FULL REPORT

CAN SPACE HELP SAVE THE PLANET?

THE FIRST EVER GLOBAL STUDY OF SATELLITE-ENABLED DECARBONISATION.

inmarsat

CONTENTS

FOREWORD

WHEN YOU CONSIDER CLIMATE CHANGE AND THE GREAT TASK FACING HUMANITY, IT IS HARD NOT TO FEEL OVERWHELMED. HOWEVER, UPON READING THIS REPORT, I HOPE YOU WILL LOOK TO THE FUTURE WITH AN EXTRA MEASURE OF OPTIMISM. I CERTAINLY DO.

RAJEEV SURI
CEO, INMARSAT

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Earlier this year Inmarsat began an ambitious research programme to understand the impact of space on the world around us. The *'What on Earth is the value of space?'* initiative began with the largest ever study of global attitudes towards space – covering 20,000 people across 11 countries. The findings were instructive in numerous ways. Perhaps the most illuminating discovery was that the key hope for 41% of the public is for space to help mitigate climate change.

This hope is certainly well founded. Satellite technology already helps to reduce CO_2 emissions in an increasing number of sectors. From boosting operational efficiency and reducing fuel use in merchant shipping, to optimising flight paths in congested airspace - to name but two - it seems the number of applications grows every week.

But what exactly is the impact of satellite communications on CO_2 emissions around the world today? And what is the potential for further positive impact in the future?

The more I considered it, the more I became convinced that our industry should provide answers. Conclusive answers, substantiated by independent research.

That is how the report you are about to read – Phase Two of our research initiative – came about. For the first time ever, we have been able to quantify the effect of satellite communications on global CO_2 emissions.

The results are illuminating and give pause for thought. While I was aware of our current role in decarbonising technologies, it is quite something to read the potential impact of these same technologies if they were universally adopted. Not to mention the future impact of nascent space-based technologies once they come online.

Of course, satellite technology cannot solve climate change alone, but this report clearly demonstrates that it should form a key pillar of any Net Zero strategy. I believe this should be required reading for anyone involved in shaping global sustainability policies.

Yet, when I assessed the outcomes of COP27, two things immediately stood out for me.

The first and most obvious is the frustration many felt as COP failed to deliver and drive the ambition for the climate action we urgently need. Indeed, there was a realisation that there is still much to be done to avoid breaching the environmental tipping point of 1.5°C.

Secondly, I was disheartened at the missed opportunities. Whilst satellites were viewed as a valuable tool for monitoring, as evidenced by the launch of the Methane Alert and Response System (MARS), satellite technologies' vital role on the journey to Net Zero was barely mentioned on 'Decarbonisation Day'. Yet we know from this new piece of research that satellite communications are already reducing CO_2 emissions, today, by billions of tonnes.

But was this to be expected? Our Phase One report into the value of space revealed that few people knew what space is doing for us. In fact, only 8% knew about communication satellites. And I can see that lack of awareness mirrored at COP27.

Therefore, I would encourage us, as a sector, to collectively act to start making the world's institutions more aware of the role we can play for them. Because what our Phase Two research has also shown us is that satellite technologies can help us reach Net Zero 2050 targets. *Ahead of schedule.*

That is an incredible opportunity and a story we must share. The potential that satellite technology offers is a real and solid foundation on which to base the hope revealed in our initial *'What on Earth is the value of space?'* research.

When you consider climate change and the great task facing humanity, it is hard not to feel overwhelmed. However, upon reading this report, I hope you will look to the future with an extra measure of optimism. I certainly do.

SPACE: EARTH'S GREATEST OVERLOOKED DECARBONISATION OPPORTUNITY

The space sector offers the global economy a vast decarbonising opportunity. It can help to reduce the carbon intensity of many industries through satellite communications, satellite navigation, the Internet of Things (IoT) and other applications. And yet, space technology is so often ignored by policymakers.

It is an immediate opportunity too. Satellite communications-enabled innovations like active engine management, route optimisation, fuel flow measurement or trajectory-based operations allow industries to reduce or avoid CO_2 emissions in the here and now. This means we can accelerate decarbonisation today, while alternative long-term solutions, such as new energy sources and new ways of storing energy, are being developed and rolled out to decarbonise the wider world.

The space sector has a fundamental part to play in this. It is already developing space-enabled technologies to help decarbonise the global economy – and will take on more responsibilities in the coming years. However, as Inmarsat has previously called for, this must be accompanied by a stricter regulatory framework to protect the space environment from exploitation and damage, at a time when the space industry is expanding faster than ever before.

In this second phase of its *'What on Earth is the value of space?'* research initiative, Inmarsat commissioned the world leading sustainable tech consultancy firm, Globant, to conduct a further landmark study.

For the first time ever, Globant has looked to estimate how much space technology is helping to decarbonise the world today, how much more could be achieved using existing technologies if they were more widely adopted, and the future role for space in the global journey to Net Zero.

The context: A global mission to hit vital targets

The UN's Intergovernmental Panel on Climate Change (IPCC) has laid out targets to limit global warming to a rise of 1.5°C (2.7°F). That means achieving Net Zero carbon dioxide emissions globally by 2050 via the avoidance, reduction or offsetting of greenhouse gas emissions (GHG).

On 4 April 2022, the IPCC stated that limiting warming to around 1.5°C "requires global greenhouse gas emissions to peak before 2025 at the latest and be reduced by 43% by 2030. At the same time, methane would also need to be reduced by about a third. Even if we do this, it is almost inevitable that we will temporarily exceed this temperature threshold but could return below it by the end of the century."

Consequently, the environmental, economic and political impact of going beyond 1.5°C could be catastrophic. "We are at a crossroads," explains IPCC Chair Hoesung Lee. "The decisions we make now can secure a liveable future. We have the tools and know-how to limit warming." [1]

Despite such stark warnings, COP27 made it clear how fragile these ambitions are, with the 1.5°C target being questioned by some delegates, who argued that it is now unrealistic within the current political and economic context.

THE CHALLENGE: INSPIRING THE PRIVATE SECTOR TO TAKE THE INITIATIVE

COP27 also underlined a lack of understanding within senior ranks of governments as to what satellite-enabled technology can achieve in the fight against global warming. It appears that they've only grasped half the story.

On the one side, space technology is rightly seen as a highly effective, passive means of monitoring carbon emitting activities and events. However, on the flipside, there is clearly little understanding of the scope of the technology's proactive decarbonising potential.

The way to change this limited perception is by increasing awareness. By not only investing resources to educate governments, regulators and others, but also by attracting those with the talent we need to build the space technologies of the future.

We simply can't wait for governments to agree an effective plan of action and recognise the right technologies to implement. Together we need to take the initiative and launch a coordinated agenda with the shortest possible countdown. The space industry must step up now to show – and deliver – what space can really do for our planet.

This concerted effort needs to provide educational material and content to the private sector to convince them of the commercial benefits associated with decarbonising technology – as well as its enormous environmental benefits.

That latter message will resonate with customers. Although we know that very few services are bought for one reason alone, we do know that the lowering of CO_2 emissions is something that is wanted by many. So, as a sector, we must make sure that customers know it's available to them.

REVEALING THE REAL IMPACT OF SATELLITE COMMUNICATIONS

The Globant analysis reveals that currently, satellite communications-enabled technology removes a staggering 1,500,000,000 tonnes (1.5 gigatonnes) of carbon dioxide equivalent per annum from the three sectors included in the study (Agriculture, Forestry, Land use; Transport and Logistics; and Energy systems), which, together, account for 60% of all global carbon emissions.

