COP30 as a Turning Point

NTNU and SINTEF's
Research-Based Advice

COP30 BRASIL AMAZÔNIA
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NTNU SINTEF

SINTEF and NTNU at COP30

NTNU and SINTEF are joining forces at the UN Climate Change Conference COP30 – the world's most important arena for international climate action. As RINGO observers (Research and Independent NGOs), we take on a threefold role: communicating research that supports the Sustainable Development Goals both globally and nationally, contributing knowledge to climate negotiators and other stakeholders by sharing insights and current status, and promoting sustainable solutions in climate and energy. With this brochure, NTNU and SINTEF share research-based insights to support the Norwegian delegation in their work at COP30.

Through education, research, and technological development, NTNU and SINTEF contribute to solving major societal challenges. Our shared mission is to support a knowledge-based transition to a sustainable society – both in our own region and globally.

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A selection of global SINTEF and NTNU projects

1. Brazil, Spain and Canada

Project: InterOpt

SINTEF and NTNU, together with partners from Brazil, Spain and Canada, are developing optimisation models for the global renewable energy industry. InterOpt will research how machine learning methods can optimise the production of renewable energy across markets.

2. Nepal

Project: EnergizeNepal

For decades, researchers from NTNU and SINTEF have helped Nepalese authorities and professionals develop sustainable hydropower. EnergizeNepal is a competence-building project to scale up renewables in Nepal.

3. India

Project: INDEE+

INDEE+ aims to encourage the refrigeration and air conditioning sector in India to adopt more environmentally friendly technologies. NTNU leads the project and SINTEF is the research partner.

4. Southeast Asia

Project: OPTOCE

Through the project, SINTEF has contributed to reducing the inflow of plastic pollution into the world's oceans by establishing a circular value chain where plastic is collected and used as an input factor in the cement industry.

5. Tanzania, Ethiopia, Uganda, Mozambique, South Sudan, Malawi

Project: Energy Technology Network (NET)

Seven African universities are collaborating with NTNU through Norad's NORHED II programme to develop small-scale renewable energy solutions for off-grid use.

6. Kenya, Uganda, South Sudan

Project: Capacity building for socially just and sustainable energy transitions

NTNU, UiS, the University of Juba, Makerere University, and the Technical University of Kenya are building capacity and expertise through education, research, and dissemination to ensure that the workforce in East Africa has the knowledge and skills needed to implement and advocate for a just and sustainable energy transition.

7. Europe

Project: ACCESS

ACCSESS will contribute to drastic cuts in industrial CO_2 emissions and to net CO_2 removal from the atmosphere (CDR). The project, led by SINTEF, targets sectors such as the paper and cement industries, waste incineration, and biorefining.

8. Europa

Project: MISSION

MISSION is an EU project that develops three SF_6-free circuit breaker technologies for medium- and high-voltage applications. The project includes 12 partners from 9 European countries and is led by SINTEF.

9. Kina

Project: CHEERS

The EU project CHEERS, led by SINTEF, has helped build the world's largest green incineration plant (4 MW) utilising the chemical circulation combustion (CLC) method. CO_2 capture is a natural part of the combustion process and is therefore almost 70 per cent cheaper than other capture methods.

10. Africa

Project: OpenMod4Africa

The EU-funded project OpenMod4Africa, led by SINTEF, aims to foster sustainable, reliable, and competitive energy systems across Africa. It is expected to significantly influence the continent's future energy landscape. The project focuses on developing regional expertise and creating a set of open models and scenarios for long-term energy system development in 26 African countries.

COP30 as a Turning Point

Asgeir Tomasgard, NTNU and Nils Røkke, SINTEF

COP30 in Belém, Brazil, marks a decisive year for implementing the Paris Agreement. We are already in the decade when global emissions must peak and begin to decline if we are to have a realistic chance of maintaining the intentions of the Paris Agreement.

At the same time, we have now experienced a full year of 1.5 °C of warming relative to pre-industrial times, and atmospheric CO_2 levels have passed 430 ppm — a point many consider marks the loss of the 1.5 °C goal. New studies (e.g. the Production Gap Report) show that there are still plans to produce far more fossil fuels — and thereby emissions — than what remains of the carbon budget needed to stay within the limits of the Paris Agreement.

Meanwhile, the same countries are expected to submit new and more ambitious Nationally Determined Contributions (NDCs) towards 2035, and the follow-up to the results of the first Global Stocktake is underway. This divergence between plans and ambitions demonstrates how challenging the transition is, and how late we are in addressing the crises of climate, nature, and land use. It also contrasts with the COP28 final declaration, which states: “Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade, so as to achieve net zero by 2050, in keeping with the science.”

However, this must not prevent us from working hard to close the gap between our ambitions and actions — the future can only improve through strong, collective effort. The COP28 declaration also states: “Tripling renewable energy capacity globally and doubling the global average annual rate of energy efficiency improvements by 2030.” There is progress on this front — despite geopolitical disruptions, or perhaps even because of them. Asia is now taking the lead in developing renewable energy and green solutions, as highlighted in reports such as the Draghi Report. The region is investing heavily and long-term, looking beyond short-term market fluctuations. One could argue that this is happening in non-market economies, but it is the reality we must face.

As a nation with strong research and technological expertise in energy and climate, Norway has both a responsibility and an opportunity to contribute internationally. Our own history shows that regulations and environmental considerations can be genuine competitive advantages for the economy, even if they may initially seem unilateral or restrictive. Examples include the ban on flaring, the construction of the gas pipeline network, strict requirements for diffuse emissions, and a specific tax on petroleum sector emissions — all of which have strengthened, not weakened, our position. We are now at a crossroads, and new measures must be taken.

In negotiations, we should highlight capacity-building, research, innovation, and technology as integral to climate action. This includes initiating partnerships for energy transition, particularly with countries in the Global South, and supporting binding targets for both renewable energy and energy efficiency in the COP30 final declaration.

COP30 will be a critical test of the Paris Agreement's continued credibility. For the first time, new climate targets will be shaped based on the outcomes of the global stocktake. Negotiations must lead to concrete solutions and partnerships that deliver impact at a global scale. This will require renewed momentum and increased investment in research and innovation, especially in areas essential to energy systems, climate technologies, and international collaboration. In recent years, global efforts in climate-related research have declined in several key areas, and reversing this trend is vital for achieving meaningful progress.

Trondheim, 28 October 2025

To succeed, we must

Increase climate finance, both through existing mechanisms and new instruments for targeted action.

Share knowledge and technology so that all countries have access to the best and most suitable solutions.

Agree on standards and frameworks for measuring, reporting, and verifying emission reductions.

What is Needed to Reach 1.5 °C

Tripling global renewable energy capacity and doubling the annual rate of energy efficiency improvements by 2030

Accelerating efforts to phase down coal power without carbon capture technology

Advancing global efforts to reach net-zero emissions in the energy sector through early and effective deployment of zero- and low-carbon fuels

Ensuring that the transition away from fossil fuels in energy systems happens in a just and orderly manne

Accelerating zero- and low-emission technologies, including renewable energy, carbon capture and storage, and low-carbon hydrogen production

Significantly reduce non-CO_2 emissions globally, with particular emphasis on methane, by 2030

Accelerating the reduction of emissions from road and maritime transport through new and improved infrastructure and deployment of zero-emission vehicles and vessels

Phasing out inefficient fossil fuel subsidies as soon as possible

Promoting accountability for the consistency between planned production and use of fossil fuels, with greater responsibility for Scope 3 emissions in each country

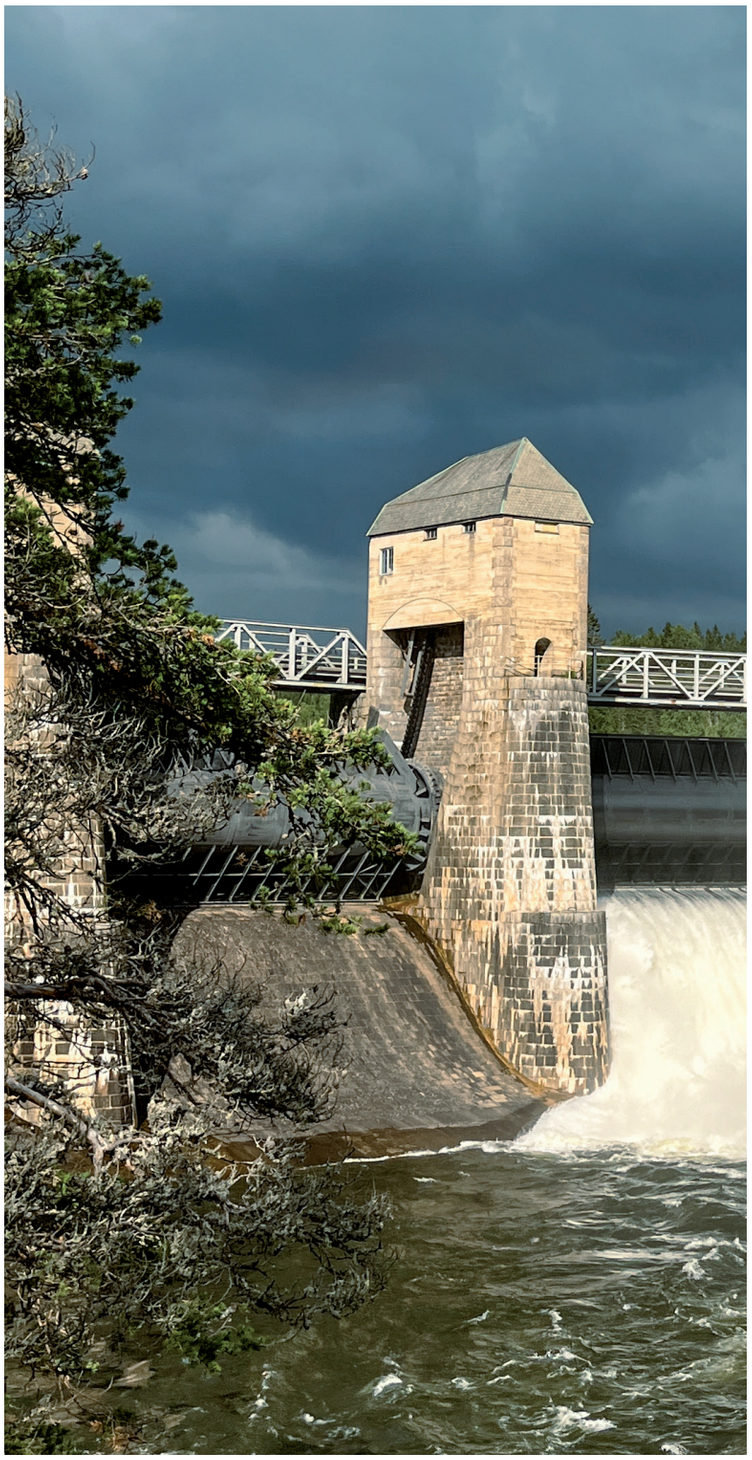

Photo: Adobe Stock

Collaboration with the Global South

1

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To succeed with the green transition, solutions must be adapted to the needs of low- and middle-income countries. This requires a holistic approach in which business, research, and authorities collaborate to develop and implement technologies that both reduce emissions and create new jobs.

Recommendations

- Strengthen partnerships between business, research institutions, and public authorities to develop climate-adapted technologies and local competence.
- Increase access to, and reduce risk associated with, financing for projects in low- and middle-income countries, particularly through innovative financial schemes and public–private partnerships.
- Promote open platforms for sharing knowledge, data, and best practices – so that countries in the Global South can adopt the most effective solutions without repeating past mistakes.

