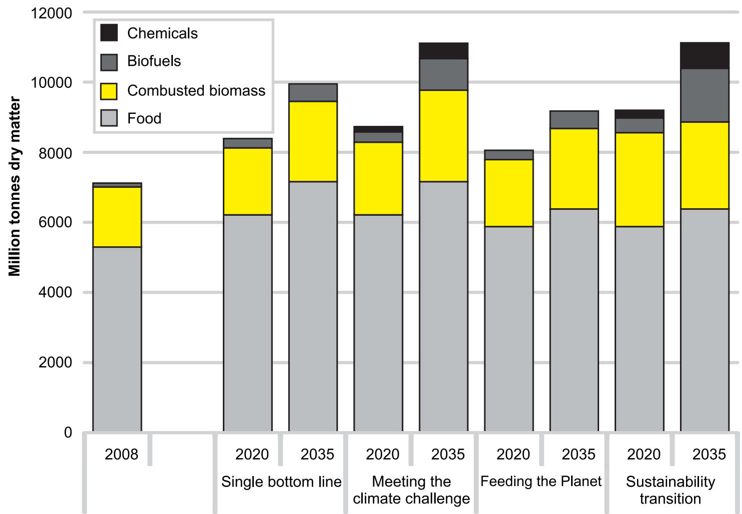


Figure 4: Biomass use under the four scenarios

A promising option

The analysis suggests that while no one path is perfect – and most would increase pressure on the land – a 'Sustainability Transition', combining a focus on both agricultural production and climate mitigation, could yield benefits on both fronts.

It is important to note, in this context, that in our current political and economic systems, resource allocation is driven primarily by effective demand, rather than human needs. For the bio-based economy, this means in the short term, development is likely to be driven by demand from wealthier 'eco-conscious' consumers. Eventually, however, it is important to ensure that products are affordable and accessible to all, while keeping resource use within critical thresholds.

The development of a bio-based economy will also require both private- and public-sector leadership. Companies can play a key role by finding a niche within the value chain and continuing to innovate. The public sector can encourage the use of bio-materials through R&D investment and purchasing.

Improving agriculture

Boosting agricultural yields is crucial, and this will require a major, focused agricultural research programme with both public and private funding. Returns on agricultural investment in both sectors are high, around 20-30 per cent, with a payoff period of 8-15 years in the private sector and 15-25 years in the public sector. Most of the research would focus on raising yield potential and closing yield gaps, but it should also seek to better understand the people who produce the crops, and how livelihoods and social and institutional dynamics affect yields.

A problem of scale

Low-carbon technologies are vitally important for climate change mitigation – and to increase energy security. Yet in order to make a significant impact, these technologies will have to be deployed on a very large scale. This could create challenges, because many depend on metals that are relatively scarce. For example, the thin films in photovoltaics use indium and tellurium; magnets in wind turbines use neodymium, and batteries in plug-in hybrid and electric cars use lithium and cobalt.

To gauge the potential for shortages of these metals, a custom-built scenario calculator was used to estimate future supply and demand under three energy scenarios and three global minerals market scenarios, described on the next page. This is essentially an accounting model that tracks the five metals from their potential production sources through to demand. Values are reported for 2008, 2020 and 2035.

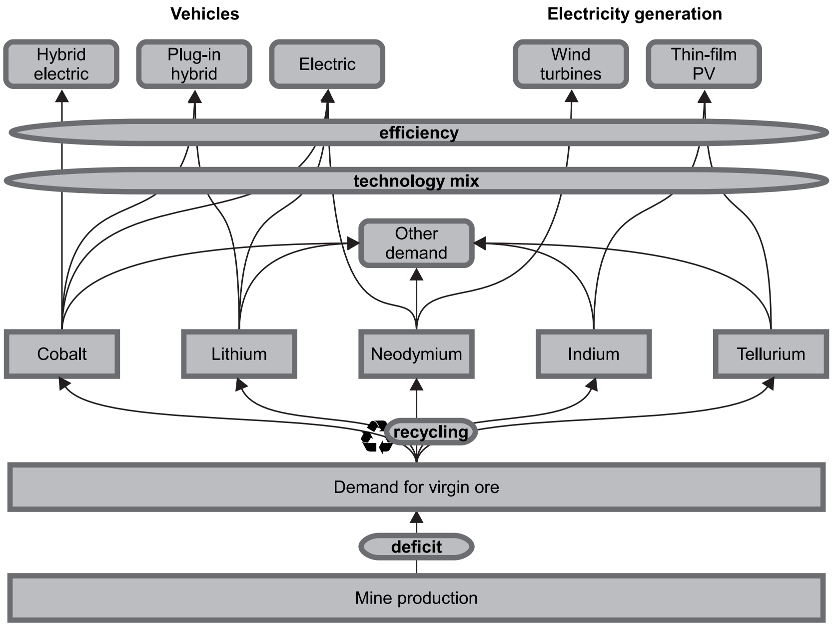


Figure 5: Metals model schematic

Demand and supply scenarios used

Energy demand and emission scenarios were drawn from the IEA's *World Energy Outlook 2011*:

IEA Current Policies Scenario: A baseline scenario in which only policies already formally adopted and implemented are taken into account.