That is almost the equivalent to the carbon emitted by all activities in the UK, France and Germany each year combined.

Furthermore, there is potentially an extra 4,000,000,000 tonnes (4 gigatonnes) of carbon emissions that could be avoided if the same decarbonising satellite technologies were universally adopted in these sectors. That's more than the estimated worldwide CO_2 emissions of all the cars on the road for a whole year.

In total, this would amount to 5,500,000,000 tonnes (5.5 gigatonnes) of carbon emissions that could be avoided in the three sectors examined in this study using existing technology - that's more than the USA's national CO_2 emissions in 2021.

An analysis into nascent technologies – such as enhanced air traffic management or autonomous shipping – shows even more astonishing results. These technologies could see satellite-enabled decarbonisation reach a total of 8,800,000,000 (8.8 gigatonnes) for the three sectors included in the study. That's like avoiding the CO_2 emissions required to provide energy to North, Central, and South America for over a year.

Calculating the benefits: our methodology

How did we come to those figures? The objective of this report was to model and quantify the amount of CO_2 equivalent (CO_2e) emissions – expressed in tonnes or gigatonnes (Gt) – that can be curbed or avoided thanks to satellite communications technology.

With that in mind, we put three sectors under scrutiny:

- Agriculture, Forestry, Land Use (AFOLU)
- Energy systems
- Transport and Logistics

Together, they are responsible for the majority (60%) of annual GHG global emissions. This is why it is essential to see how current and nascent satellite communications technologies can help them to decarbonise.

By 'nascent' we mean those new technologies that have very low adoption levels or are not yet commercially available but will soon impact the decarbonisation of our selected sectors.

We also talk in terms of 'technology efficiency' (the aggregate CO_2e reduction effect of two or more technologies) and 'technology adoption' (the percentage take-up by sector end users) which our analysts shorten to 'T_{eff}' and 'T_{adop}' respectively in their calculations.

The analysis gives an overview of each sector, and then divides them into their sub-sectors. These, in turn, are examined according to their most relevant and contributing areas and main use cases for satellite communications technologies.

Finally, each sub-sector has been placed in three different scenarios:

01 CALCULATIONS ARE BASED ON CURRENT SATELLITE COMMUNICATIONS TECHNOLOGY EFFICIENCIES AND CURRENT MARKET ADOPTION.

02 CALCULATIONS ARE BASED ON CURRENT SATELLITE COMMUNICATIONS TECHNOLOGIES, ASSUMING FULL MARKET ADOPTION.

03 CALCULATIONS ARE BASED ON THE DEVELOPMENT OF NASCENT SATELLITE COMMUNICATIONS TECHNOLOGIES, ASSUMING FULL MARKET ADOPTION.

SECTOR ANALYSIS: TRANSPORT AND LOGISTICS

In brief

The movement of people and supplies is central to everyday life. Across the world, satellite communications are decarbonising these activities to the tune of 700,000,000 tonnes (0.7 gigatonnes), according to the Globant study.

Our research has found that progress is already being made in sub-sectors like Aviation and Maritime, where satellite communications are aiding decarbonisation through a mix of technologies like vessel voyage optimisation, weather routing and air traffic control management. If the same, and other technologies were applied universally across the sector, there could be more than double the current level of decarbonisation.

Our research suggests up to 1,800,000,000 tonnes (1.8 gigatonnes) of carbon emissions could be avoided across the Transport and Logistics sector. Based on data from 2021, **that's equivalent to removing or avoiding all household CO_2** emissions in the UK **– for 25 years** .

Current impact on global emissions

Carbon impact – expressed as a percentage of total global emissions – for Transport and Logistics sub-sectors are as follows.

Sub-sector	**Main use cases**	**% of total global emissions**
Aviation	Fuel consumption / flight length	2%
Maritime	Fuel consumption / voyage time	2%
Road and rail	Travelling time	12%

ADOPTED GLOBALLY, SATELLITE TECHNOLOGY COULD REMOVE UP TO

1.8

GIGATONNES OF CO_2

EQUIVALENT TO REMOVING ALL HOUSEHOLD CO_2 EMISSIONS IN THE UK FOR

25

YEARS

SUB-SECTOR CHALLENGES AND TARGETS

AVIATION

The challenge

Current global commercial Aviation emissions are estimated at 0.92 gigatonnes CO_2[1]. Sector emissions are expected to continue to increase, reaching 1.5 gigatonnes in 2040[5] and 1.8 gigatonnes in 2050[8].

The solution

CO_2 emissions are directly related to fuel consumption. Satellite communications technologies in Aviation are enablers of operational efficiencies that optimise fuel use and reduce CO_2 emissions.

Key decarbonising technologies

Operational efficiency is achieved by improving the interactions between airlines, airport operators and air traffic management (ATM). These range from planning and scheduling flight paths right up to daily flight operation.

Satellite communications broadband connectivity makes this possible via:

- Performance-based navigation
- Free route airspace
- Flexible use of airspace
- Continuous climb operations (CCO); and
- Continuous descent operations (CDO)

AVIATION CO_2 EFFICIENCY CONTRIBUTIONS[12]

Estimate benefit pool

UPTO
80%
SUSTAINABLE AVIATION FUEL

6–10%
AIR TRAFFIC MANAGEMENT AIRCRAFT OPERATORS

15–20%
MANUFACTURERS AIRCRAFT OPERATORS

Addressing the issues

CCO and CDO are aircraft operating techniques enabled by airspace management and instrument flight procedure design, all facilitated by Air Traffic Control (ATC)[13].

Departure and climb fuel burn is highest in the initial take off and climb phase, representing up to 25% of the total fuel consumed during short-haul flights. This part of the flight requires a brief period of high engine thrust without significant opportunities for efficiency.

With increasing air traffic congestion, ATC needs to assign aircraft to specific routes and flight levels to maintain separation, resulting in aircraft climbing in a stepped manner separated by periods of level flight. This is neither fuel-efficient nor emissions-friendly.

Also, the efficiency of a flight is dependent on the fuel efficiency of the plane and other criteria, including load factor and flight length. For example, approximately 75% of excess fuel use is due to inefficiencies caused by cruise altitude, speed and weather, while 25% is due to en-route flight extension.

Optimising flights

The selection of an ideal flight path supported by satellite communications connectivity can deliver fuel efficiency and reduce CO_2 emissions.

This encompasses a range of measures, including route planning, separation minima (the minimum safe distance between aircraft) and trajectory-based operations.

Satellite communications-enabled 4D trajectory management and enhanced digital capabilities can reduce and maintain separation minima – lowering fuel use and emissions while improving safety.

What's more, Internet Protocol (IP)-enabled aircraft connectivity offers the potential to deliver gains through flight management functions that can optimise routing and increase fuel efficiency.