Current Situation

Many low- and middle-income countries have limited access to capital, technology, and expertise necessary for a just green transition. At the same time, these countries are often the hardest hit by climate change and the most dependent on natural resources under pressure. Without targeted support and inclusive cooperation, the world risks reinforcing inequalities between the Global North and South.

Several sectors are particularly important for collaboration with the Global South – both because they have large emission-reduction potential and because they are directly linked to development goals.

The food system accounts for around one-third of global greenhouse gas emissions, and many low- and middle-income countries are major producers and exporters of food. At the same time, food security in these countries is threatened by climate change, biodiversity loss, and inefficient transport.

The energy sector is often characterised by limited access to clean energy, which hampers health, education, and economic development. This applies to infrastructure related to both production and distribution, at national and local levels.

The health sector is vulnerable to climate change and requires robust, emission-free solutions – particularly in cooling, transport, and energy supply.

Plastic pollution is an increasing problem, and many countries lack systems for collection and recycling, while being hardest hit by plastic waste in the environment.

Solution

The solution lies in building strong, inclusive innovation networks that combine global knowledge with local experience. This encourages the development of fact-based, context-specific policy options that drive sustainable actions and effective implementation. By investing in technology transfer, education, and sustainable industrial development, we can create genuine transformative power in developing countries while also contributing to global emission reductions.

Cooperation should focus on key sectors where climate and development intersect:

Food systems: Investments in climate-friendly production, controlled cold chains, and reduced food waste can yield substantial benefits.

Energy sector: Local production of renewable energy and energy-efficient solutions will have immediate benefits for those with the least access, while centralised solutions promote industrial value creation at the national level. Both contribute to significant emission cuts and progress towards several Sustainable Development Goals (SDGs) and actionable National Determined Contributions.

Health sector: Cooperation can foster resilient health systems capable of withstanding climate change while reducing emissions. This includes using climate and environmental data to predict climate-driven disease outbreaks and strengthen preparedness for climate-related crises (e.g. logistics for medical supplies), ensuring access to clean energy for health institutions, climate-friendly medical equipment, sustainable waste management solutions, and telemedicine that reduces transport-related emissions.

Plastic waste management: Circular models and technologies for collection and recycling can reduce emissions and environmental pressure.

It is crucial to build upon financing and cooperation models that have already proven effective, promoting open knowledge sharing, local capacity building, and inclusive innovation. At the same time, we must ensure that countries in the Global South have the opportunity to leapfrog the carbon-intensive stages of industrialisation that characterised development in the North. Experiences from high-income countries show that short-term, fossil-based growth creates long-term environmental costs that must not be repeated.

Projects in the Global South should therefore be designed to achieve multiple benefits simultaneously: reduced climate impact, conservation of natural resources, strengthened local economies, and improved living conditions. When climate efforts are closely linked to development goals, results can be more lasting and more equitable.

COP30 should therefore emphasize fair technology development and financing – enabling all countries to take part in the transition without repeating the mistakes of the past.

Sustainable Cooling

2

NTNU: Armin Hafner
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Cooling and heating are two sides of the same coin – both are essential parts of a modern society. Whether for comfort cooling in buildings, food storage and preservation, vaccine storage, or heating through heat pumps, these technologies are central both for climate adaptation and emission reductions. With rising global temperatures and growing demand for thermal comfort and food security, we must invest in solutions that are energy-efficient, climate-friendly, and safe for the future.

Recommendations

- **Prioritise natural refrigerants in public procurement.** Solutions based on CO_2, NH_3, hydrocarbons, and water vapor should be required in all tenders.
- **Introduce strict limits on GWP** and phase out fluorinated refrigerants in line with the EU F-gas Regulation. Strengthen research to develop solutions based on natural refrigerants.
- **Establish incentives** ensuring the collection and destruction of all fluorinated refrigerants – including PFAS-based substances not currently covered by GWP-based return schemes.
- **Modernise standards for flammable refrigerants** so that larger charge sizes of hydrocarbons can be used in cooling and heat pump systems for buildings and industry.
- **Promote development of high-temperature heat pumps** using natural working fluids capable of delivering 100–200 °C process heat, replacing fossil-based heat sources in industry.
- **Incentivise technology transfer and financing** of sustainable cooling solutions to low- and middle-income countries (LMICs/UMICs) to reduce emissions, energy use, and food waste globally.

Current Situation

The demand for cooling is rising rapidly due to climate change and higher temperatures. According to UNEP, sustainable cooling is essential both for climate adaptation and for reducing greenhouse gas emissions. The Montreal Protocol (1989) stopped the use of ozone-depleting CFCs, but their replacements – HFCs – turned out to be powerful greenhouse gases. The Kigali Amendment (2019) commits countries to gradually reduce HFCs, but progress remains too slow. Switching to ozone- and climate-friendly alternatives could avoid more than half a degree of global warming by the end of this century[i].

A new challenge comes from the replacement substances for HFCs, the so-called HFOs, which have low global warming potential (GWP) but fall under the category of PFAS (perfluorinated substances). They degrade partly or completely into TFA (trifluoroacetic acid), which accumulates in nature as a "forever chemical". There are currently no restrictions on these substances, but the *Five-Country Initiative* – in which Norway participates together with Germany, the Netherlands, Denmark, and Sweden – has proposed phasing them out[ii].

Cooling is also extremely energy intensive. In countries with fossil-based power generation, cooling contributes significant indirect emissions. High energy efficiency, heat recovery, and a shift to renewable energy are therefore essential for sustainable cooling.

Norway has made great progress, with a tax system for refrigerants based on CO_2 pricing and GWP, as well as a return scheme that has enabled a complete phase-out of F-gases in the grocery sector. However, challenges remain related to PFAS-based refrigerants and standards that limit the use of natural but flammable refrigerants.

Solution

Transitioning to natural refrigerants (CO_2, NH_3, hydrocarbons, water, and air) provides climate-friendly and health-safe solutions. These substances occur naturally in the biosphere, have no ozone or climate impact, and are well-documented in both Norwegian and international research. Meeting cooling needs sustainably could help more than one billion people adapt to climate change and reduce energy transition costs by an estimated USD 3.5 trillion by 2030, according to UNEP. Many low-income countries (A5) can leapfrog directly from HCFC and HFC substances to sustainable alternatives, avoiding temporary and costly solutions that would soon need to be phased out again.

A key part of the solution is developing technologies for heat pumps and cooling systems that can replace fossil heat sources for space heating and industrial processes. Hydrocarbons (HCs) and other natural refrigerants are highly suitable for this purpose, but current standards limit system capacity, particularly for flammable substances. The development and adaptation of standards allowing larger charge sizes is therefore necessary to unlock this potential. Additionally, systems should be designed to integrate heat recovery, further reducing energy demand and optimising overall efficiency.

Beyond replacing high-GWP gases and cutting direct emissions, natural refrigerants also offer significant energy savings. For supermarkets using CO_2 as a refrigerant, electricity consumption has been shown to drop by around 35 % when all cooling, freezing, heating, and air-conditioning needs are integrated into one system. More than 150,000 such systems are now operating worldwide, and several Norwegian retail chains have successfully phased out F-gases entirely through this approach.

Another example is found in fishing vessels, where fish must be chilled or frozen. In large parts of the global fishing fleet, HCFC-22 is still used – a substance both ozone-depleting and a potent greenhouse gas – while in Norway, natural refrigerants such as NH_3 and CO_2 are predominantly used. Efficient cooling systems can preserve food quality and reduce waste, meeting the needs of a growing global population. In long-distance transport using refrigerated containers (*reefer containers*), HFCs are still the dominant refrigerants. There is a major improvement potential if efficient systems using CO_2 or hydrocarbons are developed and adopted.

Carbon Capture and Storage (CCS)

3

NTNU: Philip Ringrose
SINTEF: Mona Mølnvik, Gunhild Reigstad

CCS is a key technology for achieving net zero emissions by 2050. It is particularly important in sectors that cannot be rapidly electrified, such as cement, metals and waste management. Norway has a unique position with strong expertise, established infrastructure and vast CO_2 storage potential on the continental shelf. This enables Norway to contribute both nationally and internationally to the development and scale-up of CCS.

Recommendations

- **Prioritise CCS as a climate solution.** Deploy CCS in sectors that cannot be decarbonised by other means within a reasonable timeframe.
- **Clarify terminology in climate negotiations.** Clearly define “unabated fossil fuels”, including requirements for rapid abatement and a high degree of purification based on Best Available Technology.
- **Expand the phase-out to more sources.** Include emissions from process industries and fossil feedstocks, not only fuels, in the phase-out of unabated emissions.
- **Commit oil-producing countries.** Require that nations with significant fossil resources also provide CO_2 storage capacity corresponding to their exported emissions.
- **Establish frameworks for cross-border storage**. Develop international standards for CO_2 transport and storage between countries to enable large-scale deployment.
- **Develop new business models.** Strengthen collaboration between industry, research and public financing to accelerate scale-up.

Current situation

CCS comprises technologies for capturing CO_2, transporting it and safely storing it in geological formations. According to the IPCC, CCS is essential in almost all scenarios that achieve the climate goals of the Paris Agreement. It is the only technology capable of decarbonising certain industries such as cement and lime production, waste-to-energy, and parts of metal production. In hard-to-abate sectors such as aluminium, CCS will be crucial to achieving net zero by 2050.

For CCS to become an effective climate mitigation tool, arrangements must be made for transporting and storing several gigatonnes of CO_2 annually by 2050. To achieve this, standards and predictability must be established so that CO_2 can flow through a network of operators and across national

borders. Policymakers must find the best possible balance between regulation and market forces. CCS is also vital for producing clean hydrogen from natural gas – so-called blue or low-carbon hydrogen. Permanent CO_2 storage can help realise the hydrogen infrastructure in a cost-effective way, supporting the transition to a renewable energy future.

Successful CCS implementation requires strong industrial engagement in research projects that develop practical and cost-effective solutions. New business models must be created to ensure rapid implementation. Neither governments nor companies can solve the climate crisis alone — contributions from both public and private capital will be necessary.

Although CCS is a relatively mature technology with great potential, implementation and scale-up are progressing too slowly. For instance, Norway has stored around one million tonnes of CO_2 over ten years through the Sleipner and Snøhvit projects, while emissions from the use of exported Norwegian gas amount to approximately 315 million tonnes per year. This illustrates a major imbalance between the measures implemented and what is required to meet climate goals.

Norway's continental shelf holds enormous CO_2 storage potential. Interest in expanding CO_2 storage beyond the hydrocarbon sector is therefore high, but financing mechanisms for these new projects remain uncertain. Further research is needed to optimise the use of storage resources when multiple projects are operating simultaneously, including studies of pressure interactions between storage sites.

Solution

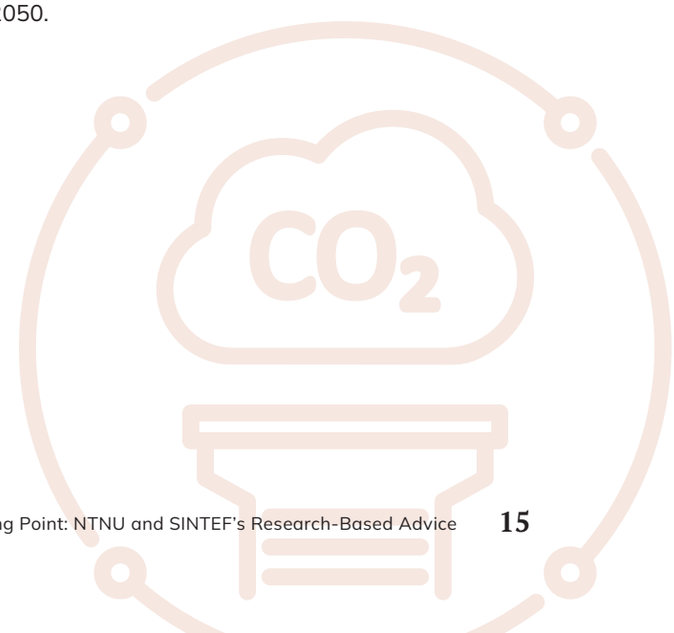
In principle, CCS can remove nearly 100 % of CO_2 emissions from the use of fossil materials — whether from fuels such as coal and oil, or from industrial processes releasing fossil or biogenic CO_2. Although the technology is mature, financial incentives such as higher carbon prices will be crucial to increase capture rates.

