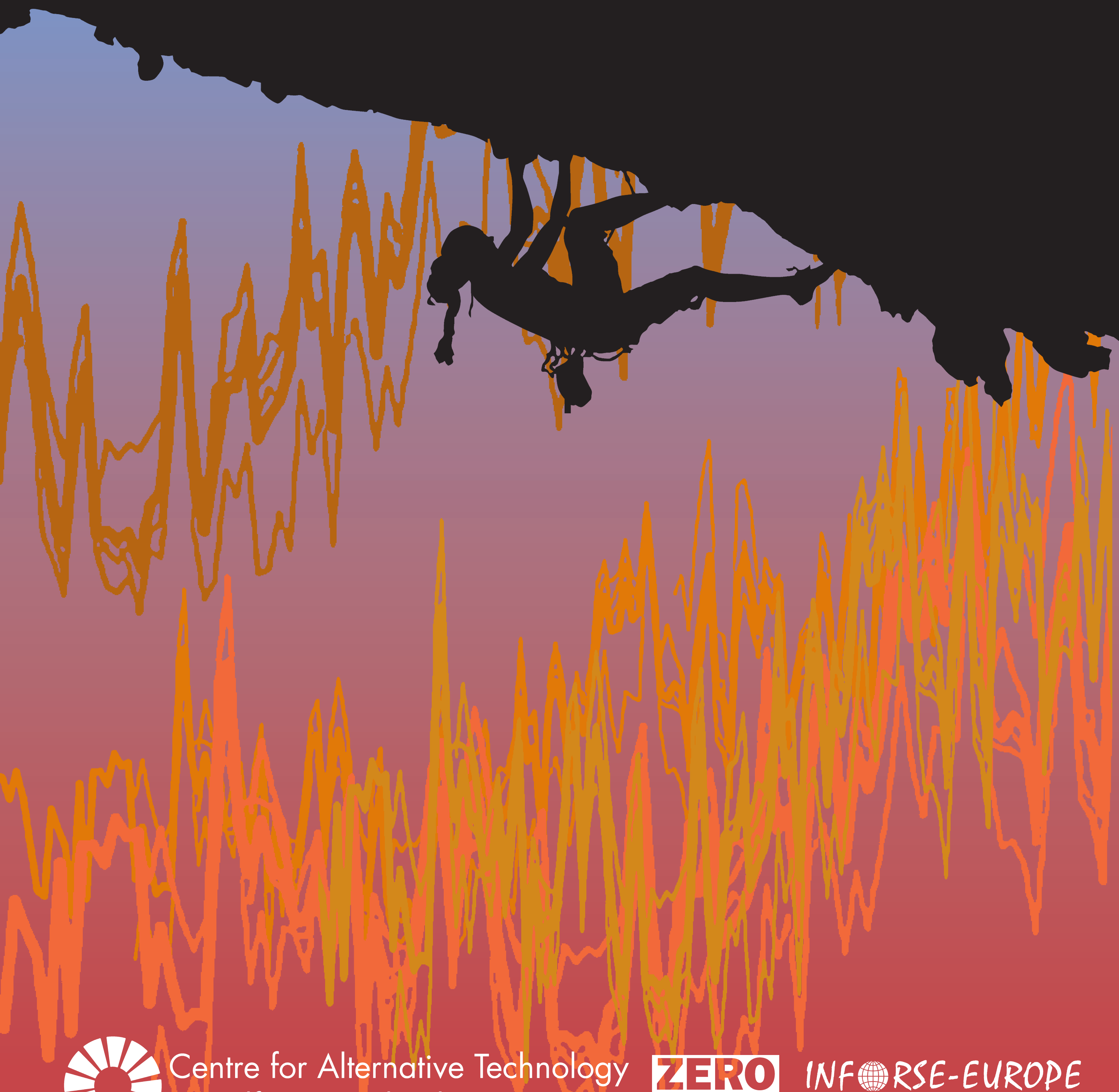
RAISING AMBITION

ZERO CARBON SCENARIOS FROM ACROSS THE GLOBE



Centre for Alternative Technology
Canolfan y Dechnoleg Amgen

ZERO CARBON BRITAIN

INFORSE-EUROPE
International Network for Sustainable Energy

RAISING AMBITION

Zero Carbon Scenarios from Across the Globe

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1. ABOUT THIS REPORT

The Centre for Alternative Technology (CAT) helps people to live well on a finite planet, from individuals gaining information and skills to politicians making decisions on a larger-scale.

Established over 40 years ago as an experiment in sustainable living, CAT Charity is now known throughout the world as a centre of excellence for environmental education. It provides a wide range of short courses, postgraduate degrees and a strong educational programme supporting schools and colleges in delivering sustainability education. In-depth information is available on a wide variety of topics, including green building and architecture, renewable energy and sustainable land-management. The on-site educational experience is supported through a visitor centre with a range of educational displays, a membership department, eco-accommodation, conferencing, retail and a an excellent vegetarian café.

Zero Carbon Britain (ZCB) is CAT's flagship research programme. Since its inception in 2007, ZCB has set out to offer the hard data and confidence required for visualising a future where we have risen to the demands of climate science; to remove fear and misunderstandings and open new positive, solution-focused conversations. CAT's first ZCB report offered a scenario outlining a pathway to zero emissions over two decades, using only proven technologies.

The process is dual tracked: the powering down of energy demand, whilst 'powering up' renewable energy supplies.

The range of ZCB reports produced since 2007 clearly demonstrates that we can reach net zero emissions using only existing technology, and that such a transition offers many positive co-benefits for society, the environment and the economy. In 2015, CAT teamed up with Track 0 to map 100 peer-reviewed zero carbon and deep decarbonisation scenarios from across the globe in 'Who's Getting Ready for Zero?'. Our 2017 report, 'Zero Carbon Britain: Making it Happen' incorporated the fields of psychology, sociology, political science, economics and other social sciences, as well as faith and spiritual practice, arts and culture, in order to explore how we can overcome the barriers and make change happen.

Through researching and communicating this work, CAT aims to stimulate economic and political debate regarding our goal of zero emissions achieving zero emissions. CAT also seeks to engage the research community and get society thinking in new ways to help build consensus and coalition around action.

2. FOREWORD

Farhana Yamin

CEO and Founder, Track 0

The Paris Agreement came into effect on 4th November 2016 and has now been ratified by 179 Parties. Despite attempts by the Trump Administration to shun climate science and thwart climate action, Parties to the Paris Agreement remain committed to keeping global temperature rise this century well below 2ºC from pre-industrial levels and will pursue efforts to limit the temperature increase even further to 1.5ºC. The 1.5ºC goal was included in Paris because the most vulnerable countries, supported by world scientists, argued it was needed for their very survival. These temperature limits mean the world needs to phase out of emissions greenhouse gases to net-zero by no later than mid-century.

Sadly, the targets set out in the first round of nationally determined contributions (NDCs) submitted by Parties under the Paris Agreement are wholly inconsistent with such a phase out. The extraordinary wildfires and heatwaves around the world in 2018 show the real face of climate change. It is happening here and now and we have very little time left if we are to avoid the 3ºC or 4ºC world which will make large parts of the planet practically unlivable and impose intolerable burdens on the world's poorest communities and nations.

The authors of this timely report from the Centre for Alternative (CAT) are to be congratulated for bringing together case studies from around the world demonstrating how levels of mitigation ambition can be raised rapidly without compromising social and economic development and in ways that can help achieve the Sustainable Development Goals (SDGs). The authors argue governments, regions, cities and sub-national actors must work together with their citizens in more inclusive and transparent ways and set aside out-dated but powerful cultural, social and political frameworks that continue to subsidise and favour centralised, fossil fuel based energy systems.

The report gathers a wealth of evidence and data from 130 scenarios drawing from the global to sub-national levels. All of these back their key conclusion that we have all the tools and techniques we need to move beyond fossil fuels and to use land more sustainably. They point out rightly that the price of renewables is continuing to fall dramatically and, in most parts of the world, renewable energy is already cheaper than conventional energy sources if the full costs of fossil fuels are taken into account.

The report also highlights the positive role of land use, energy efficiency and changes in diets as well as focusing on solutions that harness Natural Climate Systems (NCS). The authors show that by switching to renewables and looking again at NCS, we can reap huge health, employment and well-being benefits that enhance adaptation and resilience. Importantly, the authors make and back up their bold claim that the world can stay within sight of the Paris Agreement temperature limits without resorting to expensive, unproven and more controversial technologies such as carbon capture and storage (CCS).

I whole-heartedly congratulate everyone at CAT for bringing this report out ahead of the crucial 24th gathering of the Conference of the Parties to the UNFCCC and the third meeting of the Parties to the Paris Agreement (COP 24). The co-evolution between fossil fuels and our current ways of provisioning food, energy, housing and transport are creating social divisions, exacerbating inequalities, and burdening future generations. This report is an excellent resource showing how pioneering citizens, cities and countries all over the world are rethinking their relationships with each other and the planet that sustains us. We need more pioneers to join those included in this report to experiment and redefine new ways of living that align climate action with the SDGs, human rights and social justice.

TRACK

http://track0.org/2017/11/launch-achieving-the-sustainable-development-goals-staying-below-1-5c/

3. PREFACE

Adrian Ramsay, CEO Centre for Alternative Technology

September 2018

The summer of 2018 will most likely go down in history as the time it became crystal clear that humanity is facing an urgent crisis. Both the data and first-hand experiences from the increasing number of extreme weather events across the globe very clearly show humanity is now at the opening of a very serious climate emergency. But there is more to the story than scary impacts and the immediate rescue efforts. There is also a story to be told about what we can still – and must – do to change our trajectory and avoid runaway climate change.

At the Centre for Alternative Technology (CAT) our role is to inspire people to take action for a sustainable future. We demonstrate a wide range of sustainability topics and solutions at our site in Mid Wales and engage with people through our postgraduate degrees, short courses, educational programmes and visitor centre. All of this is underpinned by our research on a Zero Carbon Britain which highlights the importance of action across disciplines from green buildings and energy management to sustainable land use and diets.

Since CAT's first Zero Carbon Britain report in 2007, the awareness of the need for rapid decarbonisation is substantially greater – and since the global climate agreement made in Paris in 2015 nearly all global leaders are signed up to the keeping temperature rises to a level that will avoid runaway climate change. But the gap between this goal and the carbon reduction pledges and action is too big, and as a global society we urgently need to increase ambition in order to deliver on the goals agreed in Paris.

In this new report, we collate and highlight the work of researchers around the world to develop visions of possible climate-stable futures at the global, regional, national and sub-national scales. From our analysis of this research, it is clear that society has the technology to rise to the challenge of climate change: it's now a challenge of will, of ambition and of vision. Through sharing this work, CAT aims to stimulate economic, social and political debate around achieving zero emissions and encourage the action needed at all levels of society to create a healthy future for people and planet.

CAT is pleased to be able to offer this new work, and we are grateful to everyone who has helped us in the process.

4. EXECUTIVE SUMMARY

There is no shortage of evidence that humanity is entering a very serious place. Both data and real-life stories from the ever-increasing global catalogue of extreme weather events clearly shows we are heading into a climate emergency. There is growing recognition that we must act on climate.

Raising Ambition: Zero Carbon Scenarios from Across the Globe collects and highlights the work of hundreds of people around the world to develop snapshots and deep visions of possible futures at the global, regional, national and sub-national scales. From Tanzania to Los Angeles, South Asia to the Baltic, we take an in-depth look at 18 case studies of scenarios. These are drawn from 130 scenarios that model net zero, deep decarbonisation, and up to 100% renewable energy.

Why zero carbon?

Levels of ambition for action must reflect what climate science is telling us. To stabilise the climate system and stay below the internationally agreed limit of keeping global temperature rise well below 2ºC above pre-industrial levels, and to pursue efforts to limit the increase to 1.5ºC, humanity must move rapidly beyond fossil-fuel-based energy systems, and sequester any remaining man-made greenhouse gas emissions.

Global society needs to be collectively on a path to achieving net zero greenhouse gas emissions as far in advance of the Paris Agreement's target date of 2050 as possible. The earlier this is achieved, the greater the chance of limiting global temperature rise to near 1.5ºC, minimising the risk of severe runaway climate impacts and protecting the most vulnerable countries. There is, therefore, an urgent need to integrate accelerated short-term action with enhanced ambition in longer-term planning from all nations.

What do we mean by zero?

All emissions that can go to zero must go to zero – as rapidly as possible. Not just in electricity, but also in heat, transport, industry and land-use. Whilst researching all potential climate solutions is informative, we must resist the temptation to justify the continued burning of fossil fuels by relying on the promise of future technologies that are not yet proven at scale. These put an added burden on future generations to recapture the massive amounts of greenhouse gases caused by our lack of ambition today.

We can revitalise natural systems that offer sustainable 'net negative processes', for example by restoring forests, peatlands and soils. These can absorb and sequester the unavoidable residual greenhouse gases from the atmosphere, to achieve an overall balance, whilst also regenerating and protecting natural systems. Even with a zero emissions end-goal, the science still requires a clearly defined trajectory so that the total cumulative greenhouse gas emissions released over a specific timeframe work within the agreed total carbon budget. Early action is vital.