Looking forward to achievable efficiencies

ATM gate-to-gate achievable efficiencies include[12]:

- Taxi-in: 0.3%
- Vertical flight during climb and descent: 0.5%
- Horizontal flight during arrival: 1.5%
- Vertical flight during cruise: 1%
- Horizontal flight during en-route: 2.5%
- Taxi-out: 0.5%

The selected value for combined technology efficiency = 6%[18]

- **Airline Operations Control Services:** flight-optimising software, with live weather and dynamic routing, combined with enhanced connectivity, could result in a 1% fuel reduction per flight.
- **Nascent technologies:** satellite communications for air traffic management (such as Iris) which precisely tracks flights and efficiently manages traffic via Trajectory-Based Operations (TBO), empowering pilots and controllers to calculate the shortest available routes, cruise at optimum altitudes and use continuous climb and descent paths. Reported efficiency is between 5% - 10%[3].
- **Formation flying:** a reduced separation flying scheme that's achievable when satellite communications' connectivity is optimal. Reported average fuel reduction is 6%[3]. According to the DLR (German Aerospace Centre), 'If applied globally, formation flights have the potential to reduce fuel consumption on long-haul flights by up to 5% and reduce the climate impact by up to 25%.' [3i]

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

Scenario 3:

Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

Technology adoption is assumed to be 100% for interoceanic flights.

For domestic flights in complex areas this value is assumed to be the same.

These flights represent 60% of sector emissions[5 15 16 18]

T_{adop} = 100%*60% + 0%*40% = 60%

T_{eff} = 1 – (1–6%)*(1–1%) = 7%

Emissions excluding satellite communications = 0.92/(1–7%*60%)
= 0.96 Gt CO_2e

Achievable reduction (%) = 60% * 7% = 4.2%

Satellite communications reduction = 0.04 Gt CO_2e

Sub-sector reduction = 4.2%

02

Current technologies, 100% adoption level

T_{adop} = 100%

T_{eff} = 7%

Achievable reduction (%) = 100% *7% = 7%

Satellite communications reduction = 0.07 Gt CO_2e

Sub-sector reduction = 7%

03

Nascent technologies: e.g. Iris

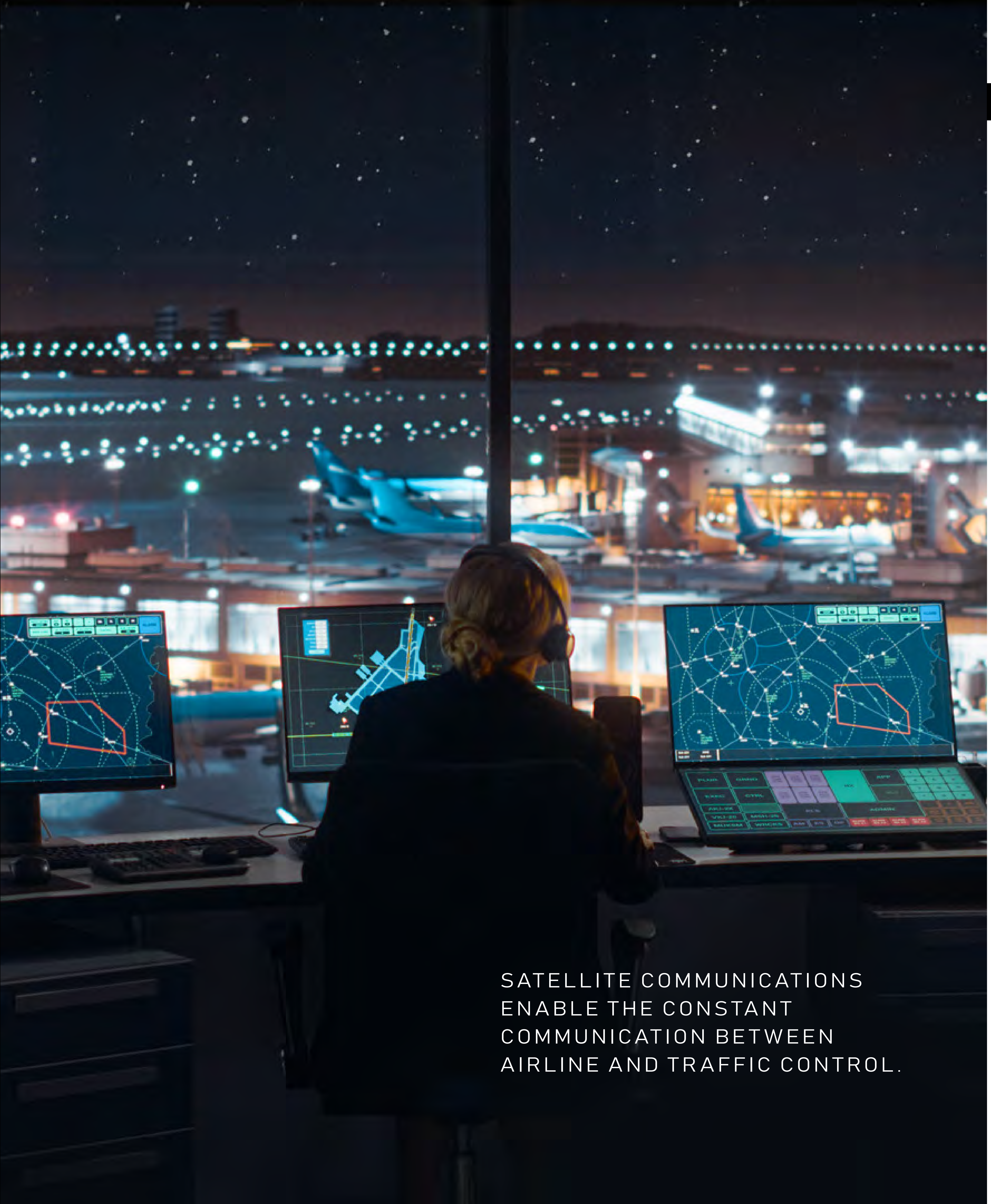
T_{adop} = 100%

T_{eff} = 1 – (1–6%)*(1–5%) = 11%

Achievable reduction global = 100% *11% = 11%

Satellite communications reduction = 0.96 Gt * 11% = 0.1 Gt CO_2e

Sub-sector reduction = 11%



SATELLITE COMMUNICATIONS ENABLE THE CONSTANT COMMUNICATION BETWEEN AIRLINE AND TRAFFIC CONTROL.

CASE STUDY: OPTIMISING AVIATION

Despite the pandemic, the Aviation industry is returning to the long-term trend of increasing flight numbers. Growth is happening, decarbonising that growth is the challenge, one that the industry is beginning to embrace.

Inmarsat and the European Space Agency (ESA) partnered to create a solution for modernising air traffic control systems. The outcome was Iris, a satellite-based data-link service.

It allows airlines to optimise the route flown through trajectory-based operations (TBO), where satellite communications enable the constant communication between airline and traffic control. Through this they can analyse flight paths, weather and congestion, among other factors, allowing them to optimise the route and reduce fuel consumption.

Assuming a gradual ramp-up of Iris, which could see it enabled on all European airliners by 2040 – Iris could save up to 6.5 million tonnes of CO_2 from European flights per year. The equivalent to the current yearly emissions of cities like Seville or Florence.[3]

BY 2040, IRIS COULD ENABLE AVIATION TO MAKE ANNUAL SAVINGS OF

6.5 MILLION

TONNES OF CO_2

EQUIVALENT TO THE CARBON EMISSIONS OF CITIES LIKE

SEVILLE OR FLORENCE FOR A WHOLE YEAR

MARITIME

THE CHALLENGE: CURRENT GLOBAL MARITIME EMISSIONS ARE ESTIMATED AT 1.1 GIGATONNES CO_2E[1 7 11]. BY 2050, THEY ARE EXPECTED TO TOP 1.5 GT CO_2[3]. ACCORDING TO THE INTERNATIONAL MARITIME ORGANIZATION (IMO) THAT'S 90-130% UP ON 2008 EMISSIONS.

The solution

Satellite communications-enabled technologies and the savings they can deliver for shipping are wide-ranging – particularly via automation.