Even with strong progress in renewable energy production and energy efficiency, CCS technologies will be required to reduce emissions from hard-to-abate sectors such as heavy industry and fossil-based energy production. CCS also forms the foundation for capturing CO_2 from biogenic processes (BECCS), directly from the air (Direct Air Capture – DAC) or from the ocean. In addition to fossil sources, CCS can be applied to biogenic processes such as biogas and waste-to-energy, potentially making these processes climate-positive.

Norway is a pioneer in CCS technology, with nearly 30 years of experience in safe CO_2 transport and storage at the Sleipner field, and 17 years at the Snøhvit field near Melkøya. CO_2 capture and transport are comparable to other process industries, involving the handling of a gas that is neither explosive nor toxic at normal concentrations. Thorough mapping and monitoring of storage sites during and after operation are essential to ensure safe and permanent storage.

The Northern Lights project, part of the Longship initiative, represents Europe's first large-scale CO_2 storage hub. In Phase 1, the project will transport and store up to 1.5 million tonnes of CO_2 from various industrial facilities onshore. Northern Lights aims to store 5 million tonnes of CO_2 under the seabed each year in the next phase, with potential for further expansion into nearby geological formations[iii]. The project has already entered Phase 2, demonstrating strong interest in additional CO_2 capture capacity. Longship provides a template for how public–private partnerships can close the gap between pilot projects and full-scale implementation. Early public investment enables companies to participate in the CCS transition and lowers total costs in the long run.

CCS is an essential tool for reducing emissions, securing the future of industry in a low-emission economy, and helping the world reach net zero by 2050.



Carbon Dioxide Removal (CDR)

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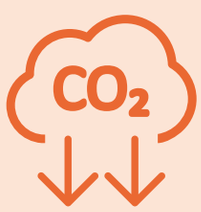
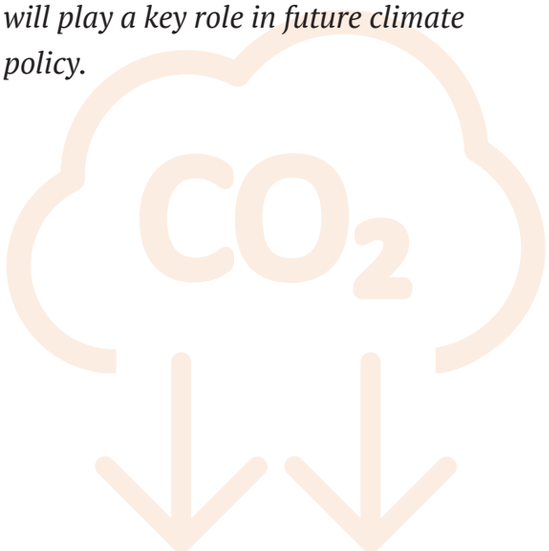


NTNU: Philip Ringrose
SINTEF: Kristin Jordal

Emissions reductions alone will not be sufficient to reach net zero by 2050. We must also remove CO_2 from the atmosphere and store it safely. This can be achieved through both nature-based solutions and technological approaches such as BECCS (bioenergy with carbon capture and storage) and DAC (direct air capture). Both have already been demonstrated in the Nordic region and will play a key role in future climate policy.



Recommendations

- **Raise CDR in climate negotiations.** Define the appropriate balance and role of carbon dioxide removal as a key complement to emissions reduction.
- **Clarify levels and roles.** Define what is meant by "hard-to-abate emissions" and set clear targets for the balance between reductions and removals.
- **Set quantitative targets.** Establish concrete goals for carbon removal (negative emission technologies), covering both nature-based and technological solutions.
- **Establish national targets.** Norway should aim for at least 500 000 tonnes of CO_2 removal annually by 2030 and build equivalent storage capacity on the continental shelf.
- **Standardise methodologies.** Develop international rules for verification, measurement and reporting of CDR.
- **Increase financing.** Require that countries with large historical emissions contribute financially to the development and deployment of CDR solutions.

Current situation

Carbon capture and storage (CCS) reduce emissions from fossil sources but does not remove carbon already released into the atmosphere. To stabilise the climate, we must also extract CO_2 from the atmosphere, oceans and soils and store it permanently — a process known as carbon dioxide removal (CDR) — to prevent it from re-entering the natural carbon cycle[v].

The greenhouse gases already emitted have raised atmospheric CO_2 concentrations above 420 ppm, far exceeding the pre-industrial level of 280 ppm. At 450 ppm, the risk of surpassing 2 °C of warming increases significantly, leading to severe and potentially irreversible climate impacts. The IPCC estimates that around 6 billion tonnes of CO_2 must be removed globally each year to keep warming below 1.5 °C.

Certain sectors are particularly difficult to decarbonise — including agriculture, heavy industry, and long-distance transport such as aviation and shipping. These sectors will likely continue to emit CO_2 even by 2050, despite major technological progress.

At the same time, the development of CDR is lagging behind. There are few international incentives to promote such solutions, and standards for measurement, verification and reporting of removed carbon are lacking. While the United States and Sweden have begun implementing CDR policies, the concept remains weakly embedded in international climate negotiations.

It is important to recognise that the potential for CDR is limited. The availability of biomass for CDR is constrained by biodiversity and land-use considerations, while removing CO_2 directly from air or seawater is extremely energy-intensive. Capturing and storing CO_2 from energy-intensive industrial processes will always be more efficient than removing it from the atmosphere or ocean. Preventing emissions in the first place is less costly and more effective than removing them afterwards — yet CDR will still be essential as a supplement to emission reductions, particularly in combination with existing CCS infrastructure.

Solution

The UN and the IPCC both emphasise that removing large amounts of CO_2 from the atmosphere and oceans is necessary to limit global warming and achieve the goals of the Paris Agreement. To realise this, we need sustainable, cost-effective and measurable solutions supported by research, innovation and international cooperation.

CDR must be integrated into international climate negotiations, with clear guidelines and standardisation for verification, measurement and reporting. The UN should assume a leading role to ensure that the development of CDR is sustainable and equitable.

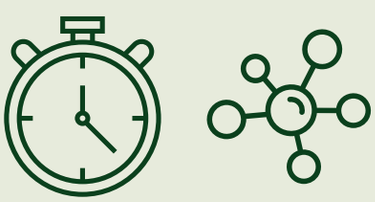
Increased funding is required for research and development of new CDR technologies and solutions to deliver the innovations needed for large-scale carbon removal. Countries with the greatest historical emissions should take responsibility by earmarking funding for the development and implementation of CDR solutions.

Norway should take the initiative to elevate CDR in international climate discussions and clarify its future role. No concrete quantitative targets have yet been established to define the share of fossil CO_2 emissions that must be reduced versus the share that must be removed through CDR. It is also essential to identify the sectors where emission reductions will not be technically or economically feasible[v].

For Norway, the Environment Agency (Miljødirektoratet) has assessed different scenarios and used 1 million tonnes of CO_2 removal per year as an indicative figure for 2030. This is a relatively new field with great need for research and innovation — and action is urgent. Norway is a global leader in CCS development and is well positioned to leverage synergies between CCS and CDR while taking a leadership role in CDR technology development. Strengthening collaboration with other Nordic countries — Sweden, Denmark and Iceland — which are also active in CDR innovation, is strongly recommended.

Short-Lived Climate Forcers (SLCFs)

5



NTNU: Anders Strømman
SINTEF: Øyvind Skreiberg

Short-lived climate forcers (SLCFs) are substances that remain in the atmosphere for a relatively short time — from days to decades — but still have a significant impact on the climate. Some, such as methane and black carbon (soot), contribute to warming, while others, such as sulphate particles, have a cooling effect. Together, these emissions have major implications for climate, air quality and public health. Reducing emissions of short-lived climate forcers is therefore an important part of the green transition.

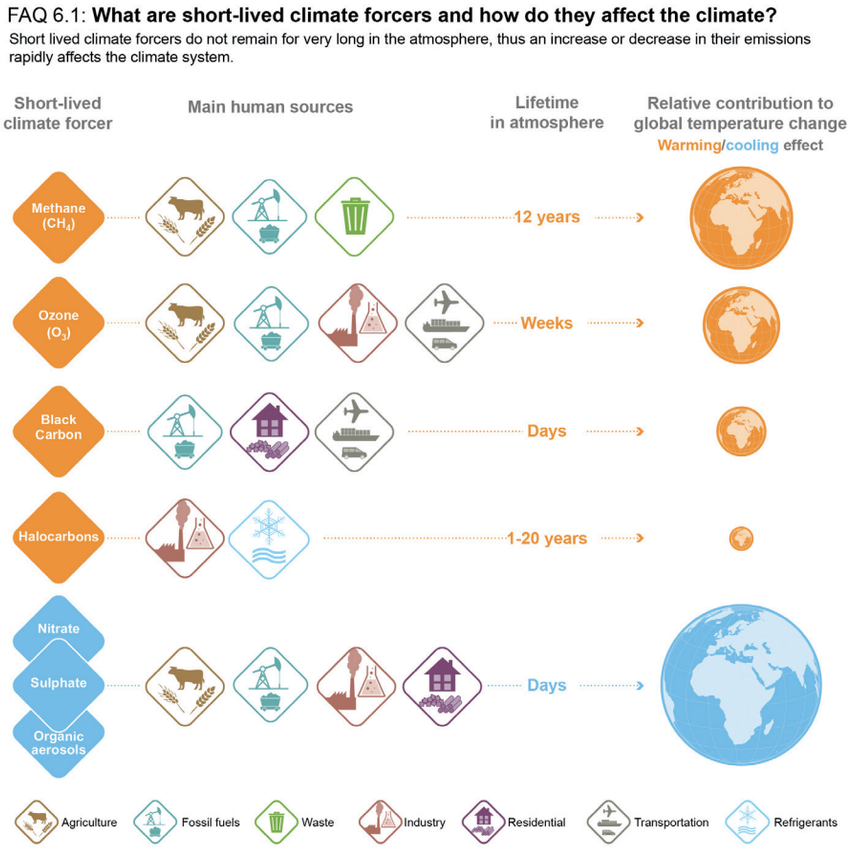
Recommendations

- **Reduce emissions from combustion.** Improve technology, process control and automation in small-scale facilities to lower emissions from both fossil and renewable fuels.
- **Reduce emissions across the fossil fuel value chain.** Minimise emissions from extraction, production and distribution of fossil fuels and materials, as well as from the transport and fuel distribution sectors.
- **Improve waste management and utilisation.** Optimise the handling and use of all waste streams to minimise emissions and maximise material recovery and circularity.
- **Strengthen the knowledge base.** Increase research on the effects of short-lived climate forcers.
- **Improve climate models.** Ensure that models include both warming and cooling drivers, and that the effects are assessed separately for each component.
- **Develop policy and technology.** Establish clear requirements, support innovation, and implement measures to reduce anthropogenic emissions of SLCFs to an acceptable level by 2050.

Current situation

Anthropogenic short-lived climate forcers originate from energy production, the use of fossil and renewable fuels, extraction and distribution of fossil resources, process industries, waste management, agriculture, commercial activity and households, as well as from transport on land, at sea and in the air. Global warming also increases natural sources of SLCFs, for example through more frequent and intense wildfires.