WHERE	WHAT	WHO	WHEN	SCENARIO SUMMARY
GLOBAL CASE STUDIES				
	Global Energy System Based on 100% Renewable Energy – Power Sector	Lappeenranta University of Technology and Energy watchgroup	2017	NET 0, 100 %, NGA
	Energy transition within 1.5°C – A disruptive approach to 100% decarbonisation of the global energy system by 2050	ECOFYS	2018	NET 0, 100 %, NGA
	10 Steps: The Ten Most Important Short-term Steps to Limit Warming To 1.5°C	Climate Action Tracker: Climate Analytics, Ecofys, New Economy Institute	2016	NET 0, 100 %, NGA
REGIONAL CASE STUDIES				
	Power Sector Vision: Towards 100% Renewable Electricity by 2050 Greater Mekong Area: Cambodia, Laos, Myanmar, Thailand, Vietnam	WWF, Intelligent Energy Systems and Mekong Economics Ltd	2016	DD, 50+ %, NGA
	100% renewable energy based electricity systems by 2030 and 2050 The Baltic Sea Region North-East Asia Southeast Asia and the Pacific Rim region South and Central America	Lappeenranta University of Technology	2016 2017 2018	NET 0, 100 %, NGA
	Nordic Energy Technology Perspectives 2016 – Cities, flexibility and pathways to carbon-neutrality Denmark, Finland, Iceland, Norway and Sweden	Nordic Energy Research & International Energy Agency	2016	NET 0, 100 %, NGA
NATIONAL CASE STUDIES				
	Energy Report for Uganda: A 100% Renewable Energy Future by 2050	WWF Uganda, IVL Swedish Environmental Research Institute, African Solar Design and KTH Royal Institute of Technology	2015	DD, 50+ %, NGA
	Net-Zero in New Zealand – Scenarios to achieve domestic emissions neutrality in the second half of the century	Vivid Economics for GLOBE-NZ: a cross-party group of 35 members of the New Zealand Parliament	2017	NET 0, 50+ %, NGA
	100% Renewable Energy for Tanzania: Access to renewable energy for all within one generation	Institute for Sustainable Futures - University of Technology Sydney, Bread for the World, Climate Action Network Tanzania and World Future Council	2017	NET 0, 100 %, NGA
	France can reach 100% renewable energy by 2050 while phasing-out nuclear	négaWatt	2017	NET 0, 100 %, NGA
	Zero Carbon Britain: Rethinking the Future	Centre for Alternative Technology	2013	NET 0, 100 %, NGA
SUB-NATIONAL CASE STUDIES				
	Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands	DLR - German Aerospace Center	2017	NET 0, 100 %, NGA
	Swansea Bay City Region: A Renewable Energy Future – Energy system vision for 2035	IWA - Institute for Welsh Affairs	2018	DD, 100 %, NGA
	Clean Energy for Los Angeles – An analysis of a pathway for 100 percent renewable energy in Los Angeles by 2030	Prepared for Food & Water Watch by Synapse Energy Economics	2018	NET 0, 100 %, NGA
	Climate Change Strategy of the Basque Country to 2050	Administration of the Basque Country Autonomous Community and the Department of Environment and Territorial Policy	2015	DD, GA

KEY GUIDE

- NET 0 – Net-zero emissions scenario for at least one sector
- DD – Deep decarbonisation scenario for at least one sector
- 100 % – Scenario uses 100% renewable energy
- 50+ % – Scenario uses 50% renewable energy or more
- GA – Governmental author
- NGA – Non-governmental author

4. EXECUTIVE SUMMARY

Key findings

Net zero is achievable

This report outlines scenarios at global, regional, national and sub-national scales that illustrate how the Paris Agreement targets could be met. Our conclusions are drawn from analysis of over 130 scenarios that demonstrate how deep decarbonisation or net-zero greenhouse gas emissions can be achieved before the second half of the century using existing technology, whilst also supporting social or economic development.

Changing how billions of people live on Planet Earth is a very special kind of problem because the forces that shape our lives exist on many different levels. However, the depth and detail of these scenarios clearly demonstrate that we already have all the tools and technologies we need to achieve the Paris targets. Rather than an unresolved technical challenge, what is actually holding us back is a mix of economic, cultural and psychological barriers.

Scenarios can help overcome carbon lock-in

The historical technical, cultural and institutional co-evolution of the relationship between fossil fuels and the ways we deliver energy, housing, transport, food and agriculture has created persistent forces that are hugely resistant to change.

This 'carbon lock-in' exerts a powerful influence, shaping the choices that define our lives. Changing institutional culture isn't easy, but lessons from across the globe show that it can be done. By developing evidence-based scenarios and unleashing practical projects, particularly at a local scale where there is flexibility to experiment and innovate, we can begin to normalise new and better relationships with transport, buildings, food and energy.

Every country should have a zero carbon scenario

There are still too many countries that have not yet prepared scenarios that align their short-term actions and long-term plans with the levels of ambition required by the Paris Agreement. Focusing on individual countries, we found that only 32 out of 199 have deep decarbonisation, 100% renewable energy or net zero scenarios. That's a mere 16%.

If we are to address the climate challenge, all countries – developed and developing, large and small – must be supported to prepare full net-zero greenhouse gas scenarios for 2050 to inform their policy and industrial strategies. This will ensure that each country's development pathway aligns with the mitigating actions required, and creates trusted investment frameworks whilst helping develop social licence for the necessary transformations.

There is also a need for a common language, framework and shared assumptions, to make the comparisons and integration of modelling work easier across international borders.

* Including Taiwan, Wales, Northern Ireland, Scotland and England as individual countries

Game over for wasteful energy use

Current high-energy consumer lifestyles were designed before we understood the very serious nature of the climate challenge, and so compel us to use far more energy than we actually require to meet our needs.

This report offers many scenarios demonstrating how we can drastically reduce demand through the smart, efficient use of energy.

"As a result of strong energy efficiency improvements, it is possible to bring global energy use below current levels to 435 Exajoules (EJ), a large contrast to business as usual growth to over 800 EJ."

Ecofys, global scenario

4. EXECUTIVE SUMMARY

Key findings continued

We have the tools to move beyond fossil fuels

Our mapping has revealed 100% renewable scenarios for a wide range of locations, including many of the world's largest emitters. It is exciting to see the diverse range of new scenarios that are now emerging. Hourly modelling from an increasing range of countries demonstrates that we can ensure that supply meets demand 24-hours a day, across all seasons.

There are experts working on scenarios for a diverse range of locations, with developing country experts coming through in greater numbers. The diversity of detailed, well-researched scenarios from around the world shows that we have all the tools and technologies we need to move beyond fossil fuels.

> *"Australia's solar resource is 10,000 times Australia's annual energy consumption. Australia also has the second largest offshore wind energy resource in the world after the Russian Federation and the wave energy resource from Geraldton to Tasmania alone would supply five times Australia's total energy requirements."*
>
> City of Sydney, city-level scenario

Land use is a key missing piece

Land use – whether in energy system modelling, government goal-setting or financial investment – is consistently underestimated or even ignored. We can become stewards of land not only for sustainable agriculture, healthy diets and recreational uses, but also for carbon management.

The scenarios that included land use demonstrated that it's a key part of how they reach net zero. Scenarios can reduce demand and decarbonise up to a point, but without the sinks provided by natural climate solutions, such as forests and peatlands, net zero eludes them.

Thinking ahead pays off

As the cost of responding to climate impacts goes up each year, the price of inaction increases. Many of the 130 scenarios compared the costs of a 'business as usual' (BAU) trajectory for the energy system with a decarbonised or 100% renewables trajectory.

Most found a decarbonised energy system paid off in the long term compared to BAU. A major contributing factor was the falling price of electricity as renewables with low to zero fuel costs pay off their capital costs and take up more of the energy generation.

> *"Total levelised cost of electricity (LCOE) on a global average for 100% renewable electricity in 2050 is 52 €/MWh (including curtailment, storage and some grid costs), compared to 70 €/MWh in 2015."*
>
> Lappeenranta University of Technology, global scenario

Scenario building processes must reflect a fair and inclusive future

Fewer than five of the 130 scenarios assessed in this report were developed using a participatory, multi-stakeholder process. Although any finished report can be made available publically, or sent out for consultation, this is not as powerful as creating it using a participatory process. Our collective capacity to multi-solve, break down silos, and integrate the findings into our places of work and ways of life is much increased by processes that create space for participation and reflection around scenarios from the outset.

It is an ethical imperative that all scenarios also embrace climate equity. How the remaining global carbon budget is distributed between nations is a complex and contested issue. The way we share this out must embrace developing country needs to lift citizens out of poverty and to increase quality of life. This requires 'climate equity', or a 'fair contribution' by developed countries, which takes some account of the role of their historic emissions in causing climate change and allocates an adequate emissions budget to allow emerging and Global South countries to develop.

4. EXECUTIVE SUMMARY

image © Shutterstock

The benefits beyond emissions - multi-solving

We recommend that multi-solving should become a vital part of all zero carbon scenario development, acting as a tool to identify and optimise co-benefits, and helping build coalition across a range of sectors. The shift to zero carbon holds the potential to be one of the most exciting opportunities in human history, offering potential to fundamentally transform current systems. Whilst there are clear challenges, there are also huge opportunities to find models that offer solutions for adaptation, resilience, employment, heath, wellbeing, economics and natural systems, as well as for achieving our agreed Sustainable Development Goals.

5. WHY ZERO CARBON?

There is no shortage of evidence that humanity is entering a very serious place. Both data and real-life stories from the ever-increasing global catalogue of extreme weather events clearly shows we are heading into a climate emergency. There is growing recognition that we must act on climate. What's more, major news channels and even banks are beginning to acknowledge the urgency of the situation, and the frightening potential for climate chaos driven by runaway feedbacks.

We must be sure our understanding of the scale and speed of this challenge fully reflects the urgency of the science. Humanity's best chance of stabilising our climate system requires an integrated strategy focused on achieving the globally agreed limit of staying well below a 2°C temperature rise from pre-industrial levels, and keeping 1.5°C well within sight.

Trajectories of the Earth System in the Anthropocene

Released in August 2018, a new report from the National Academy of Sciences of the United States explores the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilisation of the climate and cause continued warming on a "Hothouse Earth" pathway even as human emissions are reduced. Crossing the threshold would lead to a much higher global average temperature than any interglacial in the past 1.2 million years and to sea levels significantly higher than at any time in the Holocene.

They examine the evidence that such a threshold might exist and where it might be. If the threshold is crossed, the resulting trajectory would likely cause serious disruptions to ecosystems, society, and economies. Collective human action is required to steer the Earth System away from a potential threshold and stabilise it in a habitable interglacial-like state. Such action entails stewardship of the entire Earth System — biosphere, climate, and societies — and could include decarbonisation of the global economy, enhancement of biosphere carbon sinks, behavioural changes, technological innovations, new governance arrangements, and transformed social values.

http://www.pnas.org/content/early/2018/07/31/1810141115

image © Deborah Lee Soltesz

5. WHY ZERO CARBON?

image © Neil Palmer (CIAT)

As there is a direct relationship between global average temperature rise and the concentration of greenhouse gases (GHGs) in the atmosphere, such an integrated strategy must focus on rapidly decreasing our GHG emissions and reducing the current atmospheric concentration of carbon dioxide (CO_2) by enhancing natural carbon sinks, such as increasing the area of forests that store carbon. Efforts to reduce emissions are referred to as "mitigation", and enhancing sinks is referred to as "sequestration". Limiting global temperature rise directly informs the amount of GHGs the Earth's systems can cope with, and so sets a finite limit on our cumulative emissions – resulting in an inevitable end goal of net-zero carbon emissions for all countries at some agreed endpoint.

Even with a zero emissions end-goal, the science still requires a clearly defined trajectory so the total cumulative emissions released over a specific time frame meet the agreed carbon budget – so early ambition is vital.

The clock is ticking. Global society needs to be collectively on a path to achieving net zero emissions as far in advance of 2050 as possible - the earlier this is achieved the greater the chance of limiting global temperature rise to near 1.5°C, and so stabilising climate systems.

Here we map out the best work we can find from a wide range of players across the globe, bringing together the detailed research needed to bring such an integrated pathway to life.

New Intergovernmental Panel on Climate Change special report Global Warming of 1.5°C

The IPCC special report released in October 2018 makes clear the urgent need to adopt a 1.5°C target and maps out four pathways to achieve it, with varying combinations of land use and technology shifts. Global carbon emissions would have to be cut by 45% by 2030, compared with a 20% cut under the 2°C pathway, and come down to zero by 2050, compared with 2075 for 2°C.

Jim Skea, a co-chair of the working group on mitigation said: "We have pointed out the enormous benefits of keeping to 1.5°C, and also the unprecedented shift in energy systems and transport that would be needed to achieve that… We show it can be done within laws of physics and chemistry. Then the final tick box is political will. We cannot answer that. Only our audience can – and that is the governments that receive it."

http://www.ipcc.ch/report/sr15/

6. HOW WE GET THERE

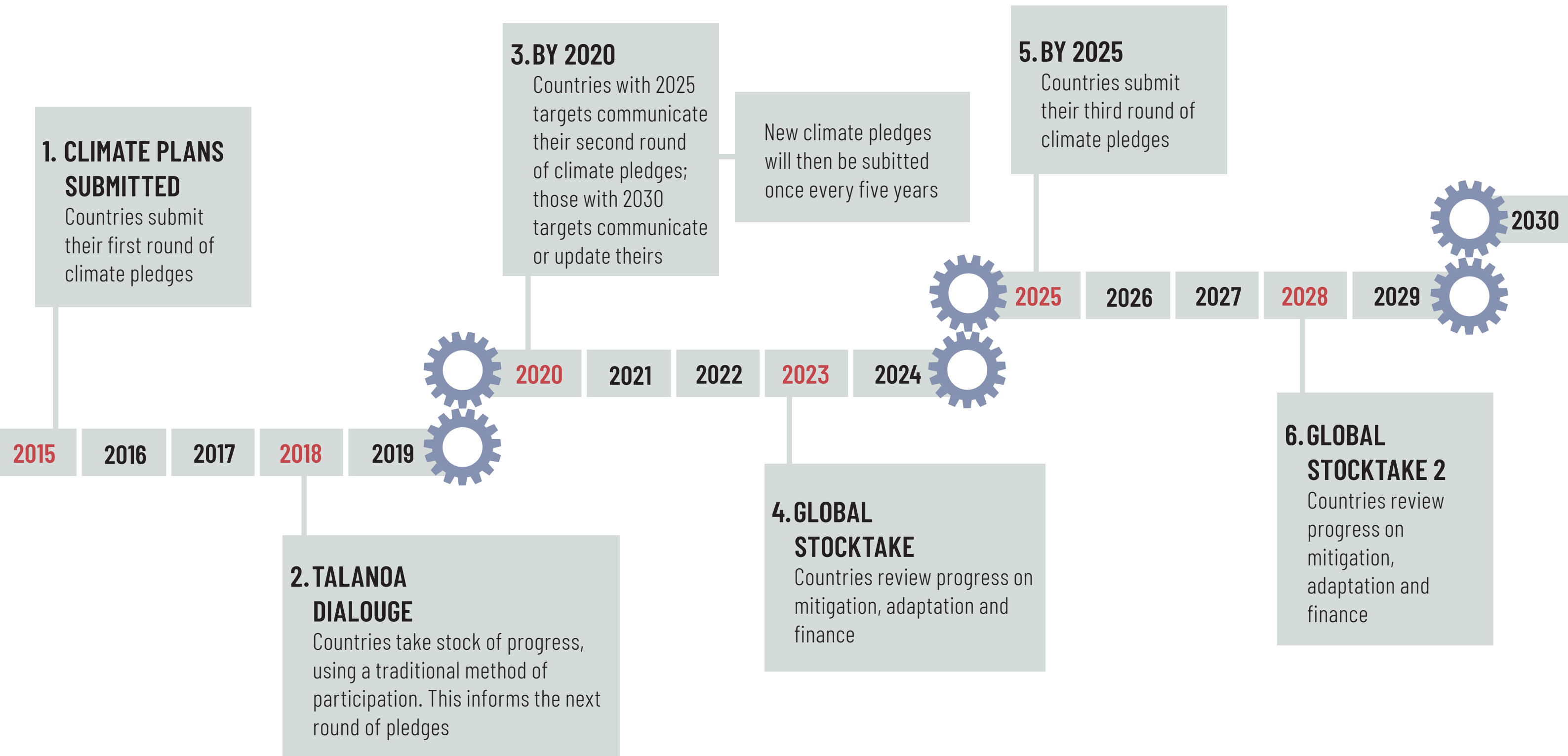
The United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement created the framework by which nations around the world will respond to the challenge of stabilising climate systems, now and into the future. The Agreement covers mitigation of GHGs, to prevent further temperature rise, plus adaptation and financing measures to support and enable countries already affected by the impacts of climate change already in the system.