IEA New Policies Scenario: This scenario assumes that existing policy commitments and plans for environmental protection or energy security are carried out, though in a cautious manner. This includes emission reduction commitments under the Copenhagen Accord and agreements to phase out fossil-fuel subsidies.

IEA 450 Scenario: In this scenario, energy-related emissions follow a trajectory that keeps CO_2 concentrations below 450 parts per million (ppm) in the long run, but only after an initial overshoot. Thus this scenario fits our definition of a "low-carbon economy", but not very robustly, since it postpones aggressive action to reduce emissions, and implies substantial carbon sequestration after 2035.

The metals supply scenarios are drawn from the World Economic Forum's *Mining and Minerals Scenarios 2010*:

Green Trade Alliance: The world is divided, and countries are defined economically by whether they belong to the Green Trade Alliance (GTA), formed in 2016 to promote "environmental sustainability without compromising competitiveness."

Rebased Globalism: The world is committed to realising the benefits of global interconnection but has become far more complex and multi-polar. Power comes from control of resources as well as possession of capital, with resource-rich countries playing by their own rules.

Resource Security: The era of globalization is a distant memory, as nations prioritize narrow self-interest. They hoard domestic resources, enter cartels based on regional and ideological alliances and resource blocs, and engage in neo-colonialism and import substitution strategies.

Scenario findings

The outlook varies considerably depending on the scenario combination, but some patterns are evident. In short, the analysis found that there would be:

- Severe risk of medium- and long-term CSD (cumulative supply deficits) of indium and tellurium;
- Moderate risk of medium-term and severe risk of long-term CSD of neodymium; and
- Limited risk of long term CSD of cobalt and lithium.

Both the public and private sectors can take action to reduce the risks, and there is evidence that they are already doing so. Conversely, some choices may exacerbate problems and imperil the future of the low-carbon economy.