Addressing the issues

CO_2 emissions in this sub-sector are directly related to fuel consumption. In turn, fuel consumption is influenced by vessel speed, weight, time of travel and weather conditions.

The main potential for energy reduction is in improved voyage execution and in improving control of the energy consumers. The latter includes better monitoring of the technical condition of systems.

Looking forward to achievable efficiencies

- Controlled speed[5 6]: from 2% to 50%, with a weighted mean of 24%
- Autopilot: 0.25% - 1.5% fuel reduction[6]
- Weather routing: up to 5% fuel reduction[6]
- Fleet information portal: up to 3%
- Voyage optimisation: 10%
- Ship Energy Efficiency Management Plan (SEEMP) reporting: 2%
- Monitoring, Reporting and Verification (MRV) reporting: 2%
- Specific Fuel Oil Consumption (SFOC) reporting: 2%
- Emission monitoring: 3%
- Asset monitoring: 5%
- Clean hull advisory: 5%
- Motion monitoring: 3%
- Comfort optimiser: 2%
- Trim optimisation: 5%
- Energy diagram: 4%

Adoption level for IoT solutions is between 47% and 65%, averaging 53%[4 8 12 13].

The possibilities of automation and autonomy

To continue improve maritime operational efficiency, several autonomy and automation projects are under development[15 16 17 19].

Ship automation is estimated to save 5-20% in energy consumption. It also increases the agility of shipping companies, allowing them to set up new routes faster, improving the competitiveness for short sea and inland waterway freight voyages.

Ship autonomy offers additional energy savings – removing energy consumption from the accommodation section, as well as crew support and safety systems.

Minimising crew on board during the voyage allows for structural improvements, such as reduced wind drag from a smaller superstructure.

In cases where ships are fully automated, crew welfare is no longer affected by weather and sea conditions, allowing both speed and heading to be optimised. This delivers energy savings of 5 - 30% (depending on ship size and type) compared to a crewed ship going at the same speed with the same cargo. Traffic management is also enhanced by 'just-in-time' arrival, while optimal speed during passage can reduce energy consumption by 10% - 50%.[19].

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

Scenario 3:

Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

T_{eff} = 33%[12]

T_{adop} = 53% *72% = 38%. Satellite communications market share is assumed to be 72% (SAT+VSAT)[13]

Emissions excluding satellite communications = 1.1 Gt CO_2 /(1–12%) = 1.25 Gt CO_2

Achievable reduction = 12%

Satellite communications reduction = 1.25 Gt *12% = 0.16 Gt CO_2

Sub-sector reduction = 12%

02

T_{eff} = 33%

Current technologies, 100% adoption

Achievable reduction (%) = 33%

Satellite communications reduction = 1.25 Gt CO_2 * 33% = 0.4 Gt CO_2

Sub-sector reduction = 33%

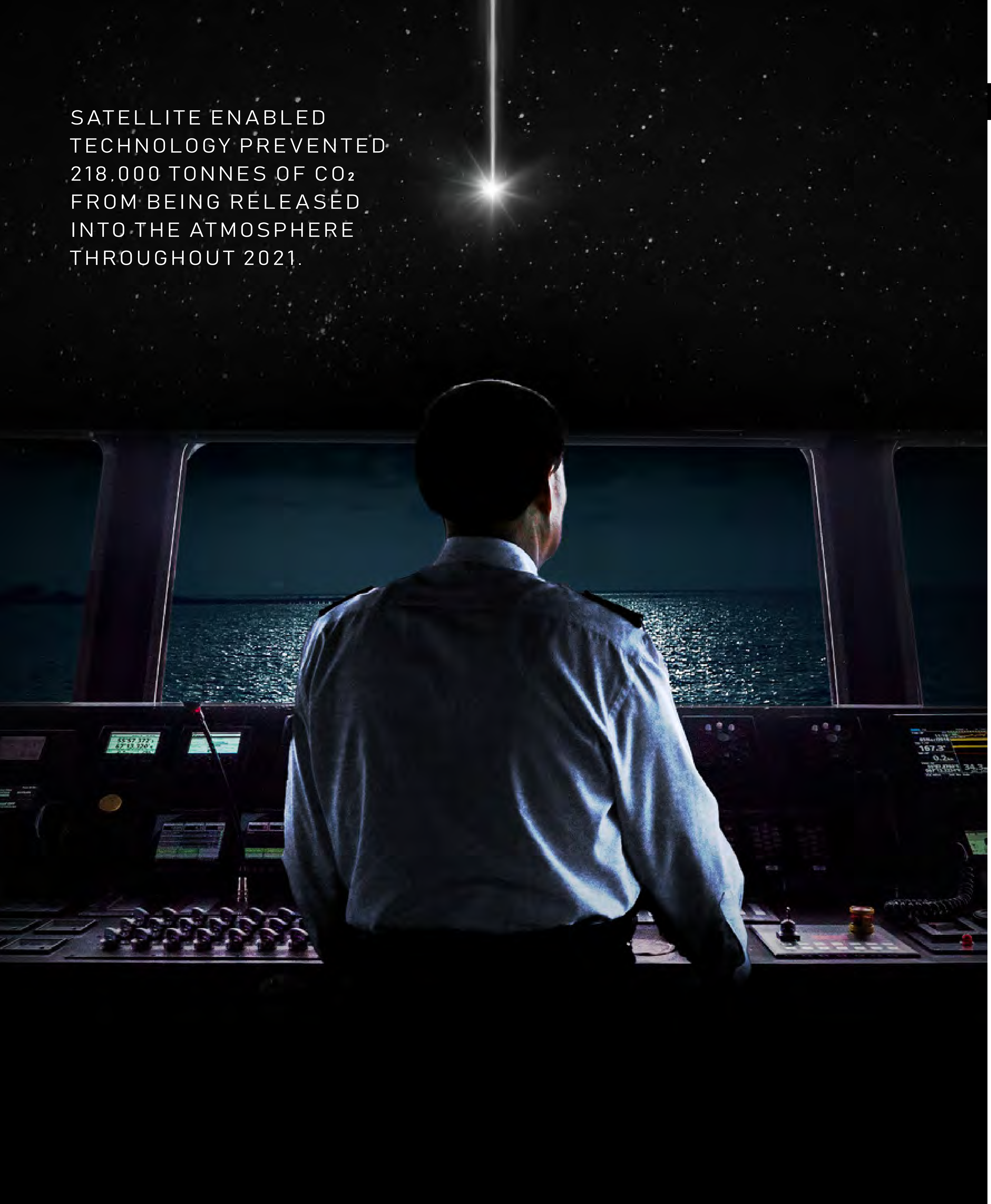
03

Nascent technologies: autonomous ships[15 19]

Due to early stages of trials, it is difficult to assess the achievable reduction in CO_2 emissions. However, it would be acceptable to consider the efficiency (Teff) lower limit as 33%, expecting reduction values between 37%[12] and 60%[16 19].

Achievable reduction (%) > 33%

Satellite communications reduction = > 0.4 Gt CO_2



SATELLITE ENABLED TECHNOLOGY PREVENTED 218,000 TONNES OF CO_2 FROM BEING RELEASED INTO THE ATMOSPHERE THROUGHOUT 2021.

CASE STUDY: FINDING EFFICIENCY AT SEA

The IMO has huge ambitions for the reduction of Maritime GHG. It is looking to cut them by 70% by 2050. Much of this could be achieved through connected digital optimisation strategies such as controlling onboard energy consumption, efficiently distributing power output and route optimisation.