The freedom to govern according to the wishes of each and every nation often limits the reach of any international agreement. The Paris Agreement deals with this by requesting each country to outline and communicate their post-2020 climate actions, known as their 'Nationally Determined Contributions' (NDCs) - allowing each nation to decide its contribution to the overall goal. The Paris Agreement also requires countries to create '2050 Pathways', that map out a national low carbon development plan, contributing to the global effort to achieve net zero emissions by, or during, the second half of the century.

The Paris Agreement also embodies a 'Ratchet Mechanism' which offers a framework by which national commitments must become more ambitious over time, so we can achieve the collective global target. Starting in 2020, every five years countries must submit new NDCs containing more ambitious targets than the previous ones. In parallel, from 2023, a 'global stocktake' will be conducted every five years to assess progress on mitigation achieved by NDCs, and to take stock of the adaptation and financing commitments that countries have made under the Agreement.

TIMELINE: HOW COUNTRIES PLAN TO RAISE THE AMBITION OF THEIR CLIMATE PLEDGES

The Paris "ratchet mechanism" is designed to steadily increase ambition over time, ensuring that the world reaches net zero emissions in the second half of the century and keeps temperature rise "well below 2C".



6. HOW WE GET THERE

The vital role of the Ratchet Mechanism in increasing countries' ambition was clarified in the sobering 2017 United Nations Environment Programme (UNEP) Emissions Gap Report. It makes clear that the initial NDCs offered under the Paris Agreement in 2015 currently add up to only around one third of the total emissions reduction needed to be on a pathway for staying well below 2°C. It shows that the gap between the existing action pledges agreed in Paris in 2015 and the 1.5°C and 2°C trajectories for 2030 ranges between 11 gigatonnes of CO2 (for 2°C) and a massive 19 gigatonnes of CO_2 (for 1.5°C).

The good news is that there is increasing evidence that we can act to minimise the future climate risks, whilst also developing more resilient and equitable human living systems. This report brings together a wide range of emerging data, showing that humanity has the tools, technologies and plans needed to rise to this vital challenge.

The essence of net-zero requires a mix of actions:

1. Rapid reductions in all global GHG emissions to an absolute minimum;
2. Sustainable 'net negative processes' to absorb and sequester the unavoidable GHGs – to achieve an overall net-zero balance.

The range of scenarios mapped in this report show that we already have all we need; many also identify innovative ways of overcoming barriers to change. We know there are massive disruptive changes already locked into the climate system, but by showing we have all the technologies needed for the shift, we offer hesitant policy-makers and citizens the ambition for a zero carbon future that that minimises the risk of runaway feedbacks. If we plan the transition now, there are massive multi-solving opportunities for adaptation, resilience, health, jobs, wellbeing, equity and more.

Under2 Coalition

The Paris Agreement charts a clear path forward for addressing global climate change. The Under2 Coalition is made up of more than 200 ambitious state and regional governments who represent over 1.3 billion people and nearly 40% of the global economy. It joins with the countries around the world that have adopted the Agreement in support of its goal of limiting the increase in global average temperature to well below 2°C above pre-industrial levels, and pursuing efforts to limit the temperature increase to 1.5°C.

For our jurisdictions, this means reducing their greenhouse gas (GHG) emissions drastically in the coming decades. Members have committed to limit their GHG emissions by 80 to 95% below 1990 levels, or to 2 annual metric tons of carbon dioxide-equivalent per capita, by 2050.

This is a significant task, requiring a complete transition in our energy systems. It is also a tremendous opportunity to build the kind of communities our citizens want to live in - with cleaner air, better health, and quality local jobs in emerging clean energy sectors.

We know this transition is possible. We also know that, to achieve it, we must begin planning now, to make sure that the actions we take today are consistent with the future we want to achieve. Therefore, at the 2018 Global Climate Action Summit, we have asked members to commit to completing a "2050 Pathways Analysis" within the next two years, which will help us chart a viable path towards net zero emissions in our jurisdictions.

https://www.under2coalition.org

6. HOW WE GET THERE

6A: SCENARIO CASE STUDIES

Drawn from a full list of over 130 scenarios, available in Annexe 1, we have assembled a collection of exemplar case studies which raise ambition for zero. They are split into four scales: global, regional, national and sub-national level scenarios. Some scenarios explore 'deep decarbonisation' with a less certain pathway for meeting the demands of the Paris Agreement as they don't yet reach net zero, but they are the most ambitious we could find for that region.

The different emphasis of each case study is summarised using the icons below.

- Net-zero emissions scenario for at least one sector
- Deep decarbonisation scenario for at least one sector
- Scenario using 100% renewable energy
- Scenario using 50% renewable energy or more
- Governmental author
- Non-governmental author

Disclaimer

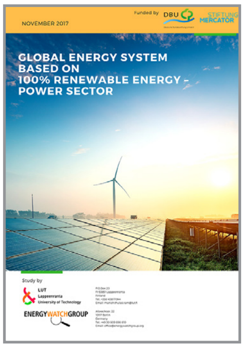
In the case studies and scenarios detailed below, it is important to note that each author or group has defined its own sector boundaries, definitions of net zero and sustainability, starting and end-dates and types of emissions included. As a result, not all scenarios are directly comparable, and for a detailed understanding of the underlying assumptions and boundaries, the texts must be read in full.

To offer a wider geographical range, some scenarios include carbon capture and storage or nuclear generation, which we recognise are controversial and not necessarily the preferred or the most sustainable option.

6A. HOW WE GET THERE - SCENARIO CASE STUDIES

GLOBAL CASE STUDIES

WHERE	All countries
WHAT	Global renewable energy system based on 100% renewable power sector
WHO	Lappeenranta University of Technology and Energywatchgroup
WHEN	2017



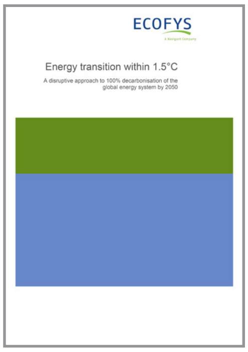
This scenario shows how a global transition to 100% renewable electricity is feasible during every hour of the year and is more cost effective than the existing system, which is largely based on fossil fuels and nuclear energy. It shows energy transition is no longer a question of technical feasibility or economic viability, but of political will. Existing renewable energy potential and technologies, including storage, can generate sufficient and secure power to cover the entire global electricity demand by 2050.

The world population is expected to grow from 7.3 to 9.7 billion. The global electricity demand for the power sector is set to increase from 24,310 TeraWatt Hours (TWh) in 2015 to around 48,800 TWh by 2050. Total levelised cost of electricity (LCOE) on a global average for 100% renewable electricity in 2050 is 52 Euros per megawatt hour (€/MWh) (including curtailment, storage and some grid costs), compared to 70 €/MWh in 2015. Due to rapidly falling costs, solar PV and battery storage increasingly drive most of the 100% renewable electricity system, with solar PV reaching some 69%, wind 18%, hydro 8% and bioenergy 2% of the total electricity mix globally in 2050.

The global energy transition to a 100% renewable electricity system creates 36 million jobs by 2050 in comparison to 19 million jobs in the 2015 electricity system. The total losses in a 100% renewable electricity system are around 26% of the total electricity demand, compared to the current system in which about 58% of the primary energy input is lost.

6A. HOW WE GET THERE - GLOBAL CASE STUDIES

WHERE	All countries
WHAT	Energy Transition within 1.5ºC: A disruptive approach to 100% decarbonisation of the global energy system by 2050
WHO	ECOFYS
WHEN	2018


ECOFYS

Energy transition within 1.5°C

A disruptive approach to 100% decarbonisation of the global energy system by 2050

To stay within the global carbon budget, global emissions need to be reduced - and fast. If society keeps on emitting CO_2 at the current pace, the carbon budget to limit the temperature increase to 1.5°C will be exceeded in one or two decades. With this in mind, Ecofys explored what a fast energy system transformation could look like.

The Ecofys team developed its scenario against a background of increasing population, with a growing demand for energy services like space heating and cooling, transportation, and materials production. They constructed this scenario so that maximum feasibility is achieved, giving preference to options that have high social and political acceptability. Their decarbonisation scenario includes several critical levers to constrain emissions:

- Ongoing efforts to deliver all energy services in an efficient way
- Electrifying energy consumption, especially for buildings and transportation
- Fast penetration of wind and solar in the electricity sector
- Adopting a range of other renewable energy technologies, from solar heat to electricity-based hydrogen
- Bioenergy as a fuel source for the manufacturing industry and specific transportation needs
- Carbon capture and storage (CCS) in specific sectors

As result of strong energy efficiency improvements, it is possible to bring global energy use below current levels to 435 exajoules (EJ), a large contrast to the 'business as usual' growth to over 800 EJ. While the total primary energy supply in the scenario is decreasing slightly, electricity demand is expected to almost triple. Ecofys estimates that all this energy can be supplied from zero-carbon or low carbon energy sources.

6A. HOW WE GET THERE - GLOBAL CASE STUDIES

WHERE	All countries
WHAT	*The Ten most important short-term steps to limit warming to 1.5°C*
WHO	Climate Action Tracker: Climate Analytics, Ecofys, New Economy Institute
WHEN	2016

Limiting global temperature increase to 1.5°C requires major transformations that need to begin immediately. This work provides insights into the ten most important steps that need to be taken in specific sectors in the short term - to 2020 and 2025 - if the Paris Agreement is to be met, using modelled scenarios to provide guidance on what needs to happen in each sector.

The stringency of the 1.5°C limit significantly constrains the levels of freedom to spread emission reductions across sectors, countries and over time. As a result of the limited carbon budget, combined with the inertia of energy, transport, industry technologies, and the difficulty of reducing emissions in some sectors - global energy models need very specific pathways. If a sector does less, in particular the energy, industry and transport sectors, it would leave a high-emissions legacy for several decades and would mean a failure to set in motion the system changes needed to achieve the necessary long-term transformation.

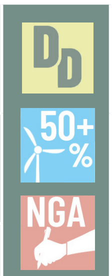
Efforts in all of these sectors that must be underway by 2020, and accelerate by 2025, if we are to achieve zero CO_2 emissions by 2050, and zero GHGs overall by roughly the 2060s. For all ten elements, they show there are signs that a transition of this magnitude is possible: in some specific cases it's already happening.

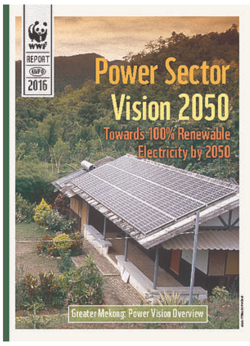
Their key conclusion is that achieving these ten steps would put the world on a pathway to limit global temperature increase to 1.5°C.

6A. HOW WE GET THERE - SCENARIO CASE STUDIES

REGIONAL CASE STUDIES

WHERE	Greater Mekong Area - Cambodia, Laos, Myanmar, Thailand, Vietnam
WHAT	Power Sector Vision 2050: Towards 100% renewable energy
WHO	WWF, Intelligent Energy Systems and Mekong Economics Ltd
WHEN	2016





Greater Mekong countries have an opportunity to become leaders in clean, renewable electricity. Renewable energy sources such as solar, wind, water, biomass, and ocean energy abound. Decreasing costs of wind and solar plants have made them competitive with gas, nuclear and coal power plants in many countries. Typically, wind projects and especially solar photovoltaic require less time to build than fossil, large scale hydro or nuclear power plants. With that in mind, WWF and partners have developed a "*Power Sector Vision – Toward 100 Percent Renewable Energy by 2050*" for the Greater Mekong and for each country individually.

These scenarios demonstrate that it is technically and economically feasible to supply everyone in 2050 with the electricity they need, with at least 86% coming from renewable sources.

- Less than 11% of energy from large hydropower
- Carbon emissions reduced by 85 - 100% by 2050
- In 2050: 80 - 100% of electricity is produced from renewables, with each country producing at least 80 - 90% of its own energy (some become energy exporters)

A sustainable, high renewable energy approach can ensure electricity cost stability and maintain system security – that is, provide enough electricity at all times to make sure there's never a risk of the 'lights going out'. The sustainable energy scenarios are 100% possible: they rely on realistic projections for proven technologies, and are economically competitive with "business as usual".

6A. HOW WE GET THERE - REGIONAL CASE STUDIES

LUT
Lappeenranta
University of Technology

WHERE	Multiple regions, see grid below
WHAT	*100% renewable energy based electricity systems by 2030 and 2050*
WHO	Lappeenranta University of Technology
WHEN	2016, 2017, 2018

NET 0

100 %

NGA

Cost optimal 100% renewable energy based systems by the year 2030 or 2050, on an hourly resolution for the whole year were developed for each region, modelling energy systems with a lower levelised cost of electricity (LCOE) than today. All scenarios divided their region into sub-regions and with different scenarios exploring various levels of high voltage direct current grid connections and conversion of renewable energy resources into electricity, energy storage, and electricity transmission.

A scenario for each region was simulated to show the benefit of integrating additional demand for industrial gas and desalinated water to provide the system with the required flexibility and to increased the efficiency of storage technologies. According to the results, grid integration on a larger scale decreases the total system cost and LCOE by reducing the need for storage technologies that result from seasonal variations in weather and demand profiles.

Across all regions they concluded that a 100% renewable energy based system could be a reality economically and technically. They also found that with the cost assumptions used in this research, it may be more cost competitive than nuclear and fossil carbon capture and storage (CCS).

The overarching message of the Lappeenranta University of Technology's research is that the intermittency of renewable technologies can be effectively stabilized to satisfy hourly demand at a cost lower than today.