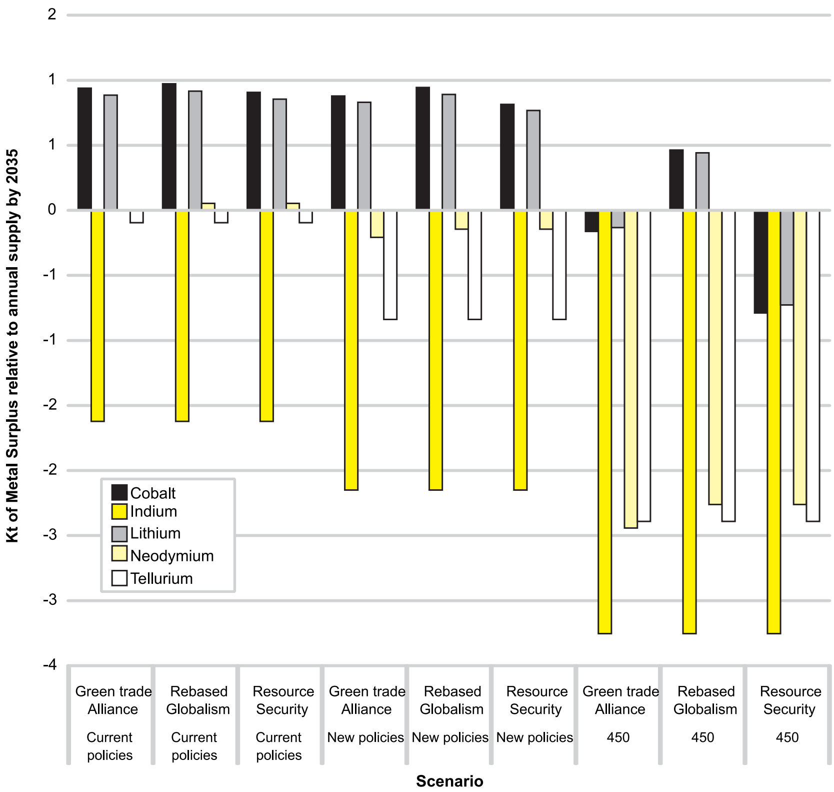


Figure 6: Annual metal surplus/deficit relative to annual supply in 2035

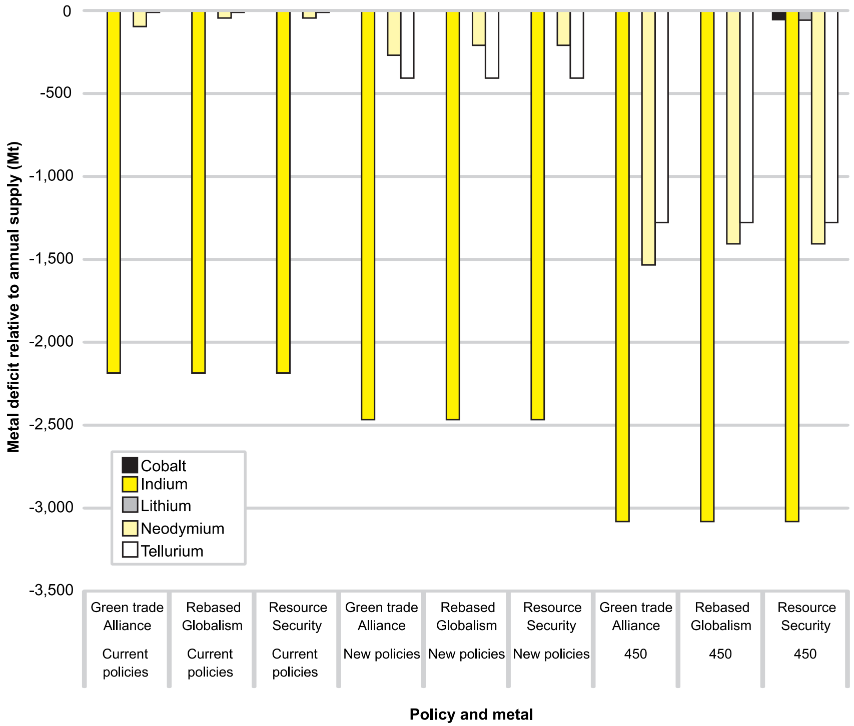


Figure 7: Cumulative metal deficits relative to cumulative supply by 2035

Cumulative effects[3]

By 2035, there are cumulative deficits of all five metals, most notably for indium, which shows significant cumulative deficits under all scenarios, but also for tellurium and neodymium, even though the annual data had not shown a deficit of neodymium under the IEA Current Policies scenario in 2035. The cumulative deficits under that scenario arise from deficits in previous years.

The amount of deficit in both indium and tellurium remain exactly the same within each IEA scenario regardless of the WEF scenario. The changes in the supply-side variables for these metals are not enough to outweigh the demand drivers of the increased low-carbon energy demand.

3 The gap between production and requirements varies from year to year. Our model assumes that in years in which there are surpluses, the extra supply can be stockpiled for use in leaner years. Although the opposite is not true – metals deficits do not build up over time – the long-term balance of surpluses and deficits determines whether surplus-year stockpiles are enough to offset annual deficits. The cumulative figure shows that deficits exceed surpluses, so stockpiling will not be enough to avoid shortages.

WHAT DRIVES METALS SCARCITY?

Factors affecting supply

Metals can come from two sources: primary supply, which is produced from mining virgin materials from environmental stocks, and secondary supply, which is produced through recycling.

Primary supply is affected by the absolute availability of a metal, the economics of production, access to reserves and produced material, and associated environmental and social impacts. Politics, economic trends and government actions – taxes, purchasing, regulations, trade policies – can all have an impact.

Regulations that restrict or increase the cost of production, for example, could increase prices and limit supplies. Also, because mines cannot adapt quickly to changes in demand, prices may be highly volatile.

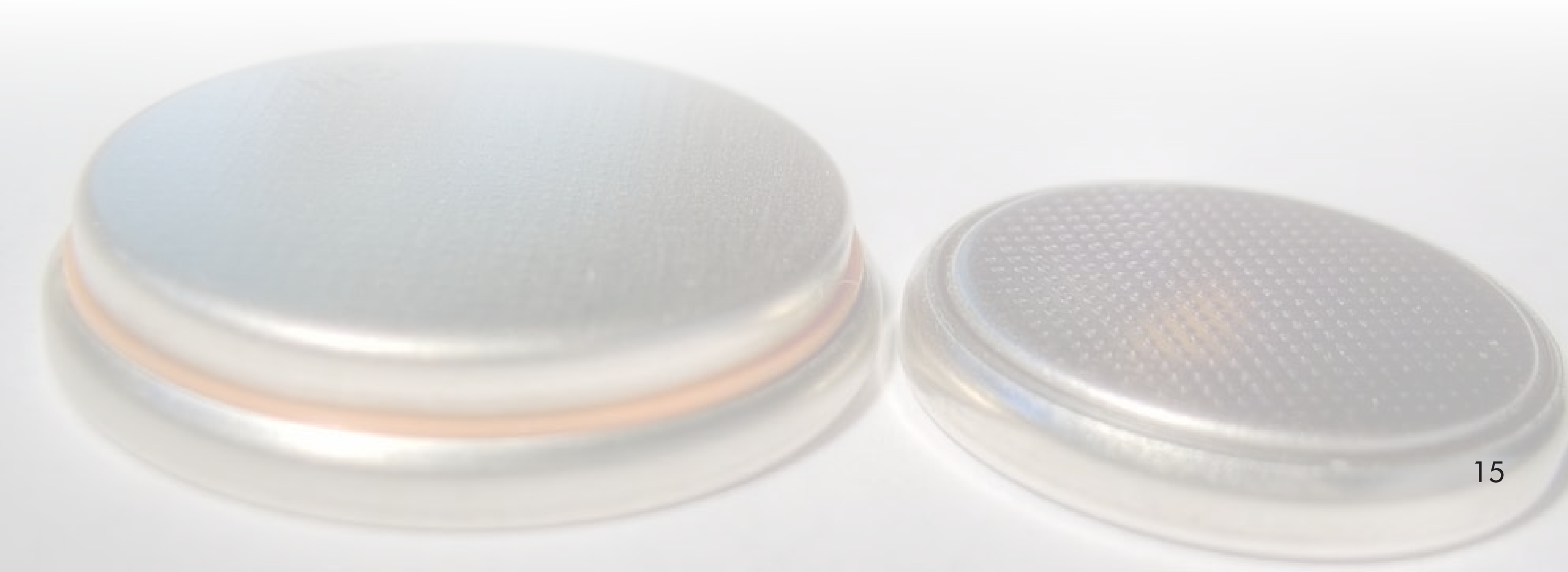
Recycling, meanwhile, is constrained by logistical, technological and economic factors, and is likeliest to succeed when metal prices are high enough to make the costly recovery process economically viable.