Some particles, such as sulphates and nitrates, cool the atmosphere by reflecting sunlight. Others, like black carbon (soot), cause warming — particularly when deposited on snow and ice, where they reduce surface reflectivity. In addition, gases such as methane (CH_4), nitrogen oxides



A diagram of different types of climate change.

Source: https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-6/

(NO_x), non-methane volatile organic compounds (NMVOCs) and carbon monoxide (CO) contribute to the formation of ground-level ozone (O_3), which is a powerful greenhouse gas. Methane is the most important of the short-lived greenhouse gases, with a longer lifetime than the others, and is therefore discussed in a separate chapter.

The IPCC has placed SLCFs on its agenda and is currently preparing a report[vi] to help countries include these pollutants in their national emissions inventories. Many countries lack reliable data on SLCF emissions, which makes it difficult to model their effects on global warming and air quality. Unlike CO_2, the impact of SLCFs depends strongly on regional conditions and where the emissions occur.

Solution

Reducing emissions from short-lived climate forcers is essential both to improve air quality and to curb the rapid warming observed today. Because these substances remain in the atmosphere only briefly, mitigation measures can deliver fast climate benefits.

A wide range of actions is needed — from energy-efficient combustion and cleaner technology in transport and industry, to improved waste management and reduced use of fossil fuels. Combustion processes must be optimised, leaks in fossil fuel value chains sealed, and the use of polluting fuels in households and small-scale industry phased out.

At the same time, knowledge and monitoring must be strengthened. Better data are needed to understand where emissions originate and how they affect both climate and human health. Climate models must include both warming and cooling drivers to provide more accurate projections.

With a comprehensive focus on technology, knowledge, policy and circular resource use, emissions of short-lived climate forcers can be reduced to levels that are sustainable for both climate and health — delivering rapid and measurable benefits in the fight against global warming.

Reducing Methane Emissions

6

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Methane is the second most important greenhouse gas after CO_2 and accounts for around 0.5 °C of today's global warming. Emissions mainly originate from agriculture, waste management and fossil energy, and methane has a very high short-term warming potential. Rapid methane reduction delivers immediate climate benefits.

Recommendations

- **Make the Global Methane Pledge binding.** Expand the agreement in collaboration with industry (OGCI) to include a zero-emission vision for technical emissions.
- **Strengthen knowledge on low-concentration sources.** Invest in research on technologies that can remove methane from agriculture, rice cultivation and natural environments.
- **Reduce methane emissions from oil and gas.** Introduce stricter requirements for monitoring, reporting and use of Best Available Technology to prevent leaks.
- **Provide economic incentives.** Use taxes and regulation so that investing in equipment becomes cheaper than emitting methane.
- **Develop conversion technologies.** Support solutions that can convert methane from low-concentration sources into CO_2 or methanol.

Current situation

Atmospheric methane is the second most important greenhouse gas influencing global warming after CO_2. According to the IPCC's Sixth Assessment Report, methane emissions from human activities have contributed approximately 0.5 °C to observed global temperature rise. Methane has a global warming potential about 30 times higher than CO_2 over 100 years — and more than 80 times higher over a 20-year period.

Methane accounts for roughly 14 % of greenhouse gas emissions in the EU[vii], 10 % in Norway[viii] and 11 % in the United States (in 100-year CO_2-equivalents[ix]). These emissions are primarily driven by agricultural activities, waste management, and the extraction and use of fossil fuels such as oil, gas and coal.

Methane emissions from oil and gas operations occur at various stages of the value chain and differ between conventional reservoirs and shale or oil sands. They result partly from leaks and

partly from equipment choices, such as pneumatic valves that release methane during operation. The U.S. Environmental Protection Agency (EPA) has investigated multiple sources of methane leaks from technical installations, finding that numerous types of equipment contribute to these emissions[x].

While emissions from the oil and gas industry, agriculture and livestock have received the most attention, rice cultivation is also a significant global source of methane. Rice is a staple food for half the world's population and accounts for about half of methane emissions from cultivated land. Wetlands are another important natural source of methane. It is technically challenging to remove methane from low-concentration sources, as methane concentrations are typically 5–200 times lower than CO_2 levels in air.

Analyses and satellite observations show that methane emissions are underreported[xi], making it difficult to obtain an accurate picture of the problem. A UNEP report on methane[xii] indicates that cutting global methane emissions by 45 % today could reduce warming by 0.28 °C by mid-century — helping to keep the world on track to stay below 2 °C of global temperature rise.

Solution

The United States and the European Union launched the **Global Methane Pledge (GMP)** at COP26, with the goal of reducing global methane emissions by 30 % by 2030 relative to 2020 levels. The pledge has raised awareness but remains voluntary. To have real impact, countries must make these commitments binding and establish national targets and reporting frameworks. The EU's regulation of methane emissions from the energy sector[xiii] is an important step toward better transparency and faster repair of leaks.

The technological potential is significant: according to the IEA, about 35 % of methane emissions from the oil and gas sector could be reduced with existing, cost-effective solutions[xiv]. Norway already has very low leakage levels, partly due to a methane tax and strict health, safety and environmental (HSE) requirements[xv]. One of the main success factors has been that investing in technical equipment is cheaper than paying for emissions.

While reducing methane emissions from the oil and gas industry represents a low-hanging opportunity achievable with current technologies, it will also be necessary to address methane from low-concentration sources to achieve reduction levels with meaningful climate impact. Technologies are under development to convert methane from such sources into CO_2 or methanol, though these are still in early stages of research and deployment.

Reducing SF_6 Emissions

7

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SF_6 (sulphur hexafluoride) is the most potent greenhouse gas known, with a global warming potential 24 300 times higher than CO_2 over a 100-year period. The gas remains in the atmosphere for at least a thousand years. Its use in electrical installations and the defence industry leads to long-term emissions that could multiply with global electrification. Without rapid action, the problem will grow significantly.

Recommendations

- **Introduce global reporting requirements.** Mandate registration of SF_6 procurement, use and emissions in all sectors, including defence.
- **Implement measures to reduce emissions.** Establish standardised requirements for SF_6 handling throughout its entire lifecycle — from production and use to destruction.
- **Use taxation as a policy tool.** Introduce harmonised global taxes on SF_6 to limit its use and promote the development of alternatives.
- **Plan for phase-out.** Set a global timeline for eliminating SF_6 from both new and existing installations.
- **Develop alternatives.** Increase research on new technologies to replace SF_6 in electrical equipment across all voltage levels.
- **Support retro-fill solutions.** Develop methods for replacing SF_6 in existing equipment with alternative gases to accelerate phase-out.

Current situation

SF_6 is the most powerful greenhouse gas known, with a global warming potential (GWP) 24 300 times[xvi] that of CO_2 and an atmospheric lifetime of at least 1 000 years. Although SF_6 once had a wide range of applications, its use today is largely limited to the electric power industry and in specific defence applications.

SF_6 is used in nearly all types of electrical switchgear (circuit breakers, gas-insulated switchgear, cable terminations, etc.) at both distribution and transmission levels (medium and high voltage). Efforts to reduce SF_6 leakage from electrical equipment have been ongoing for many years, yet for most grid operators this remains their single largest source of direct greenhouse gas emissions. Equipment failures or human error during installation and maintenance are among the most common causes of major emissions.

As global electrification advances, the world's power grid is expected to more than double in size by 2050[xvii]. If this expansion relies on current technology, the installed amount of SF_6 could multiply many times — particularly in regions outside Europe, where electrification is accelerating.

The EU has adopted a plan to phase out SF_6 in new electrical installations by 2032[xviii] under the new F-gas Regulation, and California has introduced similar measures. Several alternative technologies are now available, but implementation is slow, especially for the highest voltage levels, where solutions have been developed later and remain more expensive than conventional SF_6-based systems.

The use of SF_6 in the defence industry is poorly documented, with limited transparency about applications and quantities. Since such uses are not reported to public registries, the lack of openness makes it difficult to obtain a full picture of total emissions and hinders comprehensive regulation.

Solution

Europe has taken the lead globally by requiring leak minimisation in electrical installations through mandatory certification of personnel handling SF_6, reporting of gas procurement, emissions and disposal, and by phasing out SF_6 in new equipment. In Norway, SF_6 is subject to a high environmental tax[xix] as an incentive to reduce use and emissions. Similar schemes should be implemented globally. This would provide a comprehensive overview of the total climate impact of SF_6 while helping to reduce its use.

Research on alternative technologies for SF_6-filled electrical equipment must be intensified, alongside efforts to promote standardisation and knowledge sharing between users and manufacturers. Security of supply requirements are, and must remain, strict — any new technology must be as reliable as the existing one.

Research into retro-fill methods — replacing SF_6 with alternative gases in existing installations — is especially important for accelerating phase-out, as it will take many years to replace all SF_6-insulated infrastructure with new technology.

Reporting on SF_6 use in the defence sector, combined with research into suitable alternatives, is also vital to achieve a comprehensive understanding of total SF_6 use and emissions.

Power Supply and the Energy System

8

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The power grid is the backbone of the energy transition. At the same time, many countries — including Norway — face shortages of both generation and grid capacity. Electrification, new renewable generation and growing demand are creating new operational patterns that challenge security of supply. To succeed, we must adopt smart grids, flexible solutions, local generation, and enhanced resilience across the entire energy system.

Recommendations

- **Invest in smart grids and utilise flexibility in production, consumption and storage.** Prioritise research and development on digital and automated solutions, and on using flexibility to increase capacity quickly while reducing environmental impact.
- **Modernise operational criteria.** Transition to more flexible, risk-based grid operation that makes better use of capacity and provides a more balanced trade-off between security of supply and cost.
- **Enable local energy communities.** Provide incentives for consumers, producers and local communities to contribute with local generation and flexibility to support the power grid.
- **Improve incentive structures.** Develop regulations and price signals that reflect real costs and distribute them fairly, supporting more efficient use of the grid.
- **Ensure resilience in power supply.** Strengthen knowledge on how changes in the energy system affect supply security, improve risk understanding, reduce vulnerabilities, and enhance preparedness through cooperation both nationally and across borders.

Current situation

With increasing electrification, both Europe and the world face major challenges in ensuring a resilient, flexible and sustainable electricity supply. The power grid will be the backbone of the future energy system and will require large-scale investment and modernisation to connect vast amounts of renewable and distributed generation, as well as new electricity demand in industry, transport and other sectors, as part of efforts to reduce greenhouse gas emissions.

According to DNV, global grid capacity needs are expected to increase by a factor of 2.5, with annual investment requirements more than doubling by 2050[xx]. The growing share of variable genera-

tion from wind and solar increases the need for flexibility to balance supply and demand. Today's grid infrastructure often lacks sufficient capacity to connect large new loads or to integrate variable renewable power, leading to bottlenecks, higher prices, limited grid access and a greater risk of power outages.

Electrification with new renewable generation and changing consumption patterns also leads to new operational challenges and increased stress on both the power system and its components. Climate change increases the likelihood of natural disasters, while geopolitical tensions pose new threats to energy supply through both physical and digital attacks and vulnerable supply chains.

The global energy system is becoming more complex with renewable sources, digitalisation, and the emergence of new actors such as flexibility providers and local energy communities. Delayed grid development and capacity constraints can slow the transition to a low-emission society and threaten the achievement of climate goals. Overall, new risks, increased complexity, uncertainty and unpredictability heighten the need for stronger resilience in the energy system.

Solution

The solution lies in developing a smarter, more flexible and more robust power grid. Digitalisation and automation enable real-time monitoring and control of grid operations. Using sensors, data-driven decision systems and artificial intelligence, we can optimise operations, prevent failures and increase capacity without large physical expansions.