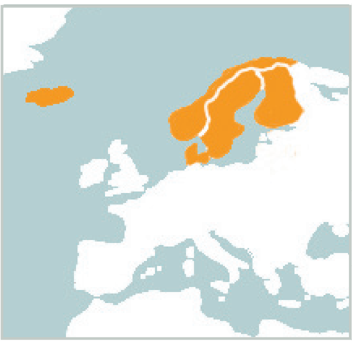
The Baltic Sea Region: Norway, Denmark, Sweden, Finland, Estonia, Latvia and Lithuania (2018)

North-East Asia: China (including Tibet and Uygur), Japan, Mongolia, North Korea and South Korea (2016)

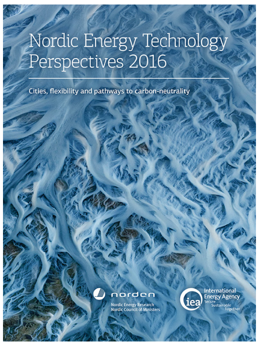
Southeast Asia and the Pacific Rim region: Australia, Cambodia, Indonesia, Laos, Malaysia, Myanmar, New Zealand, Papua New Guinea, The Philippines, Singapore, Thailand Timor-Leste, Vietnam (2017)

South and Central America: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, French Guiana, Guatemala, Guyana, Honduras, Nicaragua, Panama, Paraguay, Peru, Suriname, Venezuela (2017)

6A. HOW WE GET THERE - REGIONAL CASE STUDIES



WHERE	Denmark, Finland, Iceland, Norway and Sweden
WHAT	Nordic Energy Technology Perspectives - Cities, flexibility and pathways to carbon-neutrality
WHO	Nordic Energy Research & International Energy Agency
WHEN	2016



The Nordic Carbon-Neutral Scenario central to this report sets out three macro-level strategic actions that will achieve the climate targets of the Nordic countries by 2050. In order to deliver a near carbon-neutral energy system, governments, policy makers and private sector decision makers should:

1. Incentivise and plan for a Nordic electricity system that is significantly more distributed, interconnected and flexible than today's. This analysis demonstrates that if a carbon-neutral system is the target, it will likely cost less to transition to a more distributed electricity supply with a high share of wind, than to maintain a system reliant on centralised nuclear and thermal generation. The utilisation of abundant Nordic wind resources, together with the more active use of existing dispatchable hydropower, create an opportunity for the Nordic region to play a stronger European role. The Nordic region can both export electricity and balance European variable renewables, generating large economic revenues and facilitating the transformation of the European energy system.

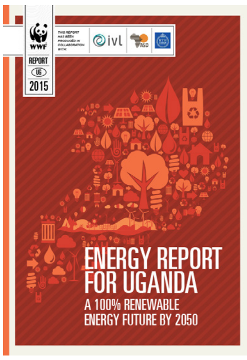
2. Ramp-up technology development to advance decarbonisation of long-distance transport and the industrial sector. Despite a broad electrification of short-distance transport, long-distance modes are unlikely to be decarbonised without utilising large volumes of biofuels. Sustainable and politically acceptable sourcing of those resources will be crucial. Emissions from industry are the most challenging to reduce, requiring rapid advances in the demonstration and deployment of carbon capture and storage (CCS) and other innovative low-carbon process technologies.

3. Tap into the positive momentum of cities to strengthen national decarbonisation and energy efficiency efforts in transport and buildings. Several Nordic capitals and smaller cities have adopted climate targets that are more ambitious than national goals. Better alignment and co-operation across national and local policies allows national efforts to leverage this urban leadership. Shifting the policy focus to improving energy services (rather than just delivering energy) is the most effective way to capture the wider benefits of a low-carbon energy system to society.

6A. HOW WE GET THERE - SCENARIO CASE STUDIES

NATIONAL CASE STUDIES

WHERE	Uganda
WHAT	Energy Report for Uganda: A 100% Renewable Energy Future by 2050
WHO	WWF Uganda, IVL Swedish Environmental Research Institute, African Solar Design and KTH Royal Institute of Technology
WHEN	2015



Uganda is endowed with abundant renewable energy potential from sources such as biomass, water, wind and the sun. However, this potential has not been fully harnessed, creating the present day situation where 15% of the population has access to electricity, while the majority (over 90%) depend on unsustainably used biomass and rudimentary technologies to meet their home energy needs. The Energy Report for Uganda makes clear that the provision of sustainable energy solutions is crucial for alleviating poverty, strengthening the country's economy and protecting the environment.

The scenario found four critical areas of focus for enabling the transition to universal access powered by 100% renewable energy by 2050:

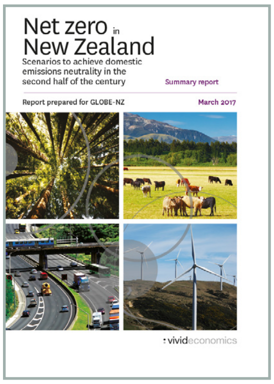
1. Modernizing the biomass sector
2. Expanding the clean grid-based electricity sector
3. Encouraging the development of off-grid electricity infrastructure
4. Building an efficient people and climate-friendly transport sector

Biomass and land-use are at the heart of the Ugandan transition to 100% renewable energy. Biomass products represent more than 75% of the present day energy mix, and are therefore one of the key limiting factors to attaining sustainable energy, due to the inefficient and unregulated use of solid biomass energy in Uganda. Without a massive push for reforestation and sustainable biomass production, Uganda will not be able to provide its citizens with sufficient biomass to meet their energy needs.

> *"In the next 35 years it is expected that total installed generation capacity needs to increase by a factor of 25. The expansion should include high levels of consideration of environmental and social impacts. In addition coordination is needed in order to avoid conflicts of interest (e.g. tourism, water rights, and land rights). Proper frameworks to minimize and mitigate negative impacts need to be put in place and enforced."*

6A. HOW WE GET THERE - NATIONAL CASE STUDIES

WHERE	New Zealand
WHAT	Netzero in New Zealand: Scenarios to achieve domestic emissions neutrality in the second half of the century.
WHO	Vivid Economics for GLOBE-NZ: a cross-party group of 35 members of the New Zealand Parliament.
WHEN	2017



The New Zealand Net Zero scenario shows that it is possible for New Zealand to move onto a pathway consistent with domestic net zero emissions, but to do this will require altering land-use patterns in the medium and long term. Net Zero in New Zealand is one of the most ambitious and realistic net zero scenarios analysed for this report. It is an excellent case study in exploring the levers by which a developed country that has implemented deep decarbonisation of an electricity system already, can reach net zero.

New Zealand's current electricity sources are 80% renewable. Despite this they find that maintaining current land-use patterns, even with optimistic projections for technology development in both the energy and agriculture sectors, will not place the economy on a domestic net zero pathway. This is a significant call to action to change the current trajectory, and to make land use management front and centre of its net zero policies.

The heavy reliance on net afforestation in Resourceful New Zealand poses particular challenges as the sequestration potential of forests diminishes as they reach maturity, and emissions are released after the timber is harvested. Scope for yet further afforestation is also limited in this scenario. Consequently, beyond 2050, New Zealand may well need to explore options that deliver negative emissions in addition to those already explored.

In pursuing the emission reductions envisaged in these scenarios, they write that all members of New Zealand society will have a role to play, supported through new policy action. Some of the opportunities to reduce emissions will rely on the activity of firms and households, such as changing business models to capture value from low-emission innovation, transforming whole supply chains through new collaborative models, and creating innovation in financing tools to deliver low emissions investment. However, while these opportunities abound, they will need a supportive policy environment in order to be unlocked.

6A. HOW WE GET THERE - NATIONAL CASE STUDIES

WHERE	Tanzania
WHAT	100% Renewable Energy for Tanzania: Access to renewable energy for all within one generation
WHO	Institute for Sustainable Futures - University of Technology Sydney, Bread for the World, Climate Action Network Tanzania and World Future Council.
WHEN	2017

The Tanzanian 100% renewable energy scenarios are based on hourly modelling of all sectors to 2050. In addressing fundamental challenges in Tanzania such as energy access within a generation, the modelling supports a wider effort to explore a vision for a sustainable more equitable future, through its energy system. It assumes of long-term average GDP growth of around 2% per year, and population growth from 53 to 137 million people by 2050.

Two scenarios are explored: a reference/business as usual scenario and a 100% renewable energy (RE) scenario. The 100% RE scenario offers three different pathways to achieve 100% RE, including a Renewables pathway, Advanced Renewables pathway and an Energy Access pathway.

The Energy Access pathway assumes a gradual transition towards a fully electrified household. Nine different household types were developed to calculate the rising power demand, beginning with very basic needs such as light and mobile phone charging, transitioning towards a household-standard of industrialised countries. As with developed country scenarios, Tanzanian sustainable energy futures also require efficiency measures. Energy efficiency measures help to reduce the current growing energy demand for wood fuel for cooking stoves, and shift to 100% modern sustainable biomass, solar and geothermal heating, as well as electric cooking and heating, by 2050.

Transport for an increased population by 2050 is an important part of the sector coupling as the greatest fuel cost savings for investment in the capital costs of renewable energies come from transitioning the transport sector, in all pathways. Hybrid, plug-in hybrid and battery-electric power trains will deliver large efficiency gains, with electric demand supplying 40% of transport's total energy demand.

6A. HOW WE GET THERE - NATIONAL CASE STUDIES

WHERE	France
WHAT	France can reach 100% renewable energy by 2050 while phasing-out nuclear
WHO	négaWatt
WHEN	2017

négaWatt offer a progressive national zero carbon scenarios based on hourly modelling. Aiming for carbon neutrality by 2050, a complete decarbonisation of CO2 in all sectors is prioritised by 2050, with any remaining GHGs being offset by France's natural sinks.

The scenario is based on three main pillars:

1. Sufficiency: reducing the overall need for energy-using services.

2. Efficiency: avoiding as much energy loss as possible, through improved equipment, buildings and vehicles.

3. Renewables: prioritising green energies for supplying remaining energy demand.

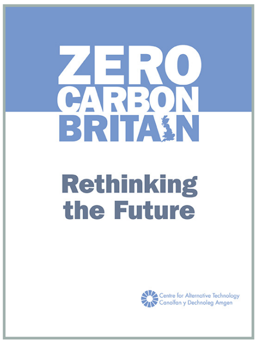
The négaWatt scenario models the implementation of energy sufficiency and efficiency actions in all sectors (buildings, transport, industry). It leads to a potential halving of the final energy consumption by 2050, whilst maintaining a high level of energy services. All remaining energy needs can be met by renewable energy sources by 2050. Solid biomass is the top contributor, closely followed by wind, then solar and biogas. This enables France to progressively shut down the country's nuclear reactors with no life extension over 40 years. The last one is decommissioned in 2035.

This scenario finds that relying on natural carbon sinks to offset remaining GHGs is only effective for as long as they continue to take up GHGs. Once they begin to plateau in uptake around 2050, the challenge of how to absorb the irreducible GHGs from agriculture and other processes additionally to existing sinks remains. This makes land use a central concern for the longevity of carbon neutrality in France.

The négaWatt land use approach is also realised in the food chain: sufficiency in diets, efficiency in production processes, and in the production and use of renewable energies. Food waste (200 kg per capita per year today) must be significantly reduced by 2050. Proportions of meat and vegetables in average diets are progressively switched, halving current meat consumption. There is also potential to move food production towards more agro-ecological and organic practices.

6A. HOW WE GET THERE - NATIONAL CASE STUDIES

WHERE	Britain
WHAT	Zero Carbon Britain: Rethinking the Future
WHO	Centre for Alternative Technology
WHEN	2013



The 2013 *Rethinking the Future* report details a technically robust scenario in which the UK has risen to the challenge of climate change by rapidly reducing greenhouse gas emissions to net zero. It demonstrates that we can do this using currently available technology, whilst maintaining a modern standard of living, eating well, and meeting our energy demand at all times with 100% renewable UK energy sources.

It integrates detailed research in two key areas:

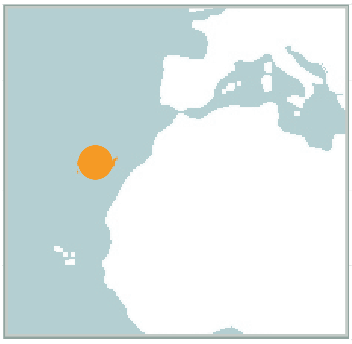
- Balancing supply and demand: How to 'keep the lights on' with a 100% renewable energy system, modelled with ten years of hourly data.

- Land use and low carbon diets: How to manage our land to eliminate emissions and provide a healthy low-carbon diet.

The 2017 *Making it Happen* report explores the economic, cultural and psychological barriers to achieving net zero greenhouse gas emissions, and sets out the positive, connected approach we need to overcome them – joining up research and practice across disciplines, borders, sectors and scales. Working within an interdisciplinary framework, it brings together thinking from researchers working in psychology, sociology, political science, economics and other social sciences, as well as faith and spiritual practice, arts and culture. Drawing on a wide range of peer-reviewed journals, books, reports and articles, as well as stories from real-life projects, it explores ways that we can overcome barriers in innovative ways.

6A. HOW WE GET THERE - SCENARIO CASE STUDIES

SUB-NATIONAL CASE STUDIES



WHERE	The Canary Islands, Spain
WHAT	Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands
WHO	DLR - German Aerospace Center
WHEN	2017

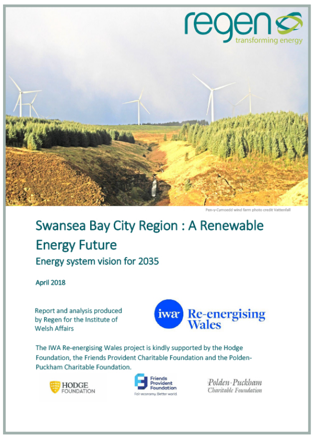
With their limitations in space, biomass, and hydro power, small islands represent the most challenging environment for the implementation of a carbon neutral energy supply. Their energy systems needs are unique, and like many other small islands and archipelagos, the Canary Islands depend to a high degree on energy imports. Islands often also rely heavily on aviation and shipping for goods and for tourism, creating a dependency that must also be addressed in zero carbon modelling, and in energy system modelling when short term users such as tourists add to demand profiles.

The modelling shows that locally available technologies are sufficient for a fully renewable supply of the islands' power, heat, and land transport demands across a range of scenarios. To follow a pathway for achieving a carbon neutral supply, expansion of renewable energy technology deployment needs to be accelerated in the short-term and efforts towards greater energy efficiency must be increased. Linkages between energy sectors, known as sector coupling, through electric vehicles as well as electric heating, and the usage of synthetic hydrogen play an important role in successfully integrating intermittent renewable energy generation. Linkages between islands with sea-cable connections were also found to reduce supply costs by around 15% compared to other scenarios without inter-island connectivity in the archipelago.

The study found a diversity of land limitations and renewable energy availabilities according to the geography of each island - for example, some had volcanoes and could therefore support geothermal energy generation, some could not. Multiple storage technologies are considered, including the innovative use of desalination for electrical load shifting. Overall the scenarios are dominated by solar PV and onshore wind, with varying smaller amounts of offshore wind (fixed and floating), concentrated solar power and hydrogen combined cycle gas turbine generators.

6A. HOW WE GET THERE - SUB-NATIONAL CASE STUDIES

WHERE	Swansea Bay, Wales, UK
WHAT	Swansea Bay City Region: A Renewable Energy Future – Energy system vision for 2035
WHO	IWA - Institute for Welsh Affairs
WHEN	2018



The modelling and scenario work by the IWA and Regen shows that demand reduction comes first and foremost in achieving the 2035 vision. 20% demand reduction is delivered through energy efficiency measures to more than 200,000 homes in the area. This paves part of the pathway towards powering down in order to power up with renewables, meeting the reduced but significant demand with 100% renewable electricity sources by 2035.