Factors affecting demand

Low-carbon technologies do not all use the same scarce metals, and the share of technologies using a specific metal may change over time. Some technologies may apply alternative, cheaper or more readily available materials, depending on manufacturers' production methods and markets.

Yet demand for some metals can also rise: for example, hybrid vehicle manufacturers have been switching to lithium ion batteries, boosting lithium demand. And scarce metals also have other, competing uses, such as in monitors and displays, microchips, lasers and many medical technologies.

The potential for reducing demand through waste management or lean production, meanwhile, is minimal, as the scarcity and price of these materials has already led companies to try to maximize efficiency and minimize waste. However, environmental regulations and voluntary efforts to reduce environmental impacts could both affect future demand for scarce metals.



RESPONDING TO METALS SCARCITY

Business responses

Potential responses to metals scarcity include substitution – of the materials or of the technologies that use them; recycling, and efficiency improvements.

Substitution

Several companies are already pursuing substitution strategies, and policy incentives can encourage this. Businesses are looking to replace indium and gallium with tin and zinc in semiconductors, for example, though efforts are still at the R&D stage.

However, some substitutions could also just create a different scarcity problem, as many alternatives use other scarce elements, such as rare earths. One solution may be non-metal substitutes, such as plastic electronics being developed for photovoltaic (PV) cells and light-emitting-diodes (LEDs).

Efficiency

Manufacturers using scarce metals already make significant efforts to maximize efficiency and minimize waste. There may also be room for efficiency improvements in materials production, particularly for those mined as by-products of a primary metal, such as indium and tellurium, which are by-products of zinc and copper mining. Refineries focused on processing ores for a primary metal may not currently have the capability to recover secondary metals.

Recycling

Indium and tellurium availability is already considered a bottleneck to thin-film PV expansion, and the prevalent response has been to promote recycling. It helps that cadmium telluride (CdTe) modules are already recycled due to the toxicity of cadmium; however, one executive interviewed noted that there is not enough tellurium in circulation to make this a viable solution.

Policy responses

Both energy policy and international trade policies and power dynamics can dramatically affect metals supply and demand. The stronger the climate policies that are adopted, the larger the projected deficits of indium, tellurium and neodymium. And WEF's Resource Security scenario, in which countries prioritize narrow self-interest, would likely exacerbate scarcity problems in much of the world.

What countries are doing now

A comprehensive global review of scarce metals policy published in 2009 by The Hague Centre for Strategic Studies identified six realms for intervention: national governance, trade restrictions, technology advancement, proactive acquisition, development cooperation, and global governance.

National approaches vary considerably, but the analysis found several common trends. First, policies view mineral scarcity as primarily a technological issue, and innovation as the top solution. Second, there is a limited focus on scarcity in policies; except for the United States, China and Japan, most countries focus on technological advancement and environmental sustainability, not on securing supplies.

Finally, the analysis shows a strategic use of international partnerships. A number of countries are working to create open markets and an international level playing field, both to secure a steady flow of resources, and to promote openness in pricing and trading.

What business leaders want

There is no consensus among business leaders about the best way for government to address metals scarcity concerns. Executives cited different priorities both for financial incentives and for interventions aimed at securing mineral supplies.

Many companies, especially the larger multinationals, are less interested in state-supported efforts to secure certain materials, often because they have access to resources in multiple countries. Such businesses favour a liberalization of international markets, with minimal government intervention, except to set a carbon pricing system to foster low-carbon technology industries.

WATER AND THE LOW-CARBON ECONOMY

A global renewables push?

On a global scale, renewable sources provided 18 per cent of electricity in 2007, according to the IEA, and climate change concerns and a desire to foster the 'green economy' have accelerated these technologies' deployment in recent years.

In its *Energy Technology Perspectives 2010*, the IEA lays out a scenario that would halve global energy related CO_2 emissions by 2050; it would require doubling renewable generation by 2020, with wind power growing at an average of 17 per cent per year, and solar power, by 20 per cent.