All of which could yield up to a 38% reduction in maritime GHG emissions by 2050.

Headquartered in Copenhagen, ZeroNorth helps vessel owners and operators to optimise voyage, vessel and bunkers to immediately reduce CO_2 emissions.

ZeroNorth revealed that its platform, enabled by Inmarsat satellite technology, has prevented 218,000 tonnes of CO_2 from being released into the atmosphere throughout 2021. By combining a variety of vessel, market, bunker and weather data with its algorithms, the ZeroNorth platform suggests a 'green route' for ships, which considers emissions and profitability when creating an optimised course.

ROAD AND RAIL

THE CHALLENGE: TRANSPORTATION BY ROAD AND RAIL INCLUDES PASSENGERS AND FREIGHT VEHICLES, WITH ESTIMATED EMISSIONS BETWEEN 6.1 GIGATONNES CO_2E[6] AND 8.2 GIGATONNES CO_2E[5]. PASSENGER SERVICES ACCOUNT FOR 60% OF EMISSIONS ARISING FROM ROAD AND RAIL TRANSPORTATION.

The solution

Satellite communications technologies, predominantly based on Global Navigation Satellite Systems (GNSS) and telemetry, could deliver a dramatic reduction.

In predicted scenarios where global warming is limited to 1.5°C, global transport-related CO_2 emissions are reduced by 59% by 2050 relative to models and predictions based on 2020 emissions with the aid of GNSS technologies [6,8].

Addressing the issues

CO_2 emissions in transport are directly related to fuel consumption which, in turn, depends on the duration, length and speed of a journey.

Global Positioning System (GPS) services with speed management applications can significantly reduce emissions by minimising travelling time and controlling driver behaviour.

Key decarbonising technologies

- GPS-based route optimisation – studies indicate fuel savings of 5% - 20%[3 4]
- Speed management
- Fleet management
- Teleworking / telecommuting – reduce transport-related GHG emissions by at least 1%[3 6].

The growth of connected and automated transportation

Eventually, satellite communications and automation will facilitate seamless integration between transportation modes[12]. Eco-driving systems that recognise driving behaviour and provide on-trip advice and post-trip feedback, could achieve a CO_2e reduction of 5-20%[12].

And looking further into the future, fully autonomous vehicles will not only take drivers out of the equation, but also take them off the ground. 'Urban air mobility' will use small, highly automated, all-electric aircraft to carry passengers and cargo in heavily populated areas [13 15]. Drone delivery testing is already well underway.

UNDERSTANDING THE SCENARIOS

Scenario 1:

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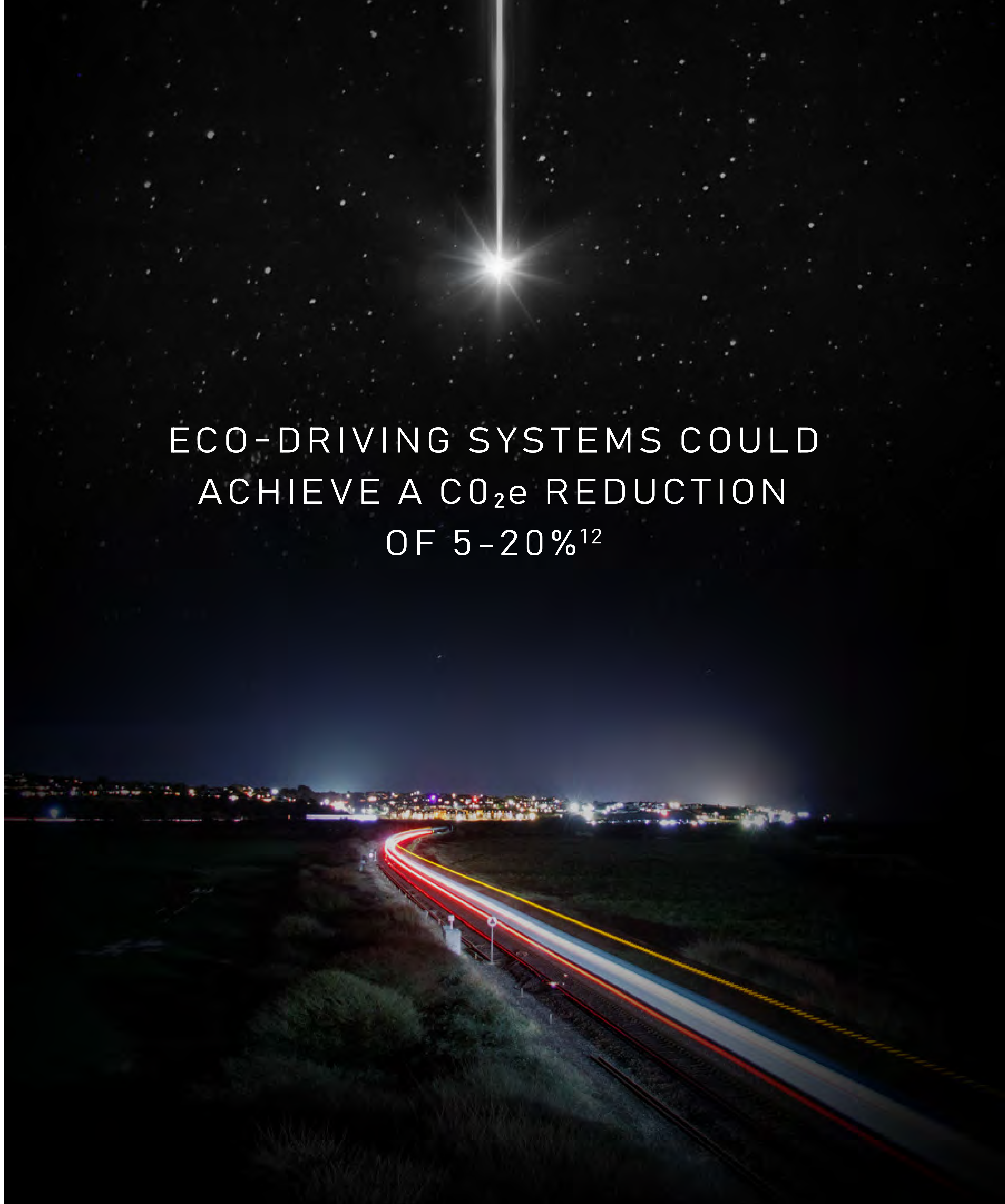


ECO-DRIVING SYSTEMS COULD ACHIEVE A CO_2e REDUCTION OF 5-20%[12]

Scenario

01

Freight and passenger transport technology at current adoption rates:

Passenger transport:

T_{eff} = 21% (route optimisation + teleworking)[9][10]

T_{adop} = 60%, based on 2021 total internet users[1][2]

Emissions excluding satellite communications for passenger transport = 6.1*60%/(1–21%*60%) = 4.2 Gt CO_2e

Satellite communications reduction = 0.5 Gt CO2e

Freight transport:

T_{eff} = 18% (fleet management + teleworking)[9][10]

T_{adop} = 10%[7]

Emissions excluding satellite communications for freight transportation = 6.1*40%/(1–18%*10%) = 2.5 Gt CO_2e

Total road emissions without satellite communications = 4.2 Gt CO_2e + 2.5 Gt CO_2e = 6.7 Gt CO_2e

Satellite communications reduction for passenger transportation = 6.7*60%*T_{eff} *T_{adop} = 6.7*60%*60%*21% =0.5 Gt CO_2e

Satellite communications reduction for freight transport = 6.7*40%*T_{eff} *T_{adop} = 6.7*40%*10%*18% = 0.05 Gt CO_2e

Achievable reduction in passenger transport (%) = 7%

Achievable reduction in freight transport (%) = 1%

Satellite communications reduction = 0.5 Gt CO_2e + 0.05 Gt CO_2e = 0.55 Gt CO_2e

02

Freight and passenger transport technology adopted up to 100%

T_{eff} for passenger transport = 21%.