For the South Wales region, renewable energy sources have a big focus on tidal and wave energies - however, the Swansea tidal lagoon is currently stalled due to high level political decision-making. The biggest portion is to be provided by solar PV, and then on and offshore wind turbines. In total this amounts to adding 4 times the existing renewable energy capacity in 2017, by 2035.

The most challenging and difficult aspect of the energy vision is to decarbonise the source of heat supply for domestic households and businesses. They identify five levers essential to achieving this:

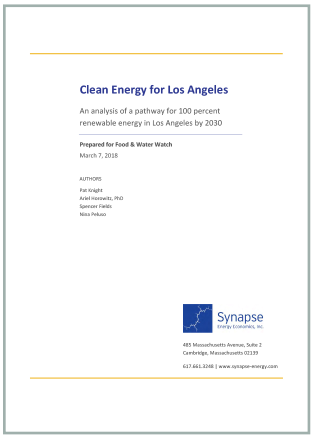
1. Energy efficiency: efficiency measures to residential and commercial buildings
2. Electrification of heat: through installing over 50,000 heat pumps
3. Decarbonisation of gas: by using green gas, biomethane and hydrogen
4. Renewable heat: from sources such as biogas and biomass
5. District heat networks: delivery of decarbonised heat sources through local networks

The technical overview of the scenario concludes that a renewables-led future in the Swansea Bay City Region is possible. The barriers are not technical, they are political.

> *"...greater ambition is needed, and could be achieved, with greater granularity and focus to cascade policy targets down to a regional and local level. Engagement with local communities and stakeholders (and industry) is therefore crucial both to garner support and also to ensure that decarbonisation strategies make best use of local resources to deliver the maximum benefit to Welsh communities."*

6A. HOW WE GET THERE - SUB-NATIONAL CASE STUDIES

WHERE	Los Angeles, US
WHAT	Clean Energy for Los Angeles: An analysis of a pathway for 100 percent renewable energy in Los Angeles by 2030
WHO	Prepared for Food & Water Watch by Synapse Energy Economics
WHEN	2018



Clean Energy for Los Angeles

An analysis of a pathway for 100 percent renewable energy in Los Angeles by 2030

Prepared for Food & Water Watch

March 7, 2018

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The Los Angeles Department of Water and Power (LADWP) is pushing ahead with ambitious goals to achieve 100% renewable energy, and has commissioned hourly modelling analysis of a 100% renewable energy future. LADWP is the largest municipally-run utility in the US, serving nearly 1.5 million residential households and businesses in Los Angeles County. This report provides LADWP with a roadmap for two possible paths to achieve 100% renewable energy by 2030.

It places the energy provider at the centre of the system for decarbonising and shifting to renewable energies, and offers an analysis of their existing portfolio's future and potential for stranded assets in a 100% renewable energy future. They find that in order to reach 100% renewable energy for every hour of the day, LADWP will need to close or divest from all fossil-fueled generators in its current portfolio. This includes retiring all of its locally owned and operated natural gas and landfill gas facilities.

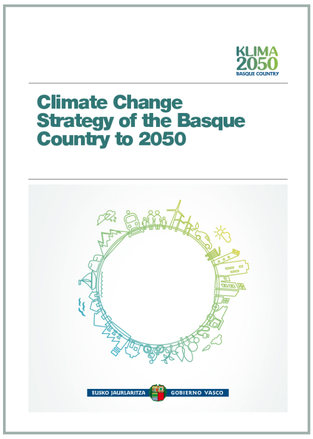
They found that the largest difference between the Reference case and the Policy cases was in the displacement of existing natural gas capacity and the growth of storage. In the Reference case, renewable capacity more than doubles by 2030 as compared to today by adding 4 gigawatts (GW) of solar capacity and over 500 megawatts (MW) of wind. In the Utility Scale case, energy efficiency and an increase in storage means that LADWP builds a similar amount of solar and wind and nearly 2GW of storage capacity. The Distributed case, on the other hand, builds 16% more capacity than the Reference case, mostly in the form of solar (4.3GW of distributed solar alone, and 5.7GW total) and storage capacity (2.7 GW). While a small amount of the wind that is built in both scenarios is located within Los Angeles County, LADWP also contracts with wind resources in the Northwest to transmit directly into the region.

LADWP conclude:

> *"A 100% renewable future is possible. With policymakers in California and the LADWP considering legislation to mandate this ambitious trajectory, it is time for system operators to actively begin to analyze 100% renewable futures. In this analysis of two potential LADWP futures, we find that it is, in fact, possible for LADWP to use exclusively renewable resources to power its system in every hour of the year."*

6A. HOW WE GET THERE - SUB-NATIONAL CASE STUDIES

WHERE	The Basque Country, Spain
WHAT	Klima 2050 Strategy: Climate Change Strategy of the Basque Country to 2050
WHO	Administration of the Basque Country Autonomous Community and the Department of Environment and Territorial Policy
WHEN	2015



The Basque Government's Climate Change Strategy (Klima 2050) has been included for its rich approach to reflecting the complexity of mitigation and adaptation to climate change through strategy, backed by modelling. Klima 2050 offers a five-dimensional picture of its approach.

Dimension 1 is the relationship between international, regional, national and sub-national scales. Klima 2050 nests its strategy within the wider contexts of the 2015 Paris Agreement at the international level; the EU 2020 energy and climate goals, the EU 2030 mitigation, renewable energies and energy efficiency targets and the EU Roadmap to 2050; and within smaller contexts of Basque county councils and municipalities. They also considered the horizontal contexts of their peer sub-national jurisdictions targets and actions in other parts of the world.

Dimension 2 is the commitment to Basque citizens agency, achieved through an active sub national government, and from diverse participation of stakeholders in drawing up Klima 2050. The KLIMA 2050 strategy has been designed as a cross-cutting tool, in keeping with the policies of the provinces and the municipalities of the Basque Country, and with the cross-ministerial involvement of all Basque Government Ministries.

Dimension 3 communicates a vision for implementing their multi-solving approach across Basque society as a whole, through culture change at multiple levels. This includes political will at the highest levels of Basque Government; the fostering of a ' zero emissions culture', the role of which is "*To foster the co-responsibility of all the stakeholders of Basque society in the adaptation and mitigation actions.*"; and leading by example in becoming a zero emissions administration.

Dimension 4 lies in identifying short term actions within their 2050 long-term planning approach. They identify 70 actions to be taken between 2015-2050 encapsulating their response to climate change, and enabling the overall path to 80% CO_2 reductions by 2050. This embeds the realisation that implementation starts today.

Dimension 5 illustrates some of the co-benefits of climate change action to the Basque Country. The economic impacts and the main associated co-benefits were analysed; specifically, the saving in energy bills and the improvement to public health arising from cutting atmospheric pollutants.

6. HOW WE GET THERE

6B: CONCLUSIONS FROM THE SCENARIOS

Changing how billions of people live on Planet Earth is a very special kind of problem, as the forces that shape our lives exist on many different levels. However, the depth and detail of the scenarios now available demonstrate that rather than an unresolved technical challenge, it has become increasingly clear that what is actually holding us back is a mix of economic, cultural and psychological barriers.

Below are some key conclusions.

Scenarios help overcome carbon lock-in

We must recognise the powerful forces of 'carbon lock-in' which have arisen as our living systems developed in a world driven by fossil fuels. The historical, technical, cultural and institutional co-evolution of the relationship between fossil fuels and the ways we deliver energy, housing, transport and agricultural systems has created persistent forces that are hugely resistant to change. 'Carbon lock-in' exerts a powerful influence, shaping the choices that define our lives. Despite the serious climate impacts being known, and despite the existence of cost-effective alternatives, the self-perpetuating inertia of these high carbon systems creates persistent forces that are very hard to overcome. It is extremely difficult for new players, such as small-scale renewable energy or food suppliers to break into a structure designed by large-scale centralised fossil fuel energy incumbents.

For example, the current highly centralised method of providing electricity is not the only, or even the best, means of keeping the lights on, particularly when all the impacts are considered. Yet it becomes very difficult to change because of the legal frameworks, institutions, financial support, investment models, consumer preferences and practices that have grown up around it. Similarly, the daily routine of commuting by car is more of a 'locked-in' practice than a 'behaviour choice' due to a lack of other transport options, cultural pressures, lack of time or the cost of alternatives. Our agricultural systems are also 'locked into' industrialised fossil fuel driven production, driven by systemic bias such as subsidy, regulation and institutional preference.

Changing institutional culture isn't easy, but lessons from across the globe show that it can be done. By developing detailed evidence-based scenarios and unleashing practical projects, particularly at a local scale where there is flexibility to experiment and innovate, we can begin to build and normalise new relationships with transport, food, buildings and energy. Unpicking how we get to zero requires working within an interdisciplinary mind-set; linking up cutting edge modelling research with stories from real-life projects exploring changes in psychology, sociology, political science, economics and other social sciences, as well as faith and spiritual practice, arts and culture.

Zero Carbon Britain: Making it Happen (2017) explores the barriers to a zero carbon transition, and sets out the positive, connected approach we need to overcome them - joining up research and practice across disciplines, borders, sectors and scales.

http://www.zerocarbonbritain.org/images/pdfs/ZeroCarbonBritain-MakingItHappen.pdf

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

Game over for wasteful energy use

Current high-energy consumer lifestyles were designed before we understood the very serious nature of the climate challenge, and so compel us to use far more energy than we actually require to deliver our needs. This report offers many scenarios demonstrating how we can drastically reduce demand by switching to the smart, efficient use of energy.

"As a result of strong energy efficiency improvements, it is possible to bring global energy use below current levels to 435 EJ, a large contrast to business as usual growth to over 800 EJ."

'Energy transition within 1.5°C', 2018

We have all the tools and technologies we need to move beyond fossil fuels

Our mapping has revealed 100% renewable scenarios for a wide range of countries, including many of the world's largest emitters. It is exciting to see the diverse range of new scenarios that have emerged since our last mapping analysis in 2015. It is also reassuring that increasing numbers of scenarios are now incorporating hourly modelling, which demonstrates that we can ensure supply will meet demand 24 hours a day across all seasons. We were also enthused to see experts working on scenarios for a diverse range of locations, and with developing country experts coming through in greater numbers.

"Australia's solar resource is 10,000 times Australia's annual energy consumption. Australia also has the second largest offshore wind energy resource in the world after the Russian Federation, and the wave energy resource from Geraldton to Tasmania alone would supply five times Australia's total energy requirements."

Sydney decentralised energy master plan, 2013

It pays to think ahead

As the costs of responding to climate impacts goes up each year, the price of inaction increases. Many of the 130 scenarios compared the costs of a Business as Usual (BAU) trajectory for the energy system against a decarbonised or 100% renewables trajectory. Most found a decarbonised energy system paid off in the long term compared to BAU. A major contributing factor is the falling price of electricity as renewables with low to zero fuel costs pay off their capital costs and take up more of the energy generation.

"The global average total levelised cost of electricity, when 100% renewable power is in place in 2050, is expected to be 52 €/MWh (including curtailment, storage and some grid costs), compared to 70 €/MWh in 2015."

Lappeenranta University of Technology, 'Global Energy System based on 100% Renewable Energy - Power Sector', 2017

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

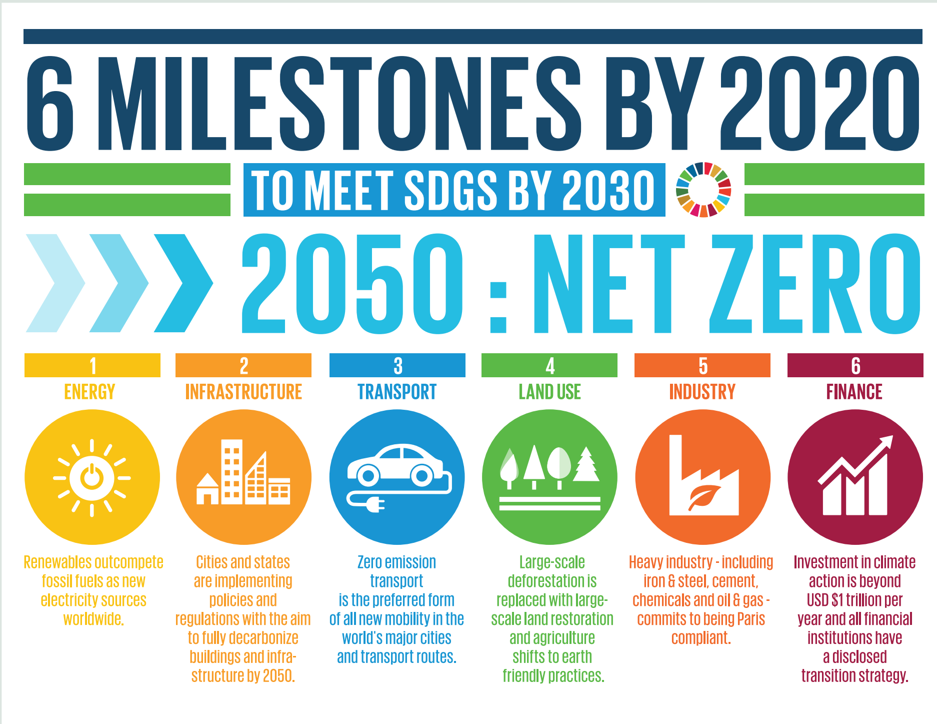
Link-up short-term action and long-term plans

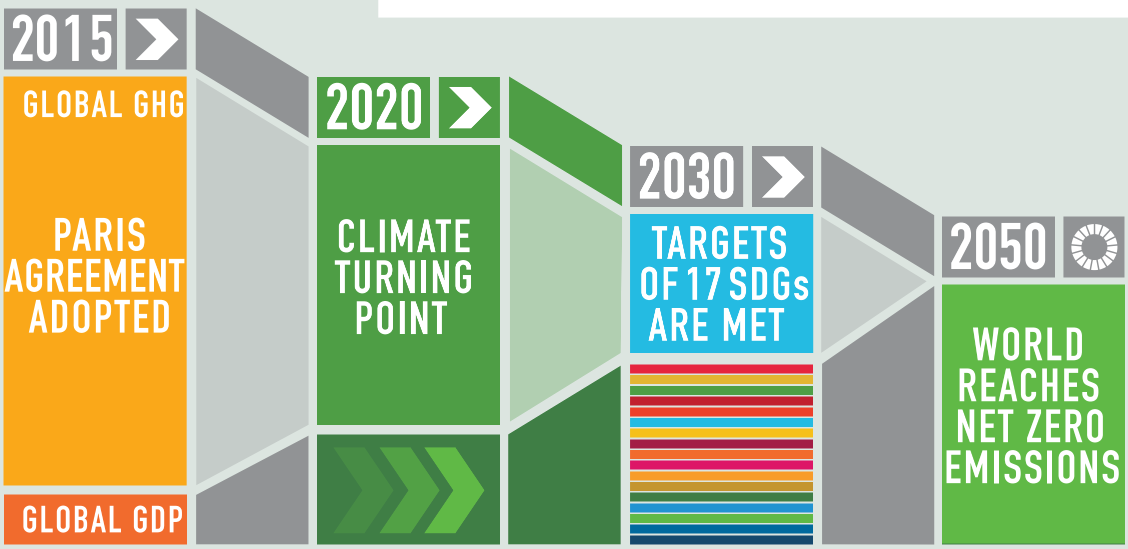
If the goals of the Paris Agreement are to remain achievable, there is an urgent need to integrate accelerated short-term action with enhanced ambition in longer-term planning from all nations.