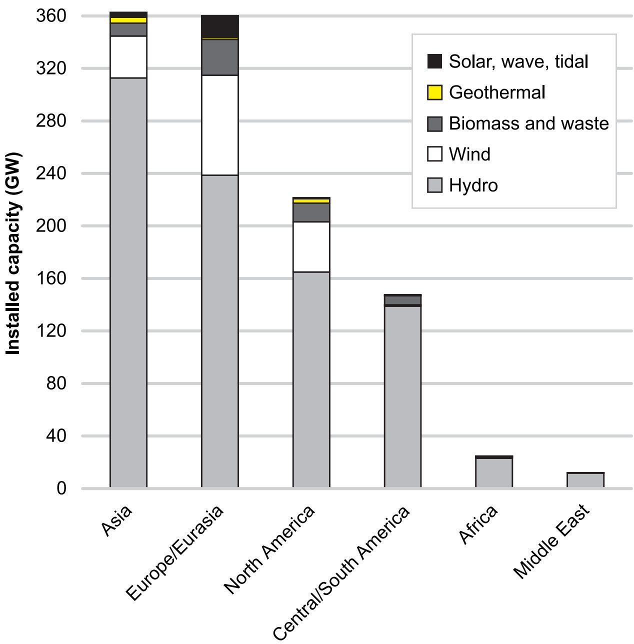


Figure 8: Installed renewable generation capacity by region, 2009

The water-energy nexus

Yet some of these technologies, like their conventional counterparts, also require considerable amounts of water. Given competing demands, resource depletion and projected climate impacts, sufficient water may not always be available to meet all needs in all places.

Some of the same factors that restrict water supplies – competing demands due to economic and population growth, and expected thermal extremes due to climate change – may also increase energy demand, and with it, demand for water for the electricity generation sector.

This study explores the ways in which climate change and associated hydrologic changes may affect water availability for electricity generation, and the implications for different low-carbon technologies. The situation in each place will be different, but our goal is to illustrate potential trade-offs and solutions.

Water and electricity production

Water is used all across the energy sector, in everything from fuel production, to power plants, to energy storage. Hydropower draws energy directly from the flow of rivers and the release of stored water. Fossil-fuelled and nuclear power plants, which generate the majority of many countries' electricity, rely heavily on water for cooling – as do solar thermal and geothermal plants.

Water requirements for power generation depend on several factors, including overall and time-specific electricity demand; how the fuel – if any – is extracted and processed; which generation technology is used – not just the basic category, but the specific configuration; the cooling technology – if any – and whether carbon capture and sequestration (CCS), which also uses water, is deployed.

Two measures of water use

Water use is gauged in two ways: withdrawals, which involve removing water from a source and either returning it to the source, or making it available elsewhere, and consumption, which is water that is not returned to the system, typically due to evaporation.

The 'thirstiest' energy technology in terms of *withdrawals* is nuclear power, which withdraws 95 to 227 m^3 per MWh when using once-through cooling, compared with 76 to 189 m^3 for a coal plant with the same cooling technology. (Natural gas plants need significantly less cooling, so 60 per cent of plants in the U.S. use dry cooling, which requires only 0.008 m^3 per MWh).

Nuclear power's *consumption*, however, while still high – 1.5 m^3 per MWh with once-through cooling – compares favourably to some concentrating solar power (CSP) technologies (e.g. Fresnel systems with wet cooling, which use 3.785 m^3 per MWh), and to some geothermal technologies (e.g. enhanced geothermal systems, which use 3.22 m^3 per MWh with dry cooling and 18.10 m^3 with tower cooling.

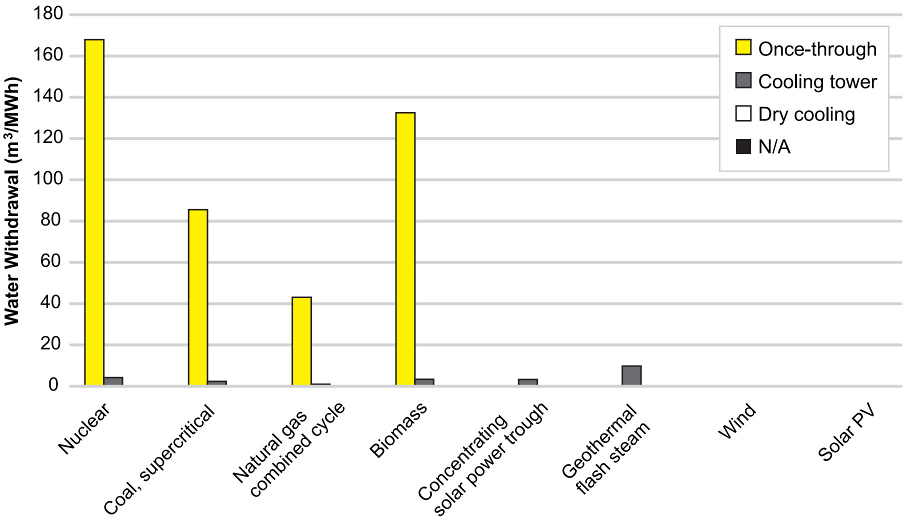


Figure 9: Water withdrawals by fuel and cooling technology during plant operation

Location matters

In places where water is plentiful, water demand for power generation may not be a concern. The difficulties arise when water supplies are limited. For example, in the Mediterranean region and southern Europe, hydropower potential is expected to decline by 20 to 50 per cent with climate change; in Bolivia and Peru, the retreat of tropical glaciers in South America already affects hydropower generation.

The challenge for certain low-carbon electricity technologies is that the optimal sites may be water-scarce by nature. CSP, for example, needs strong, direct sun rays, which means it is most viable in very hot, dry areas – Spain is the current world leader, and projects are under development in northern Africa and the Middle East, among other regions. Geothermal energy faces some of these issues as well, although often it can use geothermal fluids for cooling, reducing pressure on water supplies.