T_{eff} for freight transport = 18%

T_{adop} for passenger transport = 100%

T_{adop} for freight transport = 100%[7]

Achievable reduction in passengers transport = 6.7*60%*21%

Achievable reduction in freight transport (%) = 6.7*40%*18%

Achievable reduction in passenger transport = 21%

Achievable reduction in freight transport = 18%

Satellite communications reduction = 0.8 Gt CO2e + 0.5 GtCO2e = 1.3 GtCO2e

03

The impact of nascent technologies at 100% adoption

Connected and automated freight transport and urban air mobility for passenger transport

Passenger transport, considering same distance:

Car emission factor (average petrol) = 0.2 kg CO_2e/km14

Battery electric vehicle emission factor (UAV as air taxi) = 0.05 kg CO_2e/(km) 14

T_{eff} for air taxi = (0.2–0.05)/0.2 = 75%

T_{adop} for air taxi = 100%

Achievable reduction = 75% (switching from car to air vehicle)

Emissions excluding satellite communications for passenger transportation = 4.2 Gt CO_2e

Satellite communications reduction = 3.1 Gt CO_2e

Freight transport, considering the same cargo and the same distance:

Freight train emission factor = 0.03 kg CO_2e/(tonne*km)14

Truck emission factor(average) = 0.1 kg CO_2e/(tonne*km) 14

T_{eff} for multimodal freight = (0.1–0.03)/0.1 = 70%

T_{adop} for multimodal freight (switch from truck to train) = 100%

Achievable reduction = 70%

Emissions excluding satellite communications for freight transportation = 2.5 Gt CO_2e

Satellite communications reduction = 1.25 Gt CO_2e

Satellite communications reduction = 1.25 Gt CO_2e + 3.1 GtCO_2e = 4.35 GtCO_2e

THE RAILWAYS' OVERALL CONTRIBUTION TO DECARBONISATION THROUGH SATELLITE-ENABLED TECHNOLOGIES AMOUNTS TO 5,000,000 TONNES OF CO_2 AVOIDED.

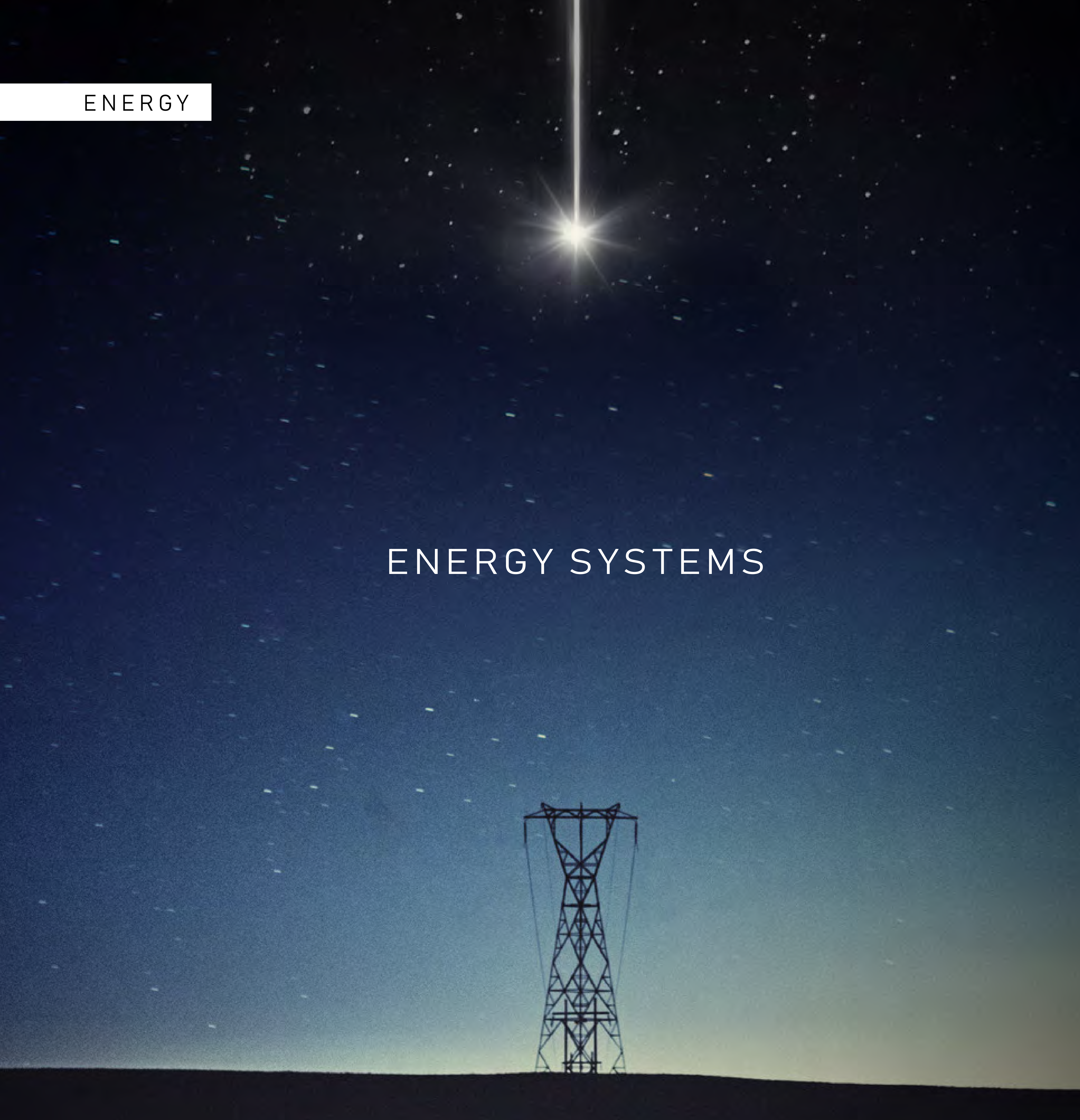
CASE STUDY: CREATING OPERATIONAL EFFICIENCIES ON RAILWAYS

Much of the world's cargo travels by train. So, finding operational efficiencies in the Rail industry will naturally have far-reaching decarbonising effects.

For example, the Brazilian railway operator, Rumo, leverages real-time communications and telemetrics to improve the speed and effectiveness of its communications.

This allows for route optimisation and journey planning – which leads to better predictability and more efficient fuel burn. When applied at scale, this can make a considerable impact on CO_2 reduction.

When you consider that Rumo alone transported 58 million tonnes of cargo in 2019, there is a clear opportunity for the Rail industry to help decarbonise global supply chains. As per Globant's research, Rail is an important contributor to decarbonisation through satellite-enabled freight transport efficiencies, which amount to 5,000,000 tonnes (0.05 gigatonnes) of CO_2 avoided.



ENERGY SYSTEMS

In brief

Understandably, methods of energy production are often the focal point of the conversation around decarbonisation. However, given the vast scale of the global energy sector, operational efficiencies in energy transmission can make a huge impact too.