The current conservative N-1 security principle — used by all European system operators — requires redundancy to handle the failure of a single component. This approach should be complemented by more flexible, risk-based criteria that balance security of supply with socio-economic costs. We must also promote local solutions that harness flexibility resources. Flexible generation, storage and consumption — from individual users or local energy communities — can help balance the system, reduce bottlenecks and free up grid capacity. Such solutions also promote local value creation and reduce pressure on the central grid.

It is equally important to develop sustainable grid components — such as switchgear, cables and transformers — that can withstand renewable generation, battery charging and more extreme weather, while being produced with lower use of critical raw materials.

Global electricity demand is expected to double by 2050, and massive investments in new grid infrastructure are planned worldwide[xxi]. Increasing capacity in existing networks will therefore be essential. By digitalising the grid, adopting new technologies and exploiting flexibility, it is possible to boost capacity in today's networks by at least 20–25 %.

Resilience in the power supply requires a solid understanding of how changes in the energy system affect security of supply. This demands comprehensive risk assessments, actions to reduce vulnerabilities and strengthened preparedness. Coordinated efforts between authorities, industry and research institutions — both nationally and internationally — will be crucial to achieve this.

Energy Efficiency in Industry

9

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Energy efficiency is the key to a successful green transition. Industry accounts for a significant share of global energy use, and every measure that reduces consumption lowers both emissions and costs. To achieve climate goals, the pace must accelerate — and energy efficiency must come first, in line with the commitments made at COP28.

Recommendations

- **Systematic energy mapping.** Establish requirements for industry to identify and prioritise measures that improve energy utilisation and enable savings.
- **Share best practices.** Update and implement proven energy efficiency solutions across sectors.
- **Provide financial incentives.** Support the adoption of new technologies and processes that improve efficiency and reduce emissions in Norway, as well as technology development and transfer to LMIC countries.
- **Ensure fair competition.** Enable low-emission and energy-efficient technologies to compete with fossil alternatives and establish equal conditions for the use of different energy carriers (electricity and heat).
- **Promote innovation and technology development.** Prioritise research and development of new technologies and components for optimal resource use.
- **Develop long-term plans and roadmaps.** Establish strategies for climate-neutral industry through close collaboration between research institutions, businesses, authorities and energy companies.

Current situation

Improving energy efficiency is the first and most important step in any decarbonisation strategy. The cleanest and cheapest energy is the energy that is not produced. Despite significant technological progress, the industrial sector still holds great potential for improved energy utilisation — both within production processes and through the recovery of waste heat. Industrial actors should therefore map their energy use to identify the most effective measures.

Enhanced efficiency in industrial production and new methods for recovering surplus energy are among the most effective ways to improve

resource utilisation and reduce the climate footprint — nationally and globally.

Measures that enable more efficient use of waste heat bring both business and societal benefits. However, many energy-efficient technologies involve high development and investment costs. Therefore, economic incentives are needed to make long-term solutions more profitable than short-term gains.

At COP28, countries agreed that the rate of global improvement in energy efficiency must double, from 2 % to 4 % per year by 2030. The principle of "energy efficiency first" was also reaffirmed as a foundation for policy, planning and investment decisions[xxii].

The main advantage of improving industrial energy efficiency is that it increases value creation throughout the value chain by reducing energy consumption at the company level. Accordingly, the *U.S. Department of Energy's Industrial Decarbonization Roadmap*[xxiii] identifies industrial energy efficiency as the first of five pillars in its strategy for decarbonising the industrial sector. Similarly, the International Energy Agency (IEA) notes in its Net Zero by 2050 report that enhanced energy efficiency is needed to reduce global energy demand by 7 % by 2030[xxiv].

In Norway, the *Green Industrial Transition Roadmap*[xxv] states that the country shall have the world's cleanest and most energy-efficient process industry. The Energi21 Strategy identifies industrial decarbonisation, energy security and the development of new green industries as the three main challenges ahead[xxvi]. Reducing energy demand through higher industrial efficiency directly addresses all three.

Solution

The Norwegian Research Centre for Environmentally Friendly Energy (FME) HighEff has focused on these crucial and challenging aspects in the race toward net zero. In June 2024, SINTEF Energy, together with partners in the European Energy Research Alliance (EERA), published a white paper[xxvii] identifying key technology gaps, barriers, R&D needs and concrete recommendations for EU policymakers.

Norway and Europe must strengthen research, innovation and industrial projects that develop energy-efficient processes, components and systems, as well as promote circular economy solutions — including industrial clusters, heat pump technologies and heat-to-power processes. There is a strong need for technologies that can capture and utilise high-temperature waste heat so that energy can be reused in the same or other processes. This reduces both energy use and greenhouse gas emissions. A key part of this effort is to ensure comprehensive oversight of resource use in industry — including raw materials, energy and water — and to comply with EU requirements for recording such data.

In Norway, the Energy Commission[xxviii] has set a clear ambition: energy efficiency measures should free up energy equivalent to 20 TWh per year from 2030. This corresponds to about 6–7 % of Norway's total primary energy consumption (315 TWh in 2022, including oil and gas)[xxix].

Increased industrial energy efficiency will strengthen both national and international energy security, reduce energy and product costs, and support the development of robust industrial symbioses and material circularity.

Hydrogen

10

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The implementation of hydrogen and its derivatives as energy carriers is essential to achieving global climate goals. As a flexible, zero-emission energy carrier, hydrogen can reduce emissions in sectors where electrification is challenging — such as heavy transport, the maritime sector and process industries. As the share of wind and solar power increases, hydrogen becomes critical for storing surplus energy and ensuring stable energy supply when renewable generation fluctuates.

Recommendations

- **Raise the price of carbon and maintain support mechanisms.** Use carbon pricing and regulation to make pollution more costly, while strengthening support schemes for scaling up zero-emission hydrogen production.
- **Establish global standards and enforce implementation.** Promote a unified international classification of hydrogen based on life cycle analysis (LCA). This will provide a transparent and comparable foundation for trade and investment.
- **Build and scale up markets, infrastructure and demand.** Establish transitional schemes — including public funding — to stimulate scale-up and market demand in the early phases. Remove regulatory barriers and support the development of national and international markets and geographic ecosystems such as *Hydrogen Valleys*.
- **Reduce methane and hydrogen emissions.** Provide incentives to use Best Available Technology for the extraction, transport and utilisation of natural gas and hydrogen to minimise climate impacts.
- **Develop international partnerships.** Strengthen cooperation with countries seeking rapid hydrogen implementation through bilateral trade agreements combined with research and technology exchange on a technology-neutral basis. Support the continuation of the *Clean Hydrogen Partnership* under FP10 and cross-border collaboration projects.
- **Strengthen research and innovation.** Prioritise development of:
  - More cost- and energy-efficient electrolysis and low-carbon production technologies.
  - New solutions for transport, storage and end-use in industry and transport.
  - Safety and sustainability across the entire value chain, including climate and environmental impacts and business models for competitive market implementation.

- Research and innovation that ensure hydrogen use and uptake across small, medium and large scales.

Current situation

Almost all hydrogen produced today comes from fossil sources without CCS, resulting in nearly one billion tonnes of CO_2 emissions per year globally. Hydrogen is currently used mainly in industrial processes such as ammonia, fertiliser and petrochemical production. It is largely consumed where it is produced, as hydrogen is difficult to transport and store. Future use will include new industrial processes such as the production of steel, glass, aluminium and metal alloys, as well as fuel for energy-intensive sectors such as maritime transport, long-distance logistics, and potentially aviation.

Zero-emission hydrogen can be produced by electrolysis, while low-carbon hydrogen can be produced from natural gas combined with carbon capture and storage (CCS). To reach net zero, emissions from existing hydrogen production must be eliminated, while total production must increase substantially — from today's 100 million tonnes to 400–500 million tonnes annually by 2050[xxx].

Countries without access to natural gas resources — such as those in Europe, Japan and South Korea — will rely on electrolysis or imports. Gas-producing countries can convert natural gas into hydrogen with close to 100 % CO_2 capture and storage, which is especially attractive in regions where renewable power is limited. Most countries, including the EU, currently lack sufficient renewable electricity to meet their hydrogen ambitions. The EU's electricity mix is about 39 % renewable on average, while Norway's share is around 97 % (excluding offshore oil and gas activities). When including all energy sectors, Norway's overall energy mix is roughly 50 % renewable.

Progress, however, remains too slow. The cost of both green and blue hydrogen remains high, demand is low, and uncertainty has caused many projects to be delayed or cancelled. Nevertheless, global investment has increased by around 50 % annually since 2020xxxi. Installed and operational electrolysis capacity in Europe reached 177 MW_e in 2025, up from 142 MW_e at the end of 2024[xxxii]. The same source projects total hydrogen demand at 2.3 million tonnes by 2030, including 0.6 million tonnes of blue hydrogen.

Hydrogen can also provide significant benefits through sector integration, where production, storage and end-use are co-located in regional clusters — *Hydrogen Valleys*. These approaches deliver economies of scale, lower costs and improved competitiveness.

Solution

Hydrogen can be a key enabler of lower CO_2 emissions if we establish frameworks that make it competitive with fossil alternatives. Carbon pricing and regulatory measures that raise the cost of emissions will make low- and zero-emission solutions more attractive, while targeted support for production and use will help build market demand.

Strict requirements for emission intensity are needed to ensure that hydrogen development progresses in tandem with renewable energy and does not become a new source of emissions. Early investment in infrastructure and value chains is critical, requiring coordinated action between governments, industry and research institutions, along with clear priorities for profitability and sustainability.

Sustained funding for research and development is vital to make hydrogen solutions more cost- and energy-efficient and to stimulate demand. Close collaboration between industry, government and research communities — combined with regional initiatives and sector-coupled projects — will be essential to build competence and infrastructure.

Countries aiming for rapid hydrogen implementation should enter bilateral agreements to share technology, experience and markets, accelerating global development.

Hydrogen is not the solution alone, but it is a necessary tool in the portfolio required to achieve net zero. With the right policies, technologies and partnerships, hydrogen can become a cornerstone of the global energy transition.

Hydropower and Energy Storage

11

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Hydropower is the most important source of renewable energy globally and will play an increasingly vital role in future energy systems. As wind and solar power continue to expand, the need for flexible and dispatchable energy sources grows. Modernising and upgrading hydropower plants is essential to ensure flexibility, storage capacity and environmental sustainability.

Recommendations

- **Increase flexibility.** Develop solutions that enhance the ability to regulate power generation while safeguarding environmental values.
- **Expand pumped storage.** Upgrade existing facilities to pumped-storage operation to strengthen energy storage and system balancing.
- **Focus on technical improvements.** Invest in research on turbines, control systems and digital operation technologies.
- **Assess and mitigate environmental impacts.** Document ecosystem effects and integrate environmental measures into refurbishment projects.
- **Adapt market frameworks.** Introduce regulations and pricing mechanisms that reward flexibility and storage capacity.

Current situation

The global energy transition now underway requires the provision of reliable, sustainable energy at an affordable cost. To achieve the Paris Agreement targets, we must deploy technologies that already exist — and hydropower is the most mature and efficient renewable energy source available.

Most existing hydropower systems were designed for a stable energy mix with multiple flexible generation sources. In the future, the energy system will be far more weather-dependent, dominated by wind and solar power, and with less inherent storage capacity. This places new demands on hydropower's role as a balancing and storage resource.

Many hydropower plants in Europe and North America are ageing and were built to older standards. Comprehensive upgrading and modernisation are needed to ensure future operation, enhance flexibility and maintain environmental performance. At the same time,

new measures must balance technical optimisation with the protection of nature and local communities.