Cities and local authorities have become the leaders in creating short-term action plans for achieving longer term targets such as 100% renewable energy.

#2020DontBeLate: A Think Piece by Mission 2020

Reaching the emission turning point by 2020 will expedite the least expensive transition to a safer fossil-free economy by 2050, protecting the most vulnerable and ushering in a safer economy. The emission turning point is when greenhouse gases peak and begin to decline irreversibly. With breakthrough actions in a few key areas, notably energy, transportation, land-use, infrastructure, industry and finance, we build on the strong momentum already achieved. A fossil-free global economy is possible, starting with a peak in emissions in 2020.





6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

Increased support for developing fully integrated net-zero scenarios

There are still too many countries that have not yet prepared scenarios that align their short-term actions and long-term plans with the levels of ambition required by the Paris Agreement. Excluding the global and regional scenarios, of a total 199 countries in the world[4] we found only 32 had deep decarbonisation, 100% renewable energy or net zero scenarios. That's a mere 16%.

Also, too few scenarios have been able to undertake full net-zero analysis. This requires integration of work across disciplines, linking energy, transport, buildings, diets, land-use and sustainable, natural carbon sinks.

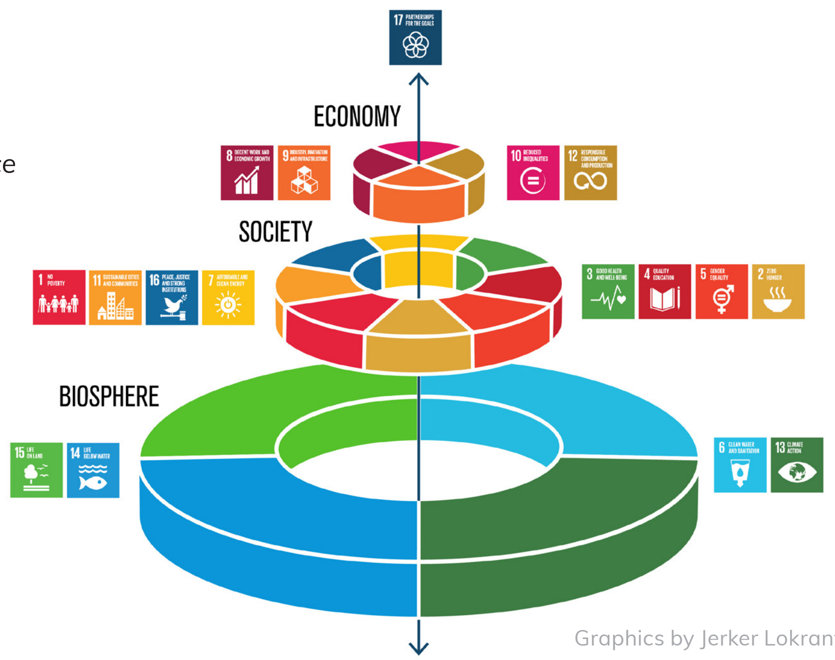
If we are to take the Paris Agreement's target of 1.5°C / well below 2°C seriously, all countries – developed and developing, large and small – must be supported to produce 2050-orientated fully integrated net-zero scenarios to inform their associated policy and industrial strategies. Robust scenarios help ensure each country's development pathway aligns with the mitigating actions required, whilst creating trust-worthy investment frameworks and helping develop social licence.

There is also a need for a common language, framework and assumptions, to make the comparison and integration of modelling work easier across international borders.

The Sustainable Development Goals

In 2015, through a process parallel to the UNFCCC, most countries in the world signed up to 17 Sustainable Development Goals (SDGs), with a target for implementation by 2030. Their respective targets and indicators represent the transformations needed beyond purely reducing GHG emissions. They remind us that emissions reduction measures cannot come at a cost to the poorest peoples, or to the biosphere on which we rely and which we are part of as a species. However, if done well, the changes needed to deliver the Paris Agreement can also help deliver SDGs. The visualisation below demonstrates the relationships between the biosphere, society and economy that the SDGs represent.

The Sustainable Development Goals 'Wedding Cake'
Azote Images for Stockholm Resilience Centre



Graphics by Jerker Lokrantz/Azotee

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

The process of building scenarios must reflect an inclusive future

Fewer than five of the 130 scenarios assessed in this report were developed using a participatory, multi-stakeholder process. Although any finished report can be made available publically, or sent out for consultation, this is not as powerful as creating it using a participatory process. Our collective capacity to multi-solve, breakdown silos, and integrate the findings into our places of work and ways of life is much increased by processes which create space for participation and reflection from the outset.

Scenarios must embrace climate equity

How the remaining global carbon budget is distributed between nations is a complex and contested issue. The way we share it must embrace the needs of developing countries to lift citizens out of poverty and to increase quality of life. This requires 'climate equity', rooted in a 'fair contribution' by developed countries which takes into account the contribution of their historic emissions in causing climate change, and allocates the necessary emissions space needed by developing countries.

As an example of how the remaining global carbon budget can be equitably shared, the Tyndall Centre in Manchester calculated their own city's fair share.

They concluded that two pillars are necessary for Manchester to stay within its carbon budget (Tyndall Manchester, 2017):

1. Immediate near-term actions to significantly reduce emissions to put Greater Manchester on a path to carbon neutrality in 2038. Combining both local and national action this requires average cuts in emissions of 15-20% per year in the Greater Manchester region.
2. For the period from 2018 to 2038, total emissions from Greater Manchester should not exceed 67 million tonnes of carbon dioxide (67 $MtCO_2$), with the remaining 4 $MtCO_2$ allocated to the period 2039-2100.

* including Taiwan, England, Northern Ireland, Scotland and Wales as individual countries

We must play our part in full now, and not increase the burden on the next generation.

Even with a 100% renewable energy system, reduced agricultural emissions, and more efficient, circular industrial processes – to achieve net zero, there will still be significant residual emissions that must be addressed with net negative processes.

Whilst all research can help inform our decisions, we must avoid the temptation to 'balance out' the continued burning of fossil fuels with speculative future technologies. These unproven methods are likely to burden future generations with the need to re-capture massive amounts of carbon. For example, mass deployment of mechanical Negative Emission Technologies (NETs) is widely cited by IPCC authors and journalists alike as the carbon capture solution the world needs. However, such scenarios rely on the mass deployment of technical carbon capture and storage systems, for which the feasibility at the scale required and the full life-cycle costs of delivery are highly uncertain at this time, and there is also little understanding of how they will be integrated into society and ecosystems.

Scientists and policy-makers are also considering *geoengineering* technologies which aim to directly alter the energy balance of the Earth's atmosphere. The aim is to cool the planet, in order to moderate some of the impacts of climate change. These emerging techo-options present a complex mix of risks, costs and benefits, and may have differing effects on different parts of the world. Much more research is needed so we achieve a greater understanding of the scalability, costs and implications of geoengineering

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

options. They also need to be delivered in a way that minimises risk, maximises benefit, and is done so ethically for all people, ensuring long-term effective governance.

The key criterion is that such tools must be considered in addition to the rapid elimination of fossil fuel emissions, not as an excuse to continue burning them.

Negative Emissions Technologies: A Think Piece from the Tyndall Centre

"Virtually all of the 2°C scenarios within the IPCC's database include negative emissions technologies removing several hundred billion tonnes of carbon dioxide directly from the atmosphere across, and beyond, the century. However, there is wide recognition that the efficacy and global rollout of such technologies are highly speculative, with a non-trivial risk of failing to deliver at, or even approaching, the scales typically assumed in the models.

Whilst the authors of the report cited below are supportive of funding further research, development and, potentially, deployment of NETs, the assumption that they will significantly extend the carbon budgets is a serious moral hazard (Anderson & Peters, 2016). Ultimately, if there is genuine action to mitigate emissions in line with a "likely" chance of staying below 2°C, and NETs do prove to be a viable and scalable option, then, in theory at least, an opportunity arises for holding the temperature rise to 1.5°C. By contrast, if action to mitigate for 2°C is undermined by the prospect of NETs, and such technologies subsequently prove not to be scalable, then we will have bequeathed a 3°C, 4°C or higher legacy [to future generations].

As is clear from the 2°C scenarios submitted to the IPCC, the inclusion of carbon capture and storage (CCS) and biomass energy with carbon capture and storage (BECCS) include considerably more fossil fuel combustion than those without them. It is evident that mitigation advice to government is already being influenced by assumptions about NETs, and indeed the rapid uptake of CCS, neither of which shows any sign of approaching the scales of rollout in the models.

If the huge uptake of very uncertain NETs were the exception amongst mitigation scenarios, it would be of value. However, evoking global-scale NETs as a viable substitute to emissions reduction, which is much more challenging, is the norm. Reinforcing this endemic bias for less onerous mitigation is the exclusion of uncertain carbon-cycle feedbacks. It is anticipated that these will, on average, to reduce available carbon budget space. This ubiquitous preference for uncertainty that favours less onerous mitigation is dangerously weighting policy towards technocratic-only responses whilst at the same time closing down more challenging debates over lifestyles and deeper social-economic change. A measured approach would be to develop most scenarios with neither NETs nor positive carbon cycle feedbacks, with such uncertain parameters informing only the fringes of the analysis and providing the more extreme boundaries of possible scenarios."

Anderson, K, and Broderick, J., 'Natural Gas and Climate Change', 2017

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

Land use is the missing piece

There are still many areas of the world urgently needing detailed multi-sector modelling to offer integrated net-zero visions that embrace land use. Whether in energy system modelling, government goal-setting or financial investment, land use is consistently underestimated or ignored. Rather than focusing on energy in isolation, modelling the full picture of GHG sources and sinks within a national boundary offers a multi-solving approach to transforming our living systems, revealing new ways of achieving net zero.

Changing land-based systems may appear more complex than installing a centralised power station with mechanical negative emissions technology, because natural systems thrive in diversity and in connection to other ecosystems. However, indigenous peoples, farmers, foresters and river folk have amassed extensive knowledge over the centuries. We have the capacity, the knowledge and skills from thousands of years of evolution to think and act with regenerative development in mind. We can become stewards of land, not only for sustainable agriculture, diets and recreation, but also for carbon management. The first step down this path is including land use, diets and Natural Climate Solutions (NCS) in our local, national and regional zero carbon modelling work.

NCS are carbon mitigating and sequestering measures originating in our natural systems across the globe. Many have existed for centuries, but more careful stewardship, monitoring and accounting techniques enable us to regeneratively develop a carbon capturing capacity that is place-based and native to both peoples and natural systems. NCS can both mitigate and sequester carbon, whilst also providing a multitude of benefits such as jobs, flood prevention and biodiverse habitats.

Our understanding of NCS has grown in recent years, as the need for sustainable net negative carbon solutions has become a critical factor in the limiting of warming close to 1.5°C.

Natural Climate Solutions Coalition

Nature 4Climate

The Natural Climate Solutions coalition of organisations have conducted research identifying 20 conservation, restoration and/or improved land management actions that increase carbon storage and/or avoid GHG emissions, across global forests, wetlands, grasslands, and agricultural lands.

Constrained by food security, fibre security and biodiversity conservation, they determine that NCS have the potential to sequester 97-553Gt CO_2 between 2018 and 2100 at a cost of less than $100 per tonne carbon (Bronson W., et al., 2017). This knowledge defines what we see as sustainable net zero, as it requires that we do not waste the precious NCS on sequestering GHG emissions from processes that could have been decarbonised in the first place. As such, what can go to zero, must go to zero.

http://naturalclimatesolutions.org/

https://nature4climate.org/n4c-mapper/

6B. HOW WE GET THERE – CONCLUSIONS FROM THE SCENARIOS

The benefits beyond emissions – multi-solving

We recommend that multi-solving should become a vital part of the process for developing any zero emissions scenario, acting as a tool to optimise co-benefits, which then helps build coalition across a range of sectors. In fact, the transition to zero carbon holds the potential to be one of the most exciting opportunities in human history, offering potential to fundamentally transform current systems. Whilst there are challenges, there are also huge multi-solving opportunities, although these vary across the globe.

Examples include:

- **Equitable and integrated economics**: Renewable energy systems, rooted in our air, land and seas, provide the opportunity for increased access to energy, and potential for its ownership and revenues to become more equally distributed.
- **Employment**: Rising to the climate challenge can create opportunities for increased and more meaningful employment with a greater sense of purpose. Although some jobs will inevitably be lost in conventional energy systems, analysis indicates new ones should more than compensate.
- **Adaptation and resilience**: The transition to zero emissions will not only reduce the degree of adaptation required, it also offers many opportunities for increasing our resilience to the changes already underway.
- **Restoring natural ecosystems**: Mapping an integrated zero emissions pathway offers a powerful opportunity to promote cross-sectoral thinking, enabling us to respect vital planetary boundaries, revitalising the global systems that support all human life.
- **Health and wellbeing**: Scenarios show how cleaner air and water, better diets and more active lifestyles can improve health, and that cleaner urban environments are more pleasant to live in and better support mental wellbeing. The Lancet's 2015 Commission on Health and Climate Change, with over 100 authors from around the world, stated as its central finding that, "*tackling climate change could be the greatest global health opportunity of the 21st century.*"

ANNEX 1

The full list of scenarios

WHERE	WHAT	WHO	WHEN	SCENARIO SUMMARY
GLOBAL CASE STUDIES				
The World	Energy Transition within 1.5C: A disruptive approach to 100% decarbonisation of the global energy system by 2050	Ecofys	2018	NET 0, 100 %, NGA
	Global Energy Transition - a roadmap to 2050	IRENA	2018	DD, 50+ %, NGA
	Global renewable Energy System based on 100% renewable power sector	Lappeenranta University of Technology and Energywatchgroup	2017	NET 0, 100 %, NGA
	The ten most important short-term steps to limit warming to 1.5°C	Climate Action Tracker: Climate Analytics, Ecofys, New Economy Institute	2016	NET 0, NGA
	Energy [R]evolution 2015: A sustainable world energy outlook	Greenpeace Energy [R]evolution	2015	NET 0, 100 %, NGA
	Global Energy Storage Demand for a 100% Renewable Electricity Supply	Reiner Lemoine Institut	2013	NET 0, 100 %, NGA
	Providing all global energy with wind, water, and solar power Part I & II	Mark Jacobson, Stanford University & Mark Delucchi, University of California	2011	NET 0, 100 %, NGA
	Report: A Solar Transition is Possible	Institute for Policy Research & Development	2011	DD, 100 %, NGA
	The Energy Report: 100% renewable energy by 2050	WWF & Ecofys	2011	NET 0, 100 %, NGA
	Sustainable Energy Visions - Visions for a Renewable Energy World	International Network for Sustainable Energy (Inforse)	2002	NET 0, 100 %, NGA