Smart grids improve the efficient distribution of power, while monitoring technologies such as leak detection are scalable applications that help curb emissions and sound the alarm on environmental issues. The study found that currently 500,000,000 tonnes (0.5 gigatonnes) of CO_2 are removed in the energy sector by these satellite-enabled technologies.

What's more, if a wider spectrum of satellite-enabled solutions is universally adopted, that number could rise to **1,900,000,000 tonnes (1.9 gigatonnes) of CO_2 removed.**

Current impact on global emissions

Carbon impact – expressed as a percentage of total global emissions – for Energy sub-sectors are as follows.

Sub-sector	Main use cases	% of total global emissions
Oil and Gas / fuel production and transmission	Energy use, methane detection	9%
Electricity and Heat	Optimisation	24%

IF CURRENT TECHNOLOGIES WERE UNIVERSALLY ADOPTED, THE ENERGY SECTOR COULD SAVE

1.9

GIGATONNES OF CO_2

EQUIVALENT TO REMOVING THE TOTAL CO_2 EMISSIONS OF

NEW YORK CITY

FOR OVER 30 YEARS

OIL AND GAS

THE CHALLENGE: ACHIEVING NET ZERO BY 2050 MEANS DELIVERING AN 80% REDUCTION IN PRODUCTION OF ALL FOSSIL FUELS IN FAVOUR OF ELECTRIFICATION[2].

Fugitive emissions from fossil fuel production, primarily methane, accounted for about 18% of Energy sector supply emissions in 2019, with 2.6 gigatonnes CO_2e linked to oil and gas production.

In total, Oil and Gas operations produced 2.9 gigatonnes CO_2e/year in 2019, roughly split equally between the two[1]. Also, the research underlines the worryingly high degree of uncertainty about the calculation of methane emissions, which are currently underestimated by at least 25% and possibly as much as 40%[14]. What's more, methane is a powerful greenhouse gas, which makes detecting and fixing leaks even more vital[1 5 6 16].

The solution

Fortunately, there is a way to dramatically reduce these figures. And it relies on the real-time knowledge and control that satellite communications-enabled technologies offer.

Key decarbonising technologies

- GPS tracking of high value assets
- Machine-to-machine solutions for monitoring, controlling, automating and optimising assets
- Remote detection and mitigation of leaks based on methane detection cameras, gas sensors, UAV/planes, satellite imaging and automated systems[1 10 11 12 13]

Addressing the issues

The emissions that occur along the Oil and Gas value chain[14] are:
- **Fugitive equipment leaks**
- **Process venting**
- **Evaporation losses**
- **Disposal of waste gas streams** by venting or flaring
- **Accidents and equipment failures:** these include well blowouts, pipeline breaks, tanker accidents, tank explosions, gas migration to the surface around the outside of wells, and surface-casing vent blows. Also, there are the relatively minor GHG emissions caused by Chlorofluorocarbon (CFC) leakage from refrigeration systems.

Ramping up LDAR programmes

Annual equipment inspections are assumed to mitigate 40% of fugitive emissions. And the more regular the inspection, the bigger the reduction. Biannual inspections mitigate an additional 20%, quarterly inspections another 10%, and monthly inspections an extra 5%. In short, implementing a monthly leak detection and repair (LDAR) programme reduces fugitive emissions by an enormous 85%[3 7 12 15].

Automation is another way forward. Optimising processes is estimated to reduce emissions by 5%[9]. And teleworking policies that reduce CO_2 emissions created by non-essential employee travel will deliver a 1% reduction.

Looking forward to achievable efficiencies

The Net Zero future for Oil and Gas is in digital twins (virtual simulations of physical objects that help owners and planners operate more efficiently), autonomous operations, and real-time demand/supply balancing[17].

Digital asset life cycle management initiatives will capture real-time information from physical assets using specialised sensors, and cloud-based analytics will process the data.

Autonomous robots will run multiple operations 24/7 and, to a large extent, replace field workers.

Together, robots and drones will help shrink upstream operational costs[17]:

- 20% reduction in drilling and completion costs (in shelf / deep water areas)
- 25% lower inspection and maintenance costs
- 20% cut in employee costs across all areas
- 20% less downtime

All of which reduce workload and material use, resulting in lower CO_2 implications from the operation of business.

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

Scenario 3:

Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

According to the IPCC's latest report (2021), annual fugitive methane leaks total 2.6 Gt CO_2e. Below, we use this number to account for optimisation of fugitive emissions. Emissions related to overall operations total = 2.9 Gt CO_2e[1].

Emissions related to leaks

T_{adop} for leak reduction initiatives = 25%*56% = 14%[8]

T_{eff} for leak reduction = 14%* 85% = 12%, applicable just to 2.6 Gt CO_2e

Emissions related to operations

T_{adop} for process optimisation = 25%*56% = 14%[8]

T_{eff} for process optimisation = 14%*5% = 0.7%, applicable to 2.9 Gt CO_2e

T_{adop} for teleworking = 100%[1]

T_{eff} teleworking = 100%* 1% = 1%, applicable to 2.9 Gt CO_2e

Total emissions excluding satellite communications = 2.6/(1-12%) + 2.9/[(1-0.7%)*(1-1%)] = 2.95 + 2.95 = 5.9 Gt CO_2e

Achievable reduction by satellite communications = 0.4 Gt CO_2e

Sub-sector reduction = 6.8%

02

Technology adoption = 100% for all technologies

Leak reduction = 85%, applicable to 2.6 $GtCO_2e$

Process optimisation = 5% , applicable to 2.9 $GtCO_2e$

Teleworking = 1%, applicable to 2.9 $GtCO_2e$

Total emissions excluding satellite communications = 5.9 $GtCO_2e$

Achievable reduction by satellite communications = 0.4 $GtCO_2e$ + 0.2 $GtCO_2e$ = 0.6 $GtCO_2e$

Sub-sector reduction = 10%

03

Nascent technologies – such as digital twinning, autonomous operations, and real-time demand/supply balancing[17] – populate this scenario .

But being nascent means that assumption of a specific T_{eff} value isn't possible yet. However, building on the premises of Scenario 2, T_{eff}'s lower, more conservative limit can be established at 10% of adoption.

Achievable reduction by satellite communications (%) > 10%

Satellite communications reduction = > 0.6 Gt CO_2e

ELECTRICITY AND HEAT

THE CHALLENGE: EMISSIONS ASSOCIATED WITH ELECTRICITY, HEAT GENERATION AND DISTRIBUTION ARE ESTIMATED AT 14 GIGATONNES CO_2E. BUILDING AND INDUSTRY ACCOUNTS FOR 90% OF ELECTRICITY AND HEAT USE[2].

Net Zero scenarios foresee electricity production rising to over 50%. This is the focus of green policies worldwide as they strive to cut emissions throughout the energy value chain. However, the process of energy transition requires a radical change in the production, transportation, storage, distribution and use of energy within our society.

The solution

A global energy revolution powered by efficiency and sustainability. Satellite communications-enabled technologies provide the metering, monitoring, automation and machine-to-machine connections necessary to make that revolution a success.

Key decarbonising technologies

Advanced metering infrastructure / smart meters: installed in households to reduce energy demand. They facilitate dynamic pricing tariffs to support low carbon electric heating and improve measurement of energy efficiency — driving standards up and emissions down.

Distribution automation: allows remote management of 'reclosers' (circuit breakers that, in the event of a fault or overload, minimise the number of customers without service).