Solution

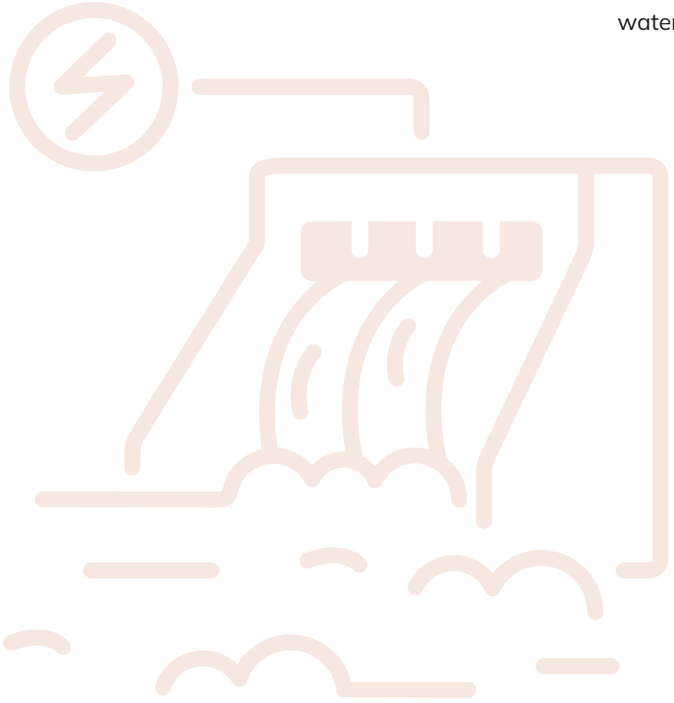
Hydropower is currently the world's largest source of renewable electricity, producing more energy than wind and solar combined — and, according to the IEA, global hydropower generation is expected to double by 2050. However, its most important role in the future will likely be to enable the large-scale integration of variable energy sources such as wind and solar.

As the power system shifts from fossil fuels to intermittent renewables, there will be an increasing need for balancing and energy storage across time scales ranging from seconds to days, weeks and seasons. This requires system-level analyses, updated market designs and optimised operational planning.

No other renewable technology offers the same combination of flexibility, controllability and storage capacity at a comparable cost. Pumped storage — which accounts for over 90 % of all grid-connected energy storage capacity worldwide — is also essential for achieving a renewable energy future. The remaining untapped hydropower potential is primarily located in Asia, Latin America and Africa, though there is still some potential in Europe and North America.

Together, these measures will make hydropower more sustainable and increase public acceptance. Modernisation can deliver significant capacity upgrades, more flexible operation and improved use of storage resources. At the same time, refurbishment should include effective environmental measures such as two-way fish migration systems, ecological flow releases and other initiatives to improve the ecological status of regulated rivers.

Hydropower reservoirs can also provide valuable co-benefits, including flood control, irrigation, water supply, navigation and recreation.



Batteries

12

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Batteries are essential for zero-emission transportation and for balancing power systems with an increasing share of wind and solar energy. The global battery value chain is currently shaped by geopolitical tensions and significant regional differences in production capacity. To ensure security of supply, sustainability and lower climate impact, we must develop new technologies, strengthen recycling and establish stable, transparent value chains.

Recommendations

- **Reduce the carbon footprint.** Establish global requirements for low-emission production and minimal environmental impact throughout the entire battery value chain.
- **Strengthen research and innovation.** Prioritise more sustainable Li-ion solutions, new battery chemistries, next-generation battery technologies and improved recycling.
- **Implement international standards.** Develop certifications for climate and environmental footprint, material origin and recycled content.
- **Promote industrial scale-up.** Simplify permitting and financing schemes to accelerate production start by new companies.
- **Enhance and expand Nordic cooperation.** Strengthen incentives and instruments for joint research and industrial projects across the Nordic region.

Current situation

Batteries are a key technology for the transition to a low-emission society. They enable zero-emission transport and help balance power grids by storing energy when wind and solar production is high. They also contribute to frequency regulation and peak-shaving, which can limit the need for costly grid expansion — particularly in areas with constrained capacity. According to COP29 estimates, global battery capacity must increase sixfold between 2022 and 2030 to support electrification[xxxiii]. Batteries will also play a crucial role in energy storage for microgrids in low- and middle-income countries.

Currently, the market is dominated by lithium-ion (Li-ion) batteries, which are used in electric vehicles and increasingly in stationary energy storage systems. Production is heavily concentrated in Asia — particularly in China, which also controls large parts of the supply chain for raw materials such as lithium, cobalt and graphite. This dependency creates vulnerability amid rising

geopolitical tensions and trade restrictions. Recent developments, such as China's export controls on high-energy batteries and battery manufacturing equipment[xxxiv], and the potential repeal of the *Inflation Reduction Act (IRA)* in the United States[xxxv], further weaken the position of Western producers.

Europe has sought to build a competitive battery industry, but progress has been slow due to high costs, lengthy regulatory processes and strong price competition from Asia. Establishing large-scale battery factories requires substantial capital and rapid facilitation — processes that currently take significantly longer in Europe than in China.

China also dominates export of raw materials for battery cell production. The new *EU Critical Raw Materials Act*[xxxvi] lists many of the key materials that are essential to current battery technologies, especially within Li-ion systems. In addition, circular value chains are not yet well developed and cannot currently support a rapidly growing battery industry. Asian — particularly Chinese — dominance thus poses challenges for security of supply[xxxvii], carbon footprint and sustainability.

The EU Battery Regulation[xxxviii,xxxix] sets stringent requirements for sustainability, recycling and documentation throughout the value chain. This includes digital "battery passports," information on carbon footprint, material origin and the share of recycled content. The requirements will be phased in gradually until 2027 and will affect producers, importers and waste operators across Europe. The goal is to establish a circular, competitive European battery industry that creates value while reducing environmental impact.

Solution

Batteries will be a cornerstone of the future zero-emission energy system — both for transport and for integrating renewable energy. To achieve this, technological development, industrial scale-up and sustainable value chain design must go hand in hand.

Research and development should focus on improving existing lithium-ion technologies and developing next-generation batteries such as sodium-ion, solid-state and recyclable systems. New technologies must be safer, less resource-intensive and based on more accessible raw materials. Batteries will also be a vital component of future hybrid energy systems — for example, in combination with hydropower in hybrid plants, where environmental concerns limit flexibility[xl].

In parallel, local value chains for battery production must be established in Europe and the Nordic region — from raw material extraction to recycling and reuse. This will reduce dependency on imports from unstable markets and strengthen energy and supply security. The Nordic countries have particular advantages in this regard, including access to renewable energy, critical raw materials and high technological competence.

Faster permitting processes, stable policy frameworks and targeted incentives are essential to attract investment. Closer collaboration between research institutions, industry and authorities — both nationally and across the Nordic region — can help build a competitive battery sector aligned with the EU's green industrial strategy.

For Europe and Norway, the competitive edge will not primarily be in price, but in sustainability, safety and verified traceability. Production based on renewable energy and circular solutions can become a distinct brand — and a strategic export advantage[xli].

Offshore Wind

13

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Offshore wind has enormous global potential and can become a cornerstone of the future renewable energy system. The technology enables the generation of large amounts of zero-emission power but requires predictable regulatory frameworks, industrial development, and close cooperation between authorities, research institutions, and industry. Norway and Europe can play a key role — but it demands targeted action now.

Recommendations

- **Strengthen North Sea cooperation.** Expand the *North Seas Energy Cooperation (NSEC)* to enable coordinated development of offshore wind and related offshore grids.
- **Ensure predictability.** Introduce annual licensing rounds for new offshore areas to provide stable and long-term conditions for the industry.
- **Require innovation.** Include obligations for research, development and competence building in licensing and support schemes.
- **Share measurement data.** Require developers to make collected data available for research and technological advancement.
- **Develop the power system.** Expand grid connections both offshore and onshore to enable efficient integration of offshore wind with hydrogen, hydropower and other renewables and storage.
- **Plan infrastructure.** Establish frameworks for long-term investments in essential infrastructure such as ports, cables and service vessels.

Current situation

Offshore wind currently accounts for a small share of global wind power capacity, but its potential is enormous — several times greater than today's total global electricity consumption[xlii]. Offshore wind can be developed near major population and industrial centres and often entails fewer land-use conflicts and less environmental impact than onshore wind.

Rising costs and profitability pressures pose challenges for the offshore wind sector. While the cost of offshore wind fell sharply until just a few years ago, it has since increased — in line with other energy technologies — as a result of the war in Ukraine and subsequent global economic disruption, including higher prices for raw materials, capital, and labour. Several major players have incurred significant losses, but the market is beginning to recover, and several successful auctions have recently been completed.

Floating offshore wind is still in an early development phase and remains more expensive than fixed-bottom technology, but its potential is substantial. Around 80% of the world's offshore wind resources are located in waters too deep for bottom-fixed structures, making advances in floating technology critical — both for Norway and internationally. Gaining more experience with floating wind projects, costs will go down by learning, innovation and scaling.

To realise offshore wind ambitions, the power system must also adapt. New transmission infrastructure is needed — both offshore and onshore — to integrate offshore wind with other renewable energy sources, hydrogen and hydropower. At the same time, careful consideration of nature and coexistence with other marine sectors must underpin development.

Solution

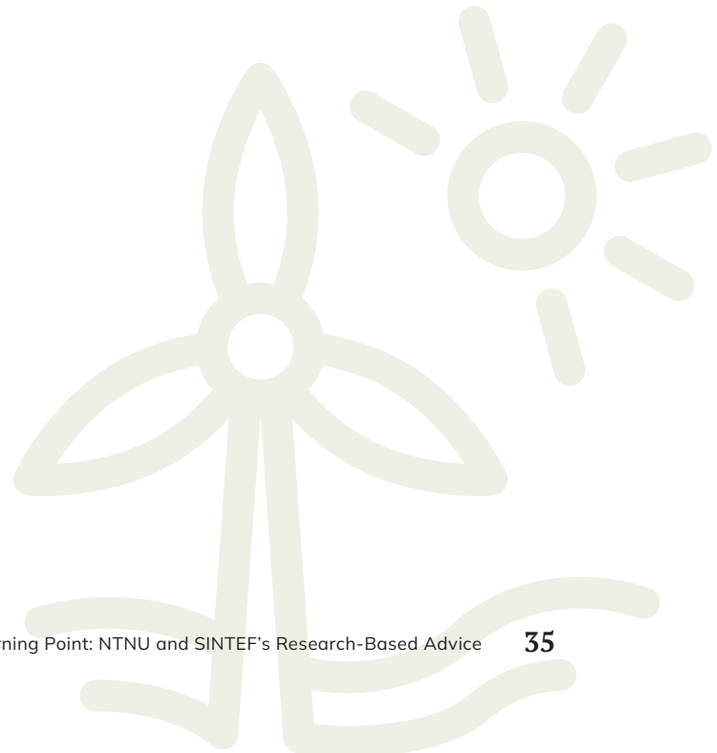
Onshore wind has grown into a large-scale industry, installing over 100 GW of new capacity annually. Achieving a comparable build-out rate for offshore wind is fully possible — but it requires industrial and supply chain development, infrastructure expansion, and competence building. Environmentally responsible design will be a prerequisite for sustainability and a key competitive factor going forward, ensuring that offshore wind deployment respects both ecosystems and communities.

In Europe, the North Sea countries aim to increase installed offshore wind capacity from 30 GW at the end of 2022 to 300 GW by 2050[xliii]. This could reduce emissions by up to 1,000 million tonnes of CO_2 if offshore wind replaces coal, or about 500 million tonnes if it replaces natural gas. Total investments are estimated at around EUR 1 trillion, representing an immense opportunity for Norwegian and international supplier industries.