KEY GUIDE

- NET 0 — Net-zero emissions scenario for at least one sector
- DD — Deep decarbonisation scenario for at least one sector
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REGIONAL CASE STUDIES				
Sub-Saharan Africa	A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030	Child M., Koskinen O., Linnanen L. and Breyer Ch., Laappeenraanta University of Technology	2018	NET 0, 100%, NGA
Baltic Sea	The Baltic Sea Region: Storage, grid exchange and flexible electricity generation for the transition to a 100% renewable energy system	Child M., Bogdanov D., Breyer Ch., Lappeenranta University of Technology	2018	NET 0, 100%, NGA
Europe	The role of storage technologies for the transition to a 100% renewable energy system in Europe	Child M., Bogdanov D., Breyer Ch., Lappeenranta University of Technology	2018	NET 0, 100%, NGA
Southeast Asia and Pacific Rim	A Cost Optimized Fully Sustainable Power System for Southeast Asia and the Pacific Rim, Energies	Gulagi A., Bogdanov D., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0, 100%, NGA
SAARC	Electricity system based on 100% renewable energy for India and SAARC.	Gulagi A., Bogdanov D., Choudhary P., Breyer Ch., Lappeenranta University of Technology	2017	NET 0, 100%, NGA
South and Central America	Hydro, wind and solar power as a base for a 100% Renewable Energy supply for South and Central America	Barbosa L.S.N.S., Bogdanov D., Vainikka P., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0, 100%, NGA
Greater Mekong Area	Power Sector Vision 2050: Towards 100% renewable energy. Greater Mekong Area Overview; Cambodia Power Sector Vision; Laos Power Sector Vision; Thailand Power Sector Vision; Vietnam Power Sector Vision	WWF, IES (Intelligent Energy Systems), MKE (Mekong Economics Ltd.)	2016	NET 0, 100%, NGA
Northeast Asia	North-East Asian Super Grid for 100% Renewable Energy supply: Optimal mix of energy technologies for electricity, gas and heat supply options	Bogdanov D. and Breyer Ch., Lappeenranta University of Technology.	2016	NET 0, 100%, NGA
South East Europe	Zero carbon energy system of South East Europe in 2050	D.F. Dominkovic´, I. Bacˇekovic´, B. C´osic´, G. Krajacˇic´, T. Pukšec, N. Duic´, N. Markovska	2016	NET 0, 100%, NGA
South East Asia	Energy [R]evolution: A sustainable ASEAN energy outlook	Greenpeace Southeast Asia	2013	DD, 50+%, NGA
Africa	Prospects for the African Power Sector: The renewable scenario	IRENA	2012	DD, 50+%, NGA
European Union	Energy Roadmap 2050	European Commission	2011	NET 0, 100%, GA
Europe and North Africa	100% renewable electricity: A roadmap to 2050 for Europe and North Africa	Price Waterhouse Cooper & Potsdam Institute	2010	NET 0, 100%, NGA
European Union	Re-thinking 2050: A 100% Renewable Energy Vision for the European Union	European Renewable Energy Council (EREC)	2010	NET 0, 100%, NGA

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REGIONAL CASE STUDIES				
European Union	Roadmap 2050 - 80% GHG emission reductions by 2050	European Climate Foundation	2010	DD 50+% NGA
European Union	Europe's Share of the Climate Challenge: Domestic Actions and International Obligations to Protect the Planet	Stockholm Environment Institute	2009	DD 50+% NGA
European Union	Roadmap 2050, European Climate Foundation	Power Perspective 2050	Unknown	DD 50+% NGA
NATIONAL CASE STUDIES				
139 Countries	100% renewable energy by country	Solutions Project	2018	NET 0 100% NGA
Australia	Zero Carbon Australia	Beyond Zero Emissions	2010-2017	NET 0 100% NGA
Australia	Pathways to deep decarbonization in Australia	DDPP	2015	DD 50+% NGA
Belgium	Towards 100% renewable energy in Belgium by 2050	Vito & Belgian Federal Planning Bureau	2013	DD 100% NGA GA
Bhutan	A national strategy and action plan for low carbon development	Royal Government of Bhutan	2012	DD 50+% GA
Brazil	Pathways to deep decarbonization in Brazil	DDPP	2015	DD 50+% NGA
Brazil	Energy [R]evolution For a Brazil with 100% clean and renewable energy	Greenpeace Brazil	2016	NET 0 100% NGA
Canada	Pathways to deep decarbonization in Canada	DDPP	2015	DD 50+% NGA
Canada	Energy [R]evolution: A Sustainable Energy Outlook for Canada	Greenpeace Canada	2010	DD 50+% NGA
Chile	MAPS Chile - Mitigation options for a low carbon development	Mitigation Action Plans & Scenarios (MAPS)	2013	DD 50+% NGA GA

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NATIONAL CASE STUDIES				
China	Pathways to deep decarbonization in China	DDPP	2015	DD 50+% NGA
China	China's Future Generation: Assessing the Maximum Potential for Renewable Power Sources in China to 2050	WWF China; By William Chandler, Chen Shiping, Holly Gwin, Lin Ruosida, Wang Yanjia	2014	DD 50+% NGA
China	China's Future Generation 2.0: Assessing the Maximum Potential for Renewable Power Sources in China to 2050	WWF China; By William Chandler, Holly Gwin, Lin Ruosida, Wang Yanjia	2015	DD 50+% NGA
Denmark	2020, 2035, 2050 Scenarios for energy decarbonisation	Danish Energy Agency	2012	DD 100% GA
Denmark	The IDA Climate Plan 2050	Danish Society of Engineers	2009	DD 100% NGA
Denmark	Fast transition to Renewable Energy with Local Integration of Large-Scale Windpower in Denmark	Gunnar Boye Olesen, Sustainable Energy	2014	NET 0 100% NGA
Denmark	The IDA Energy Vision 2050: A Smart Energy System strategy for 100% renewable Denmark	Danish Society of Engineers, Aalborg University	2015	NET 0 100% NGA
Denmark	Fast Transition to 100% Renewable Energy by 2030	Gunnar Boye Olesen, SustainableEnergy, Denmark.	2015	NET 0 100% NGA
Ethiopia	The path to sustainable development - Ethiopia's Climate-Resilient Green Economy Strategy	Federal Democratic Republic of Ethiopia	2010	NET 0 100% GA
Finland	The Role of Solar Photovoltaics and Energy Storage Solutions in a 100% Renewable Ener gy System for Finland in 2050	Child M., Haukkala T., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0 100% NGA
France	Pathways to deep decarbonization in France	DDPP	2015	DD 50+% NGA
France	France can reach 100% renewable energy by 2050 while phasing-out nuclear	The négaWatt Association	2017	NET 0 100% NGA
Germany	Kombikraftwerk - detailed 100% renewable energy scenario for Germany	Fraunhofer-Instituts für Windenergie und Energiesystemtechnik (IWES)	2007	DD 100% NGA
Germany	Germany in 2050 - a greenhouse gas-neutral country	German Federal Environment Agency	2014	NET 0 100% GA

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NATIONAL CASE STUDIES				
Germany	Pathways to deep decarbonization in Germany	DDPP	2015	DD 50+% NGA
India	The energy report- India 100% renewable energy by 2050	WWF India and The Energy and Resources Institute (Teri)	2013	DD 50+% NGA
Iran	Analysis of 100% renewable energy for Iran in 2030: integrating solar PV, wind energy and storage	Aghahosseini A., Bogdanov D., Ghorbani N., Breyer Ch., Lappeenranta University of Technology.	2018	NET 0 100% NGA
Iran	Transition to a 100% renewable energy system and the role of storage technologies: A case study for Iran	Ghorbani N., Aghahosseini A., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0 100% NGA
Israel	Solar driven net zero emission electricity supply with negligible carbon cost: Israel as a case study for Sun Belt countries	Solomon A.A., Bogdanov D., Breyer Ch.	2018	NET 0 100% NGA
Italy	Scenario analysis for RES-E integration in Italy up to 2050	Power System Scenarios and Energy Efficiency Research Group	2011	DD 50+% NGA
Italy	Pathways to deep decarbonization in Italy	DDPP	2015	DD 50+% NGA
Italy	Energy [R]evolution: A Sustainable Italy Energy Outlook	Greenpeace Italy	2013	DD 50+% NGA
Japan	The advanced energy [r]evolution: A sustainable energy outlook for Japan	Greenpeace Japan	2011	DD 50+% GA
Japan	Pathways to deep decarbonization in Japan	DDPP	2015	DD 50+% NGA
Macedonia	Transition Towards Sustainable Energy - Macedonia	Jasmina Said, Eko-svest, Macedonia	2017	DD 100% NGA
Mexico	Pathways to deep decarbonization in Mexico	DDPP	2015	DD 50+% NGA
New Zealand	A 100% renewable electricity generation system for New Zealand	University of Canterbury	2010	NET 0 100% NGA
New Zealand	The Future is here: New Jobs, New Prosperity and a New Clean Economy.	Greenpeace New Zealand and The Institute of Thermodynamics of the German Aerospace Centre (DLR)	2013	NET 0 100% NGA

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NATIONAL CASE STUDIES				
New Zealand	Net-zero in New Zealand Scenarios to achieve domestic emissions neutrality in the second half of the century	Vivideconomics	2017	NET 0, 50+ %, NGA
North America	A techno-economic study of an entirely renewable energy based power supply for North America for 2030 conditions	Aghahosseini A., Bogdanov D., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0, 100 %, NGA
Norway	Knowledge base or low-carbon transition in Norway	Norwegian Env. Agency	2014	DD, 100 %, GA
Pakistan	Energy Transition roadmap towards 100% renewable energy and role of storage technologies for Pakistan by 2050	Sadiqa A., Gulagi A., Breyer Ch., Lappeenranta University of Technology.	2018	NET 0, 100 %, NGA
Portugal	How to achieve a 100% RES electricity supply for Portugal?	University of Zagreb & Instituto Superior Técnico, Lisbon	2014	NET 0, 100 %, NGA
Portugal	Electricity decarbonisation pathways for 2050 in Portugal	MIT Portugal Program, University of Lisbon	2014	DD, 100 %, NGA
Scotland	Pathways to Power: Scotland's route to clean, renewable, secure electricity by 2030	WWF Scotland	2015	DD, 50+ %, NGA
South Africa	Pathways to deep decarbonization in South Africa	DDPP	2015	DD, 50+ %, NGA
Sweden	Energy Scenario for Sweden 2050 Based on Renewable Energy Technologies and Sources	IVL Swedish Environmental Research Institute & WWF	2011	DD, 50+ %, NGA, GA
Tanzania	100% renewable energy for tanzania: Access to renewable energy for all within one generation	Institute for Sustainable Futures - University of Technology Sydney, Bread for the World, Climate Action Network Tanzania and World Future Council	2017	NET 0, 100 %, NGA
Turkey	An Energy Transition Pathway for Turkey to Achieve 100% Renewable Energy Powered Electricity, Desalination and Non-energetic Industrial Gas Demand Sectors by 2050	Kilickaplan A., Bogdanov D., Peker O., Caldera U., Aghahosseini A., Breyer Ch., Lappeenranta University of Technology	2017	NET 0, 100 %, NGA
Uganda	Energy Report for Uganda: A 100% Renewable Energy Future by 2050	WWF Uganda, IVL Swedish Environmental Research Institute, African Solar Design and KTH Royal Institute of Technology	2015	DD, 50+ %, NGA
Ukraine	Role of storage technologies for the transition to a 100% renewable energy system in Ukraine	Child M., Bogdanov D., Breyer Ch., Fell H.-J., Lappeenranta University of Technology.	2017	DD, 100 %, NGA
Ukraine	Transition of Ukraine to the renewable energy by 2050	Child, Michael & Bogdanov, Dmitrii & Breyer, Christian. Lappeenranta University of Technology; and Heinrich Boll Foundation Kiev office.	2017	NET 0, 50+ %, NGA

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ANNEX 1: The full list of scenarios

WHERE	WHAT	WHO	WHEN	SCENARIO SUMMARY
NATIONAL CASE STUDIES				
Ukraine	*Transition towards sustainable energy - Ukraine*	Olexandra Tryboi, Renewable Energy Agency Ukraine	2017	DD, 100%, GA
United Kingdom	*Positive Energy: how renewable electricity can transform the UK by 2030*	WWF UK	2011	DD, 50+%, NGA
United Kingdom	*A plan for Clean British Energy: Powering the UK with renewables – and without nuclear*	Friends of the Earth	2012	DD, 50+%, NGA
United Kingdom	*Zero Carbon Britain: Re-thinking the Future*	Centre for Alternative Technology	2013	NET 0, 100%, NGA
United Kingdom	*Pathways to deep decarbonization in The United Kingdom*	DDPP	2015	DD, 50+%, NGA
United States	*Energy [R]evolution: A sustainable USA energy outlook*	Greenpeace International	2009	DD, 50+%, NGA
United States	*Renewable Electricity Futures for the United States*	National Renewable Energy Laboratory	2014	DD, 50+%, GA
United States	*100% Wind, Water and Sunlight Energy Plans for the 50 United States*	The Solutions Project	2015	NET 0, 100%, NGA
United States	*Pathways to deep decarbonization in the United States*	DDPP	2015	DD, 50+%, NGA
SUB-NATIONAL CASE STUDIES				
Åland, Finland	*Scenarios for a Sustainable Energy System in the Åland Islands in 2030*	Child M., Nordling A., Breyer Ch., Lappeenranta University of Technology.	2017	NET 0, 100%, NGA
Basque Country, Spain	*Climate Change Strategy of the Basque Country to 2050*	Administration of the Basque Country Autonomous Community and the Department of Environment and Territorial Policy	2015	DD, GA
Berlin, Germany	*Climate-Neutral Berlin 2050*	Berlin Senate	2014	DD, 50+%, GA
Berlin-Brandenburg, Germany	*Transforming the electricity generation of the Berlin-Brandenburg region, Germany*	Moeller C., Mueller B., Meiss J., Hlusiak M., Breyer Ch., Kastner M., Twele J., Lappeenranta University of Technology	2014	NET 0, 100%, NGA