The CCS conundrum

Given the large share of global CO_2 emissions produced by the energy sector (28 per cent from coal plants alone), many see CCS as a crucial technology for rapid mitigation; the IEA's rapid-mitigation scenario envisions its use with more than 90 per cent of coal power by mid-century. Yet adding CCS to a coal-fired or natural gas plant increases water withdrawals by 41 to 95 per cent, and consumption by 45 to 91 per cent, the U.S. National Energy Technology Laboratory found.

Water use with CCS will vary significantly depending on both the energy and the CCS technology involved. Integrated gasification combined cycle (IGCC) plants, a newer technology, are a promising option, as they produce electricity more efficiently while still allowing for capture of CO_2. In all cases, however, CCS also consumes electricity and thus decreases the power output of the plant.

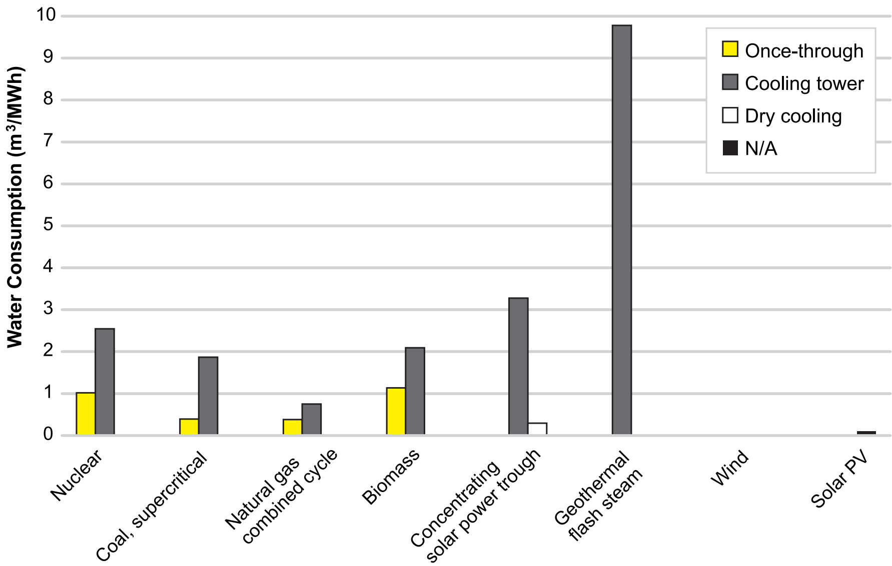


Figure 10: Water consumption by fuel and cooling technology during plant operation

The impact of climate change

Water availability is affected by many factors, including land cover change, urbanization, industrialization and engineering schemes designed to maximize human access to water, such as reservoirs, irrigation systems and inter-basin transfers.

Climate change will affect the distribution and availability of water supplies. New areas may become water scarce and drought-prone, while others will have more rain and fuller rivers; it is impossible to generalize, as impacts will be regional or even more narrowly location-specific.

Water-energy conflicts are already arising, however, particularly during droughts and summers, when energy demand is high and water availability is low. Sometimes power plants are being forced to curtail output or shut down. In the future, power generation is likely to be even more vulnerable.

Climate change and the water-energy nexus

Year	Region/ Country	Climate Event	Consequence
2011	Texas, USA	Drought and heat wave	Farmers, cities and power plants compete for the same limited water resource. After the driest 10 months on record (since 1895), at least one plant was forced to cut its output, and some plants had to pipe in water from new sources to maintain generation. If the drought continues throughout 2012, several thousand MW of electricity may go offline (O'Grady 2011; Averyt *et al*. 2011).
2010	Washington, USA	Low snow-pack, followed by heavy rains	Given changes in precipitation regime, the peak streamflows were not aligned with power projections, straining hydropower generation and affecting electricity prices (Averyt *et al*. 2011).
2010	Lake Mead, Nev. & Ariz., USA	Low water levels	Lake Mead water levels in dropped to levels not seen since the 1950s, prompting the U.S. Bureau of Reclamation to reduce the Hoover Dam's generating capacity by 23% (Walton 2010; Averyt *et al*. 2011).
2007	North Platte River, Neb. & Wyo., USA	Extended drought	After a 7-year drought, power generation from the North Platte Project, which includes hydropower plants on North Platte River, was reduced by about 50%. A Laramie River coal-fired Station (Wyo.) was at risk of insufficient cooling water and avoided impacts to power production by consuming water from local irrigation districts and the High Plains aquifer (Cooley *et al*. 2011; Averyt *et al*. 2011).
2006	Midwest	Heat wave	Nuclear plants forced to reduce output at time of peak demand; high river water temperatures, typically used for cooling, forced a Minn. plant to reduce generation by 50% (Averyt *et al*. 2011).
2006	Uganda	Drought	Hydropower capacity was reduced by one-third, with subsequent electricity shortages (Collier 2006).
2003	Germany	Heat wave	Increased river water temperatures led German authorities to close a nuclear power plant and reduce output at two others (Cooley *et al*. 2011).
2003	France	Heat wave	Increased river water temperatures induced the French government to shut down 4,000 MW of nuclear generation capacity (Cooley *et al*. 2011).
2001	Brazil	Drought	Combined with increased energy demand, country experienced 'virtual breakdown' of hydro-electricity and reduced GDP (Bates *et al*. 2008).