Long-term predictability is essential. The industry needs stable frameworks and clear signals about future licensing rounds in order to invest in manufacturing capacity. Auctions that focus solely on price per kWh may drive down costs but do not necessarily promote innovation or sustainable solutions. Award criteria should therefore also include requirements for research collaboration, technology development and open data sharing.

A strong, coordinated effort on research, innovation and education is a prerequisite for achieving offshore wind ambitions. Knowledge, new technology, efficient solutions and a skilled workforce are critical success factors. Leading European research institutions, in collaboration with major industrial actors, have highlighted two particularly important research priorities[xliv]: floating offshore wind and large-scale grid integration of offshore wind power.

The vision is for offshore wind to become a backbone of the future energy system — developed with respect for nature and society, delivering prosperity through clean and affordable energy for all.



Solar Energy

14

NTNU: Steve Völler
SINTEF: Gaute Stokkan

Solar energy is growing rapidly worldwide and is now the largest source of investment in new power generation. The technology is scalable, affordable, and flexible — but requires sustainable solutions, efficient land use, and a stronger European value chain.

Recommendations

- **Promote solar on buildings.** Use legislation and incentives to accelerate the rollout of rooftop and building-integrated solar panels.
- **Invest in large-scale solutions.** Develop dual-use solar projects (e.g., combining solar power and agriculture) to reduce land-use conflicts.
- **Ensure circularity.** Design panels for recyclability and build a circular value chain for solar energy.
- **Counter monopolies.** Rebuild a European solar industry to reduce dependency and mitigate global dominance by a few countries.
- **Harmonise regulations.** Establish shared incentives and standards across national borders.
- **Integrate with storage and grids.** Develop energy storage solutions, digital control systems, and forecasting tools.
- **Advance new technology.** Prioritise silicon-based tandem cells to achieve higher efficiencies.

Current situation

Solar photovoltaic (PV) cells convert sunlight directly into electricity without the need for intermediate energy carriers. The technology is extremely versatile — it can be used in everything from small specialised applications to large solar parks, and electricity can be produced close to where it is consumed. This has driven an average annual growth rate of around 26 % in solar PV installations between 2013 and 2023[xlv]. Today, global investments in solar power exceed those in all other generation technologies combined[xlvi], and solar is expected to become the largest contributor to renewable electricity production by 2028[xlvii].

Like all renewable energy, solar requires considerable land area. It is estimated that about 2.2 % of Europe's total land area could be used for solar and wind energy production — with only 0.2 % currently occupied by rooftop solar[xlviii]. Rapid scaling of solar capacity could therefore lead to land-use conflicts. At the same time, solar

technology has significant material demands, and as older panels reach end of life, the volume of waste will increase. This makes circularity and recycling critical for a sustainable value chain.

The efficiency of commercial solar panels has improved from 16 % to over 22 % over the past decade. The most advanced solar cells are now approaching the theoretical efficiency limits of current technologies, and further progress will require new materials and production methods.

From both a political and security standpoint, it is vital to ensure local manufacturing capacity to avoid monopolisation by a few countries or regions. Europe — and particularly Norway — once played a central role in the solar value chain, but Asia (94 %), and especially China (86 %), now dominates the market. Re-establishing a European and Norwegian solar industry will require decisive policy action and technological innovation that also meets environmental and labour standards.

Solar power is inherently variable, with fluctuations across seasons, days, and weather conditions. This variability creates challenges for balancing supply and demand — a factor that could limit deployment unless addressed through advances in grid and storage technologies. Beyond this, challenges within the PV systems themselves increasingly concern digital solutions that enhance predictability through data modelling and artificial intelligence.

Solution

Solar energy from buildings must be fully and rapidly utilised. To succeed, all stakeholders in the value chain need stable and predictable framework conditions that enable long-term investments. There is also a need for more research on solar energy performance under Nordic and Arctic conditions, where low temperatures and unique light environments affect both efficiency and lifetime. For instance, lower temperatures can have a positive impact on system durability, directly improving investment profitability.

However, rooftop solar alone will not be sufficient. Large-scale solar solutions must be developed in parallel. The environmental and ecological impacts of solar farms must be quantified to allow for evidence-based trade-offs. Dual-use land strategies — combining solar installations with agriculture — will be a key part of the solution. By allowing solar panels and food production to share land, highly efficient land use can be achieved without compromising food supply. Floating solar installations can also utilise less conflict-prone areas, though it is crucial to assess and mitigate potential impacts on aquatic ecosystems and develop robust, cost-effective structures.

Silicon will likely remain the dominant material for solar cells in the foreseeable future, but further research into combining silicon with other materials — so-called *tandem solar cells* — is needed to boost efficiency and enable new applications. Solar panels must also be designed for recyclability to allow materials to be reused and to minimise environmental impacts.

In addition to advances in energy storage and grid infrastructure, it is essential to develop digital systems that can forecast variations in solar generation from different types of installations to ensure optimal integration. Harnessing the capabilities of artificial intelligence will be crucial in this regard.

To secure local energy supply and avoid markets dominated by a few large global actors, businesses must be given favourable economic conditions and protection from unfair competition. For Europe, it is critical to develop technologies that adhere to strict health, safety and labour standards. A strengthened European value chain that leverages national and regional strengths will be key to building a sustainable and resilient solar energy sector.

Maritime transport

15

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The maritime sector accounts for significant greenhouse gas emissions globally. To achieve zero emissions, the industry must combine energy efficiency, new fuels, and the development of the necessary infrastructure. International agreements set the direction, but rapid implementation is essential.

Recommendations

- **Increase energy efficiency.** Establish requirements and provide support for energy-saving technologies and optimised ship designs.
- **Support green fuels.** Use contracts for difference to close the cost gap between fossil and low- or zero-carbon alternatives.
- **Develop green corridors.** Establish ports and infrastructure for zero-emission transport.
- **Ensure climate-friendly refrigeration solutions.** Support the development of natural refrigerants for use on ships.

Current situation

The maritime sector is responsible for about 3 percent of global greenhouse gas emissions. Decarbonising shipping is therefore a key step in achieving both national and international climate targets. In July 2023, the International Maritime Organization (IMO) reached agreement on a strategy for reducing greenhouse gas emissions from ships, with targets of 20–30 percent reduction by 2030, 70–80 percent by 2040, and net-zero by 2050, compared to 2008 levels[xlix]. This was followed by the introduction of the IMO Net-Zero Framework in 2025.

The challenge lies in the implementation. Green fuels such as hydrogen, ammonia, methanol, and biofuels are currently expensive, space-demanding, and not yet available in sufficient volumes. At the same time, shipping is a cost-driven industry, and low- and zero-emission solutions still compete poorly economically with fossil alternatives. This means that development must be supported by both policy, economic instruments and technological development. Energy efficiency also plays a crucial role. Measures such as improved logistics planning, optimal route management, modern hull design, and new propulsion systems can substantially reduce fuel consumption.

For temperature-controlled cargo, on-board refrigeration systems are essential. Today, most systems use high-GWP refrigerants — 96 percent of refrigerated containers use R134a[l], which has a global warming potential (GWP) of 1430. There is a risk that operators will switch to low-GWP refrigerants classified as PFAS, which pose undesirable health and environmental effects. Use of natural refrigerants can solve this through development of safe and energy efficient systems.

Solutions

The IMO's greenhouse gas reduction strategy[li] opens the door to implementing a regulatory framework that can drive transformation within the maritime sector IMO regulations are key for international shipping, which dominates global maritime emissions.

Cargo owner demands and regional regulations (e.g. Northern Europe) can accelerate change, as shipowners and operators prefer vessels that can sail in as many parts of the world as possible. This provides regions (for example Northern Europe) with an opportunity to influence global development by introducing regional rules and restrictions. The basis for these actions is better teamwork among all parts of the shipping industry to create a solid foundation for investment. This involves working together between cargo owners and shipping companies, funding projects that reduce emissions in shipping, coordinating between transport operators and ports to reduce waiting times, aligning different transport methods in the supply chain, and working together to ensure fuel is available, such as through green shipping corridors.

Energy efficiency can be improved in several ways and should be backed by research in various areas. This includes better ship design using modern sail technology, improved planning to maximize the load of cargo ships, scheduling arrivals at ports to allow for slower speeds, and using efficient electric engines with batteries (which applies mainly to specialized ships, not the main deep-sea fleet). Cleaning the hull to reduce drag is also important, along with creating new antifouling coatings or using air lubrication systems to decrease resistance.

The maritime sector is highly diverse, and there is therefore a need for multiple emission-free concepts that can be adapted to different vessel types. Numerous technologies and systems already exist for various green fuels, but further development and scaling are required to lower costs and accelerate the transition. Increased investment in renewable power generation is also critical to produce sufficient volumes of low-carbon fuels.

On-board carbon capture and storage (CCS) can be an alternative to low- or zero-emission fuels. When combined with carbon-based zero-emission fuels such as biofuels, this can even deliver net-negative emissions. On-board CCS technology already exists, but effective CO_2 reception and handling chains must be established to make it a viable solution.

To cut emissions from refrigerated maritime transport, we must focus on safe, energy-efficient refrigeration using natural refrigerants. This involves developing new systems tailored for maritime conditions that meet climate and safety standards. Global shipping operations face temperature ranges from –30 °C to +50 °C, making this challenging. Public support for pilot projects and technology standardization is vital for progress. It is also important to require refrigerants with low Global Warming Potential (GWP) and no PFAS emissions to avoid health and environmental issues. Adopting natural refrigerants is the best approach. By combining innovation with clear regulations, refrigerated transport can significantly contribute to the maritime sector's green transition.

Climate-Neutral, Energy-Efficient Buildings, Districts and Smart Cities

16

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Buildings, cities, and urban areas account for a large share of global energy use and greenhouse gas emissions. To meet climate targets, we must reduce energy demand, deploy renewable energy, and develop smarter, more flexible solutions that integrate buildings, transport, and energy systems.

Recommendations

- **Reduce energy and electricity demand** through efficiency measures, especially in existing buildings.
- **Deploy building-integrated solar systems** (for both electricity and heat) and district heating.
- **Develop integrated urban strategies** that combine energy, transport, buildings, and land use in line with the EU Renewable Energy Directive[lii] and the Electricity Market Directive.[liii]
- **Introduce clear price signals.** Design tariffs that are understandable for end users and drive desired societal outcomes.
- **Enable flexibility.** Support coordinated solutions at neighbourhood and city level to enhance resource efficiency.
- **Strengthen collaboration.** Increase cooperation between business, academia, and the public sector to leverage digitalisation and sustainable urban development.
- **Engage citizens.** Ensure that technology is used inclusively, promoting participation and improving quality of life.

Current situation

Today's cities account for a large share of global greenhouse gas emissions due to high energy consumption and inefficient resource management. Climate-neutral and smart cities aim to balance their greenhouse gas emissions through measures that reduce, capture, or offset them — achieving net zero. Both the EU and Norway target a 55 % reduction in greenhouse gas emissions by 2030 and climate neutrality by 2050.[liv]

Residential and commercial buildings account for about half of Norway's annual electricity consumption.[lv] Aligning energy use in buildings and urban areas more closely with renewable energy generation will help reduce emissions.[lvi] Achieving a net-zero Europe by 2050 requires a significant increase in renewable energy — much

of which will be variable and weather-dependent (solar and wind). To maintain power system balance, electricity consumption must become far more flexible. Smart technologies need to be better utilised to collect and analyse data in real time, enabling improved energy management.