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SUB-NATIONAL CASE STUDIES				
California, US	*California Pathways*	E3, commissioned by California Government	2015	DD 50+% NGA GA
Canary Islands, Spain	*Carbon neutral archipelago – 100% renewable energy supply for the Canary Islands*	DLR - German Aerospace Center	2017	NET 0 100% NGA
Christchurch, New Zealand	*Zero Carbon Christchurch*	University of Auckland	2012	NET 0 100% NGA
Copenhagen, Denmark	*Copenhagen 2025 Climate Plan – a Green, Smart and Carbon Neutral City*	City of Copenhagen	2012	DD 50+% GA
Frankfurt, Germany	*Master Plan 100% Climate Protection Frankfurt*	Stadt Frankfurt am Main	2015	DD 100% GA
La Gomera, Spanish Canary Islands	*Assessment of sustainable energy system configuration for the island of La Gomera in 2030*	Meschede H., Child M., Breyer Ch., Lappeenranta University of Technology.	2018	NET 0 100% NGA
Limerick, Ireland	*Limerick Clare Energy Plan: Climate Change Strategy*	Limerick - Clare	2012	NET 0 100% NGA
Los Angeles, US	*Clean Energy for Los Angeles: An analysis of a pathway for 100 percent renewable energy in Los Angeles by 2030*	Prepared for Food & Water Watch by Synapse Energy Economics	2018	NET 0 100% NGA
Maryland, US	*Prosperous, renewable Maryland roadmap for a healthy, economical, and equitable energy future*	Arjun Makhijani, Ph.D. Institute for Energy and Environmental Research	2016	NET 0 100% NGA
Massachusetts, US	*Massachusetts Clean Energy and Climate Plan for 2020: 2050 Scenario Analysis*	Executive Office of Energy and Environmental Affairs' (EEA)	2015	DD 50+% GA
Melbourne, Australia	*Zero Net Emissions by 2020*	City of Melbourne	2014	DD 50+% GA
Michigan, US	*100% Renewable Energy Plan for Leelanau County, Michigan USA*	University of Michigan School of Natural Resources & Environment for Northport Energy Action Taskforce	2016	NET 0 100% GA
Minnesota, United States	*A technical and economic analysis of a 100% renewable energy-based electricity system for Utah.*	Renewable Minnesota - Institute for Energy and Environmental Research	2010	DD 100% NGA
Munich, Germany	*Carbon free Munich*	Wuppertal Institut	2009	DD 50+% GA

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SUB-NATIONAL CASE STUDIES				
New York State, US	*Making Residential Heating and Cooling Climate-Friendly in New York State*	Arjun Makhijani, Ph.D. Institute for Energy and Environmental Research - Prepared for Alliance for a Green Economy	2017	DD, 100%, NGA
Oxford County, Ontario, US	*100% Renewable Energy Plan*	Oxford County Council	2016	100%, GA
Samsø, Denmark	*Samsø Energy Vision 2030: Converting Samsø to 100% renewable energy*	Mathiesen, Brian Vad; Hansen, Kenneth; Skov, Iva Ridjan; Lund, Henrik; Nielsen, Steffen; Aalborg University	2015	NET 0, 100%, GA
Seattle, US	*Seattle Climate Action Plan* and *Seattle CAP Implementation Strategy*	Seattle Government	2011 and 2013	DD, NGA, GA
Sonderborg, Denmark	*'ProjectZero' - creating a Zero Carbon Sonderborg by 2029.*	Zero Carbon Sonderborg	2009	DD, 50+%, NGA
Stockholm, Sweden	*Roadmap for a fossil-fuel free Stockholm by 2050*	Stockholm City: Planning & Environment Unit of the Environment and Health Administration.	2014	NET 0, GA
Swansea Bay, Wales	*Swansea Bay City Region: A Renewable Energy Future Energy system vision for 2035*	Institute for Welsh Affairs and Regen	2018	DD, 100%, NGA
Sydney, Australia	*City of Sydney decentralised energy master plan renewable energy 2012–2030*	City of Sydney	2013	DD, 100%, GA
Vancouver, Canada	*Renewable city action plan economic modelling results*	City of Vancouver	2016	NET 0, 100%, GA
Vancouver, Canada	*Renewable City Strategy*	City of Vancouver	2015	NET 0, 100%, GA
Washington State, US	*Deep Decarbonization Pathways Analysis for Washington State*	Ben Haley, Gabe Kwok and Ryan Jones of Evolved Energy Research, commissioned by the State of Washington Office of the Governor and Office of Financial Management	2016	DD, 50+%, NGA, GA

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ANNEX 2

Talking zero – terms, definitions and guardrails

Definitions, scope and methodology

Negotiators, business leaders, cities and regions use a wide range of technical definitions around net zero carbon. This is illustrated throughout the diverse collection of case studies and scenarios we have assembled from across the globe. The usage of terms has arisen independently and without common definitions. To offer some clarity about what we mean by 'net zero' and related terms such as 'decarbonisation', we offer the following definitions below.

Net zero and zero net emissions

We define net zero emissions as:

> *Emissions of greenhouse gases are reduced by the maximum extent technically possible. Only when no alternatives to the emitting sources are available and where the use of these sources is regarded as essential, and where the goods or services provided are considered essential, can the resulting 'residual emissions' be sequestered by negative emissions solutions achieved in a transparent, sustainable and equitable way.*

The term net zero can also be used to indicate zero total emissions within the confines of any specific sector (e.g. a net zero electricity system, a net zero building, etc.). On its own, net zero does not prescribe the use of any particular technology or method for reducing, absorbing or capturing emissions. It also does not specify a timeline for reaching zero emissions, nor the scope of emissions to be covered.

The scenarios we have examined demonstrate that we literally cannot reach the necessary zero emissions goal without some negative processes to compensate for unavoidable residual emissions from agriculture, land-use and industrial processes. Therefore every zero emissions scenario is effectively a net zero scenario.

Definitions of net zero require that any GHG-negative processes used, either within a country or between countries, must be well regulated and approved as both sustainable and equitable.

The key criterion is that 'all emissions that can go to zero must go to zero' on a rapid timescale – not just in electricity, *but also in heat, transport, industry and land-use.* We must avoid the temptation to 'balance out' the continued burning of fossil fuels with use of speculative future technologies. These unproven methods are likely to burden future generations with the need to re-capture massive amounts of carbon.

For example, CAT's *Zero Carbon Britain: Rethinking the Future* scenario shows that 'net zero' can be achieved within the UK by implementing efficiencies and renewable technologies across all sectors – and then dealing with the remaining emissions through natural sequestration such as peatland restoration and reforestation.

Even with a zero emissions end-goal, the science still requires a clearly defined trajectory that takes into account total cumulative emissions released over a period of time, not just 'in 2050'.

A zero emissions target by mid-century must be supported by:

1. an early peaking date;
2. the phase-out of emissions from fossil fuels and the decarbonisation of every sector to as near to zero as possible;
3. deployment of sustainable negative emissions processes to reach net zero.

The term 'net zero', as set out by the IPCC, requires this trajectory to be adhered to.

ANNEX 2: Talking zero – terms, definitions and guardrails

Be specific

We must also recognise there is another complexity in defining a 'net zero GHG emissions' target. That is, can we offset one type of GHG, for example methane, with reductions in another GHG such as carbon dioxide? The accounting for this can be done using Global Warming Potentials (GWPs) to equate one GHG to another. However, the correct value of these GWPs is debated and has changed over time – the IPCC's GWP for methane has increased from x 25 to x 34 in its latest report. Therefore, when we use the term 'net zero', we should specify the timeline and define the gases we are considering in terms of CO_2, CO_2e or GHGs. These are defined as follows:

> **CO_2**: Carbon dioxide.
>
> **CO_2e**: Carbon dioxide is not the only greenhouse gas and it is useful to express a carbon footprint consisting of a range of different GHGs as a single comparable unit: CO_2 equivalent (CO_2e). For example, during 2013, the UK released 467 million tonnes of CO_2. If you include its emissions of methane, nitrous oxide and other GHGs, the UK's total emissions work out at 568 million tonnes of CO_2e.
>
> **GHGs**: Although CO_2 is the most abundant, other greenhouse gases (GHGs) include methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6).

In order to be as accurate as possible, all scenarios must be clear about references to CO_2, CO_2e or GHGs.

Sustainability guardrails

In a recent study by energy system modellers at Lappeenranta University of Technology, sustainability guardrails in global energy scenarios were reviewed and further developed based on a literature review of global energy system transition scenarios.

They found insufficient exploration, use and adherence to sustainability principles and quantified planetary boundaries in modelling work around the world – in most cases a complete absence. Sustainability guardrails go further than a sustainable net zero (where everything that can go to zero must go to zero); they incorporate representation of peoples and future generations, and include the socio-cultural impacts and changes implied by major transformations of energy systems.

"*Determining energy mixes for energy scenarios requires ethical choices due to long reaching impacts of energy decision-making and profound impacts on economics, the environment and people's lives. Consequently, future energy scenarios take on the role of long-term social contracts, which must be based on principles of justice.*"
(p.322, Child et al., 2018)

Sustainability guardrails not only interrogate the principles and impacts underlying scenarios, they also require transparency. Child et al. state that, "*an energy scenario can be handcrafted to drive certain interests. For this reason, transparency in the creation of energy scenarios is essential, since model assumptions greatly affect the modelling outcomes.*"
(p.321, Child et al., 2018)

When creating stories, snapshots and narratives about potential futures there is a responsibility to be transparent about the underlying assumptions – technical, economic and cultural – to bring the consideration of human and ecosystem impacts into the centre of modelling work, and to generate open discussion spaces on the work that is inclusive, to prevent the 'danger of the single story' effect. (Adichie, 2009)

The authors identified the following criteria to improve the transparency and credibility of climate solutions scenarios:

- better disclosure and clear referencing of used sources of information;
- indication of how data is processed (e.g. type of model used);
- provision of a full set of cost assumptions;
- exploration of how variations in cost assumptions influence the outcomes of the study;
- setting of objectives on sustainability targets and measuring of results in that dimension;
- discussion of the impact of the scenario results on given planetary boundaries;
- adequate description of the major flexibility characteristics of energy systems with high shares of renewables (storage capacities, function of grids, demand response, resource complementarity, supply side management and energy sector coupling);
- disclosure of who has ordered the study by clarifying sources of funding and organisational affiliations.

"*The ultimate goal of scenario modellers should always be to reduce uncertainty about the future, and to expand meaningful scientific and public discourse on the transition towards greater sustainability in global energy systems.*"
(p.332, Child et al., 2018)

ANNEX 2: Talking zero – terms, definitions and guardrails

Carbon neutrality and climate neutrality

Carbon neutrality means achieving net zero CO_2 by balancing any carbon released with an equivalent amount captured through net negative processes, either locally or elsewhere. If the term carbon neutrality is intended to include other GHGs, they must be measured and included in terms of their CO_2 equivalence.

The inclusion of all gases and sectors is often referred to as climate neutrality as this clearly signals that the focus in not just on carbon / CO_2 but on all gases and the effect they have on the atmosphere.

Decarbonisation

'Decarbonisation' is the reduction in emissions through physical mitigation, or the removal of carbon from the sector being referred to, e.g. the decarbonisation of the energy sector. Once again technologies or methods of removal (carbon capture and storage or use of offsets) are not defined within this term.

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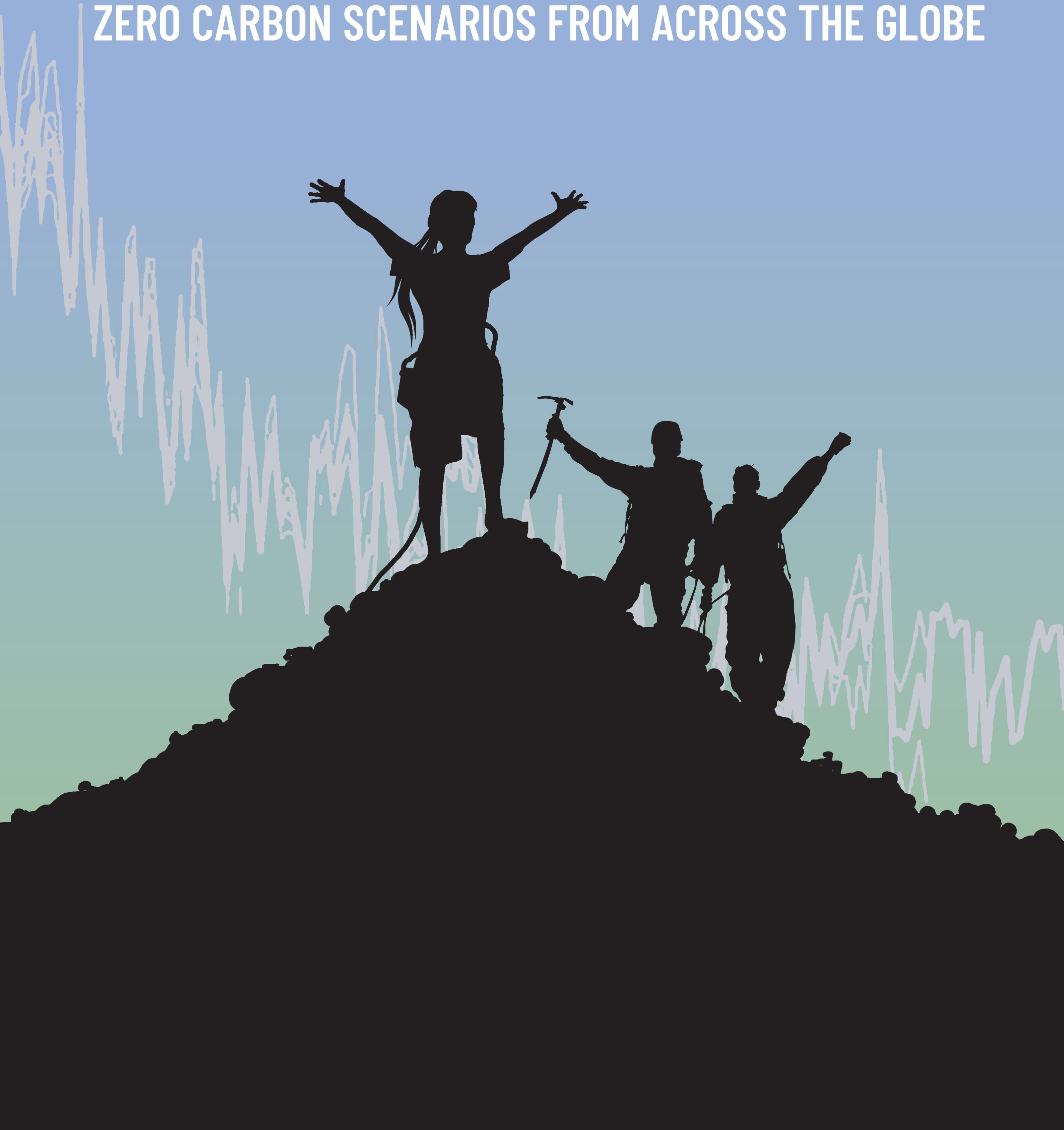
RAISING AMBITION

ZERO CARBON SCENARIOS FROM ACROSS THE GLOBE



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