CASE STUDY: CALIFORNIA

California is the most populous U.S. state, with 37 million residents as of 2010, and has a larger economy than Brazil, with a $1.89 trillion gross state product in 2009. California is also increasingly water-constrained, with warmer winters and reduced snowpack in its mountainous areas, and high water stress in its drier southern areas. These constraints, and concerns about how climate change may worsen them, have forced California to proactively address the water-energy nexus.

A renewables pioneer

California has also been a leader in supporting renewable energy development through market-based incentives. In 2009, approximately 20 per cent of all electricity generated within California came from renewable resources such as wind, solar, geothermal, biomass and hydroelectric facilities. This is expected to rise to 33 per cent by 2020 under the state's Renewables Portfolio Standard (RPS), which was adopted in 2002 and enhanced in 2011.

Case study approach

The case study evaluates the carbon emissions and water use implications of the RPS, and investigates the potential impacts of modifying the RPS to favour technologies that reduce both emissions and water use.

The study used the Long-range Energy Alternative Planning (LEAP) system, developed by the Stockholm Environment Institute, to build an integrated electricity and emissions model, using data on electricity consumption, power plant capacities, generation by fuel and technology, and emissions.

For each power generating technology, water intensities for withdrawals and consumption were incorporated. Three scenarios were then investigated up to 2020,

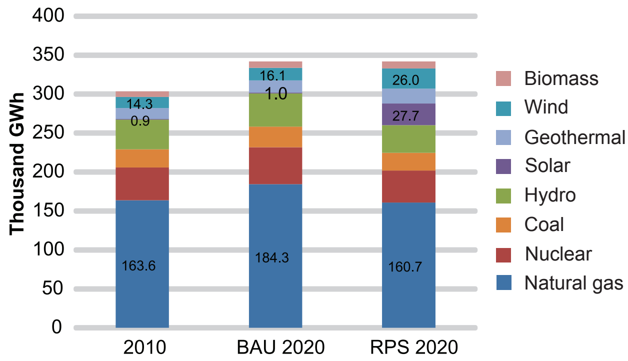


Figure 11: Simulated electricity generation by fuel type for the baseline (BAU) and RPS scenario

which is the target horizon of the current RPS: a baseline scenario, the RPS, and a modified version of the RPS that was called RPS+Technology.

RPS+Technology in detail

For this scenario, the same fuel mix as the RPS scenario was assumed, but technologies were switched. The RPS solar portfolio, dominated by CSP (70 per cent vs. 30 per cent photovoltaic), was switched to a 50:50 mix by 2020, and a portion of once-through systems was changed to wet-recirculating, and a portion of biomass and natural gas wet-recirculating, to dry cooling.

Because some of these changes affect energy efficiency, leading to slightly higher greenhouse gas emissions, CCS technology was also added to 17 per cent of the state's natural-gas generation capacity.

Scenario results

The analysis shows that under business as usual (BAU), greenhouse-gas emissions, water withdrawals and water consumption all increase going forward, as overall electricity demand increases. Under the RPS, emissions and water withdrawals drop, but water consumption increases. Under RPS+Technology, both emissions and water withdrawals decline considerably compared with BAU, while water consumption rises modestly, far less than under the other two scenarios.

The RPS scenario thus illustrates how various generation, cooling, and carbon management strategies can be packaged in an attempt to reduce both GHG emissions and pressure on water resources. The exact 'optimal' combination, of course, will also depend on economic factors, and will vary by location.