Despite extensive research and experience from programmes such as FME ZEB (Zero Emission Buildings) and FME ZEN (Zero Emission Neighbourhoods), implementation remains slow. The market is fragmented, and suppliers often lack the competence to deliver integrated solutions. As a result, costs are inflated due to perceived risk. Investing in climate-neutral or zero-emission solutions requires upfront capital, and current regulations and business models are still designed for traditional practices rather than innovation.[lvii] There is also a lack of new business models and services that reflect the opportunities of future zero-emission districts.

Solutions

The transition to climate-neutral and energy-efficient cities requires comprehensive cooperation between research, industry, government, and citizens. Research shows that it is possible to halve energy consumption in the building stock by 2050,[lviii] freeing up around 40 TWh of electricity — enough to meet growing demand in the transport and industrial sectors. Moreover, research indicates that material-related climate footprints can be reduced by at least 50 % compared to today's solutions.[lix]

To realise these reductions, action must be taken quickly and collaboratively. Knowledge development, capacity building, and significant measures from both public and private actors are needed — and must be implemented well before 2030 to have measurable effects by 2050.

Although climate-neutral and zero-emission solutions require initial capital investment, they are profitable over their lifecycle.[lx] As technologies mature and become standard, costs will fall further. Reduced energy use and local energy production also generate both savings and potential income streams.

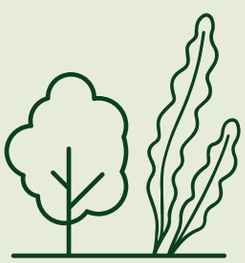
Energy flexibility must be better utilised through smart control and optimisation. Flexibility exists at both the building and district level and can involve thermal energy systems (district or local heating) as well as the power grid. Coordinated use of such resources improves energy efficiency and system resilience.

Demonstration projects can showcase innovative solutions, drive learning, and reduce costs through market experience.[lxi] Climate-neutral and smart solutions in buildings, neighbourhoods, and cities will also create new jobs and business opportunities.

Finally, achieving rapid, fair, and cost-effective global emission reductions requires binding international cooperation — including shared standards and common goals for climate-neutral buildings and cities.

Bioenergy

17



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SINTEF: Kathrin Weber, Øyvind, Skreiberg, Michaël Becidan, Judit Sandquist, Morten Seljeskog

Bioenergy can be used for heating, power generation, biofuels, and biocarbon. Because biomass is part of the natural carbon cycle, it can be climate neutral if managed sustainably. To unlock its full potential, we must develop efficient and environmentally sound solutions that optimise biomass utilisation — including as a foundation for carbon capture and storage (BioCCS).

Recommendations

- **Establish a national strategy** for modern bioenergy that recognises its role in energy transition, carbon dioxide removal (CDR), and energy security.
- **Promote local utilisation** of waste and by-products rather than export, through incentives, regulation, and improved logistics.
- **Expand district heating** and other bioenergy solutions to relieve pressure on the electricity grid and reduce vulnerability in heat supply.
- **Support the development and use of biochar** as a critical input for green metal industries and as an effective CDR technology.
- **Increase research investment** in bioenergy, including digitalisation and the use of artificial intelligence for value-chain optimisation.
- **Develop industrial production** of sustainable biofuels (including SAF and renewable low-carbon marine fuels) and bio-based chemicals as a basis for new value creation and strengthened national preparedness.

Current situation

Bioenergy is a key but underutilised element of the renewable energy transition. It can replace fossil raw materials in the chemical industry, supply carbon for metal production, and help cut emissions in sectors where electrification is difficult — such as aviation and long-distance shipping.

In Norway, substantial quantities of waste and residues that could be used for domestic heat production are currently exported. At the same time, the energy system is highly electricity-dependent, with a large share of consumption used for space heating. This creates additional strain on the power grid, increases vulnerability to price fluctuations, and weakens energy security.

Bioenergy can ease pressure on the power system, diversify the energy mix, and strengthen national energy resilience. It also plays a pivotal role in

the development of carbon dioxide removal (CDR) technologies, which are becoming increasingly important for limiting global warming.

Solutions

Biomass represents a flexible, storable resource that can provide energy, carbon, and raw materials for a green industrial transition. Norway and Europe have significant untapped resources that can be sustainably managed to enhance energy transition, create value, and strengthen energy security. Instead of exporting waste and side streams, these should be used locally for the production of heat, fuels, and materials. Expanding district heating and other bioenergy systems can substantially relieve the electricity grid, particularly since space heating represents a large portion of household energy use.

Technologies such as pyrolysis, gasification, and hydrothermal processing can convert biomass into heat, gas, or liquid fuels while producing secondary raw materials that replace fossil inputs. This opens up new value chains in the chemical industry, textiles, construction, metallurgy, and transport.

Marine biomass also has potential as a feed-stock for such processes. Bioenergy is central to the development of carbon dioxide removal (CDR) technologies. The combination of bioenergy with carbon capture and storage (BECCS) has the potential to deliver large-scale negative emissions, as it relies on renewable biomass while permanently removing CO_2 from the atmosphere.

In the short term, biochar is the most accessible CDR technology. It can be produced from various feedstocks using existing technology, improves soil quality, promotes circular resource use, and can deliver significant negative emissions. In the longer term, BECCS will complement biochar as a large-scale solution, particularly in sectors with high point-source emissions and access to biogenic resources.

Biochar also plays a crucial role in the green metal industry, where carbon is needed in reduction processes for producing silicon, manganese, titanium, and chromium. Establishing sustainable biochar production chains will enhance supply security, reduce emissions, and help preserve industrial jobs in Europe.

Biogenic CO_2 can also be utilised in carbon capture and utilisation (CCU), for example in the production of synthetic fuels such as e-SAF. Biofuels represent a particularly important area: so-called *drop-in fuels* can be used in existing infrastructure and provide high energy density. This is vital for transport sectors like aviation, where alternatives such as batteries and hydrogen will only be viable for the short- and medium-haul segments in the foreseeable future. Substantial financial support is required to establish industrial-scale production of Sustainable Aviation Fuels (SAF) in line with ReFuelEU targets.

For maritime transport, bioenergy can also play a decisive role in reducing emissions, as drop-in biofuels can directly replace conventional fossil fuels — enabling emission reductions in the existing fleet. Local production of biofuels will also be important for energy preparedness and national security.

Bioenergy provides not only heat and electricity, but also carbon and hydrocarbons — the essential building blocks for green industrial transformation. Developing bio-based value chains can reduce dependence on fossil resources, strengthen the circular economy, and create new industrial opportunities.

Circular Bioeconomy

18

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A circular bioeconomy is about utilising biological resources more efficiently and creating value with a lower climate footprint. Norway has abundant bioresources, strong technological expertise, and world-class research and innovation environments. To realise this potential, coordinated action between policy, industry, technology, and research is required to enable more efficient and profitable resource management.

Recommendations

- **Strengthen cross-sector collaboration.** Foster cooperation between aquaculture, agriculture, industry, and energy sectors to improve utilisation of by-products and residual streams.
- **Develop digital and physical infrastructure.** Build platforms, transport solutions, and standards that facilitate sharing and circular resource flows.
- **Modernise regulation and incentives.** Adapt laws and policy instruments to enable safe and profitable use, transport, and trade of biological by-products, and to support the establishment and scaling of industrial symbioses.
- **Promote innovation and competence development.** Increase efforts in biotechnology, material recycling, circular logistics, value chain development, and business models that make circularity economically viable.
- **Connect land- and sea-based value chains.** Facilitate efficient, low-emission value chains that strengthen food security and value creation.
- **Establish test arenas for circularity.** Pilot integrated solutions where technology, markets, and regulation are developed together.

Current situation

Norway possesses large quantities of biological resources from aquaculture, fisheries, agriculture, and forestry, but utilisation remains fragmented. Many by-products are used for low-value applications or not used at all. Industrial symbiosis is still in its early stages — while good examples exist, upscaling and collaboration between companies is hindered by a lack of overview of resource flows and legal barriers.

Value chains are poorly connected, and markets, logistics, and technology must all evolve to support circularity. Investment is discouraged by profitability challenges, unclear responsibilities, and uncertainty about quality and stability of resource flows.

Circular bioeconomy has gained increased political attention, but comprehensive strategies and policy instruments are still lacking — ones that connect resource potential with industrial development and food security. Norway has strong competence in biotechnology, process industry, digitalisation, and logistics, but this potential is not fully realised. More knowledge is needed about how markets, regulation, and technology can work together to create value from renewable resources.

Today, Norway's economy is estimated to be only about 2 % circular[lxii], highlighting both a major improvement potential and the need for clear priorities and trade-offs. Questions of profitability, responsibility, transport distances, and actual demand for reused materials must be addressed holistically — at local, national, and global levels.

Solutions

The transition to a circular bioeconomy requires a systemic shift in which technology, regulation, markets, and collaboration evolve in parallel. Digital tools for resource mapping and sharing can be key enablers for industrial symbiosis, but they must be supported by well-functioning markets and predictable framework conditions.

Such a systemic transition demands coordination across sectors and governance levels. Public authorities must develop a more coherent policy framework for the circular bioeconomy, aligning industrial, climate, agricultural, and fisheries policies toward common goals. National targets and indicators for circularity should be established to measure resource efficiency and value creation.

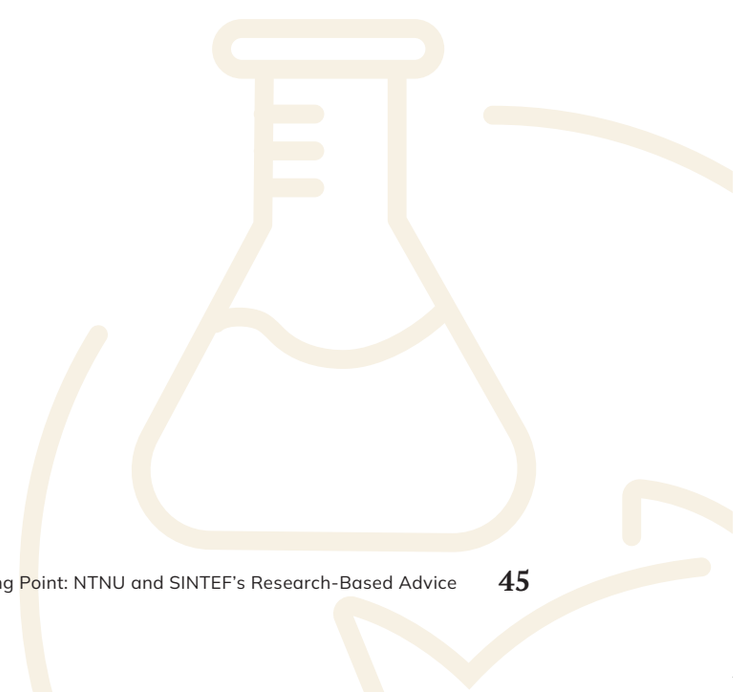
Market development is as important as technology. To ensure profitability, functioning markets for secondary raw materials and biological by-products must be created. Public procurement can play a decisive role by demanding circular solutions and stimulating new value creation.

A circular bioeconomy requires resource management across sectors — from production and processing to transport, consumption, and recycling. This integrated approach makes it possible to connect value chains, reduce waste, and create new value based on biological materials.

Technologies for bioprocessing, material upgrading, sensors, and digital traceability can enhance efficiency. Equally important are social and economic incentives, competence building, and collaborative arenas that make these solutions scalable.

Integrated testbeds and demonstration projects can connect technology, markets, regulation, and logistics in practice. By developing such ecosystems, Norway and other Nordic and European countries can share experiences internationally and contribute to global solutions for sustainable resource use.

A more circular bioeconomy will not only reduce waste and emissions — it will also strengthen food security, value creation, and the green transition, demonstrating how economic growth can be combined with lasting emission reductions.



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