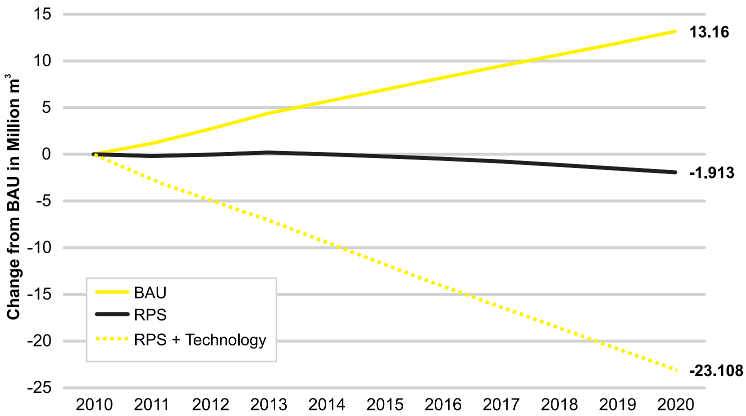


Figure 12: Change in GHG emissions under the three scenarios

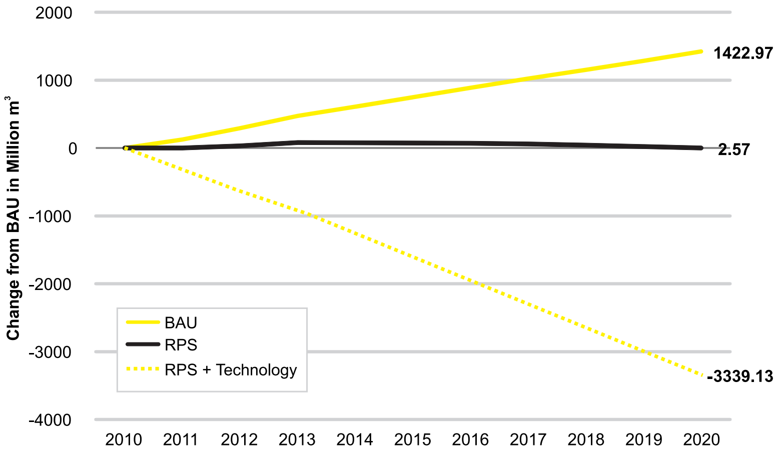


Figure 13: Change in water withdrawals under the three scenarios

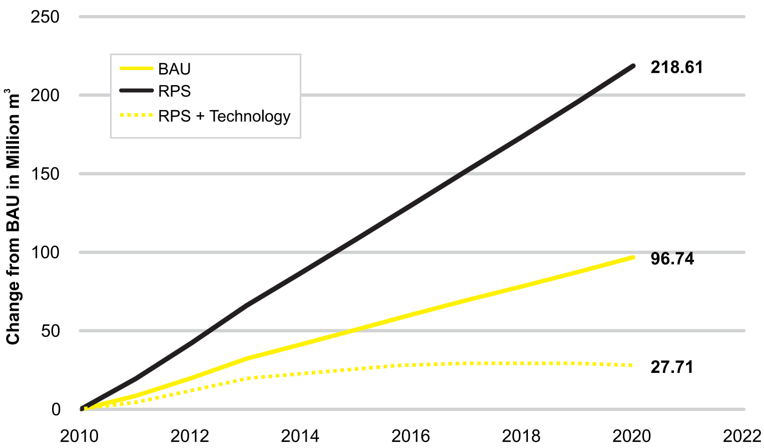


Figure 14: Change in water consumption under the three scenarios

ENERGY PLANNING IN A WATER-CONSTRAINED WORLD

Key considerations

All energy planning – including efforts to boost renewable capacity – should carefully consider future water availability under multiple usage and climate scenarios, to ensure that new generation capacity is viable even in the lowest water availability scenarios.

Given projected water shortages and competing demands in many places, energy planners may want to prioritize low- and no-water renewable energy technologies such as solar PV, wind, small-scale hydropower and binary-cycle geothermal. Water-efficient cooling technologies can also significantly reduce water demand. However, efficiency may sometimes be compromised, especially in very hot areas. In these cases, a hybrid system that uses wet cooling on hot days may work best.

Efficiency and recycling

There is significant potential to reduce demand for electricity – and thus for water for power plants – through efficiency improvements in electrical devices, electricity transmission and distribution systems, and power plant operations. All these options should be explored and pursued when feasible.

Water recycling and reuse also could decrease the need for water withdrawals. Several types of wastewater are being considered for power plant cooling: Treated municipal wastewater is a huge unclaimed water resource, with 32 billion gallons treated daily in the U.S. Water discharged during oil and natural gas mining, wastewater from industrial processes, and agricultural runoff may also be options.

Energy storage

Energy storage can help even out demand for power generation (smooth the load) and enable power plants to operate at maximum efficiency, making it critical to a low-carbon future.

Technologies such as pumped hydro and compressed energy storage systems (CAES) offer the largest and most economical grid-scale energy storage options. These technologies can also give power plants more flexibility to reduce production during times of drought or high water demand for other uses.

CONCLUSION

These studies confirm that business leaders and policy-makers are right to be concerned about potential resource scarcity and its implications for the low-carbon economy. Yet none of the challenges are insurmountable, nor is there any reason to believe that a low-carbon transition is unfeasible. Instead, careful consideration of the issues reveals new opportunities.

The key lesson here is that technologies and industries cannot continue to develop without regard for the bigger picture. The future of the low-carbon economy depends on the ability of businesses and policy-makers to recognise these real constraints and respond appropriately.

The studies offer many examples of viable strategies to address resource scarcity. They also highlight the importance of focused investment in research and innovation – by both the public and private sectors – and of smart policies. The 'right' answers are not always clear, but with proactive efforts and collaboration, the low-carbon transition can succeed.

This document summarises work in the second of three research projects within the partnership programme between 3C (Combat Climate Change) and the Stockholm Environment Institute. The project team has included Matthew Chadwick, Victoria Clark, Elena Dawkins, Richard Falk, Jesse Fahnestock, Amanda Fencl, Sivan Kartha, Eric Kemp-Benedict, Vishal Mehta, David Purkey, Katy Roelich, Annika Varnäs and David Yates

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3C (Combat Climate Change) is a business leaders' initiative started in 2007 to provide recommendations on global climate policy. More than 70 companies around the world have supported the initiative and, since 2010, 3C has collaborated with the Stockholm Environment Institute (SEI) on research into climate policy. This document is a summary for decision-makers of the second of three joint research projects within the partnership programme.

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