Smart grids: automated electricity networks that use mobile communications technology to monitor and control grid activities — detecting, pre-empting and reacting to changes in usage. They regulate electricity demand and transmission, while improving coordination and distribution. In short, they ensure the efficient two-way flow of electricity and information between power plants, consumers and all points in between[4 10 11 12].

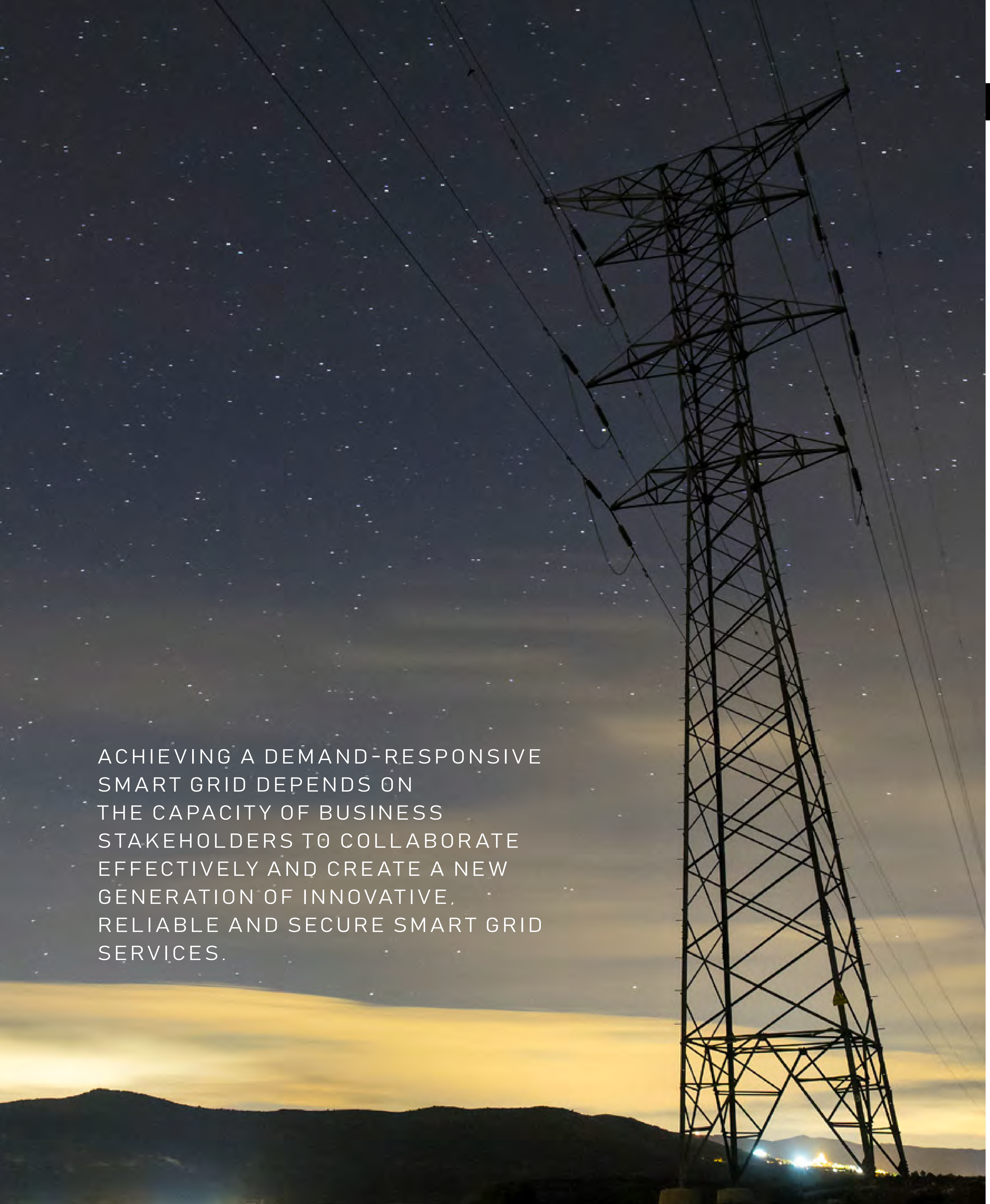
Additionally, small-scale renewable electricity generators participate in the wider market by using machine-to-machine connections, increasing the amount of green and local energy in the grid.

Addressing the issues

Achieving a demand-responsive smart grid depends on the capacity of business stakeholders to collaborate effectively and create a new generation of innovative, reliable and secure smart grid services.

In an environment of increased collaboration, success depends on meeting four strategic challenges at the intersection between Information and Communication Technologies (ICT) and energy infrastructures:

1. **Interoperability** to ensure convergence of network (ICT) and transmission (grid) protocols for enhanced cooperation and communication.
2. **Reliability and security** to deliver trusted services and enhanced resilience.
3. **Decentralised and self-organising architecture** that enhances the flexibility of grid control and management, while increasing resilience via self-healing.
4. **Innovative business models** to promote stakeholder participation.



ACHIEVING A DEMAND-RESPONSIVE SMART GRID DEPENDS ON THE CAPACITY OF BUSINESS STAKEHOLDERS TO COLLABORATE EFFECTIVELY AND CREATE A NEW GENERATION OF INNOVATIVE, RELIABLE AND SECURE SMART GRID SERVICES.

LOOKING FORWARD TO ACHIEVABLE EFFICIENCIES

Smart grids can reduce GHG emissions in five ways, by:

1. Increasing the use of electricity from fluctuating renewable energy sources by managing demand — reducing demand when electricity availability is low and storing electricity when it's abundant. This lowers GHG emissions by limiting more carbon-intensive energy carriers.

2. Reducing line losses by operating the grid at optimal load and by integrating distributed electricity sources in the grid — shortening the distance from generation to consumption.

   Also, smart grids empower neighbourhood networks that generate their own energy to optimise consumption using local low radiation 5G networks. These highly flexible 'microgrids' reduce energy transportation losses and associated GHG emissions.

3. Using the existing grid infrastructure better by avoiding the buildout of electricity grid infrastructure, whose construction and operation is both material- and energy-intensive.

4. Giving consumers information on their electricity consumption via feedback systems, such as smartphone apps.

5. Facilitating the transformation towards e-mobility by, for example, optimising the charging times of electric vehicles according to individual mobility needs and the availability of electricity. Also, if this leads to a faster substitution of GHG-intensive combustion engines with GHG-efficient electric engines, further emissions will be reduced[14].

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

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Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

Solution	$\mathbf{T_{eff}}$	$\mathbf{T_{adop}}$
Smart metering	4%	22% *32%
Smart grid	5%	22% *32%

Smart metering and smart grid solutions for electricity and in the use-case of satellite communications-enabled operational efficiencies. Technology efficiency and adoption are reported and calculated. (Sources: T_{eff}[5 6 7 8] / T_{adop}[19], where 22% is average adoption percentage and 32% is satellite communications market share.)

T_{adop} smart metering = 7%

T_{eff} smart metering = 4%[8]

Tadop smart grid = 7% T_{eff} smart grid = 5%[8]

Emissions excluding satellite communications = 14/(1-(1-4%*7%)*(1-5%*7%)) = 14.1 GtCO_2e

Achievable reduction = 1%

Satellite communications reduction = 0.1 Gt CO_2e

02

T_{adop} = 100%

T_{eff} = 9%

Achievable reduction = 9%

Satellite communications reduction = 1.3 Gt CO_2e

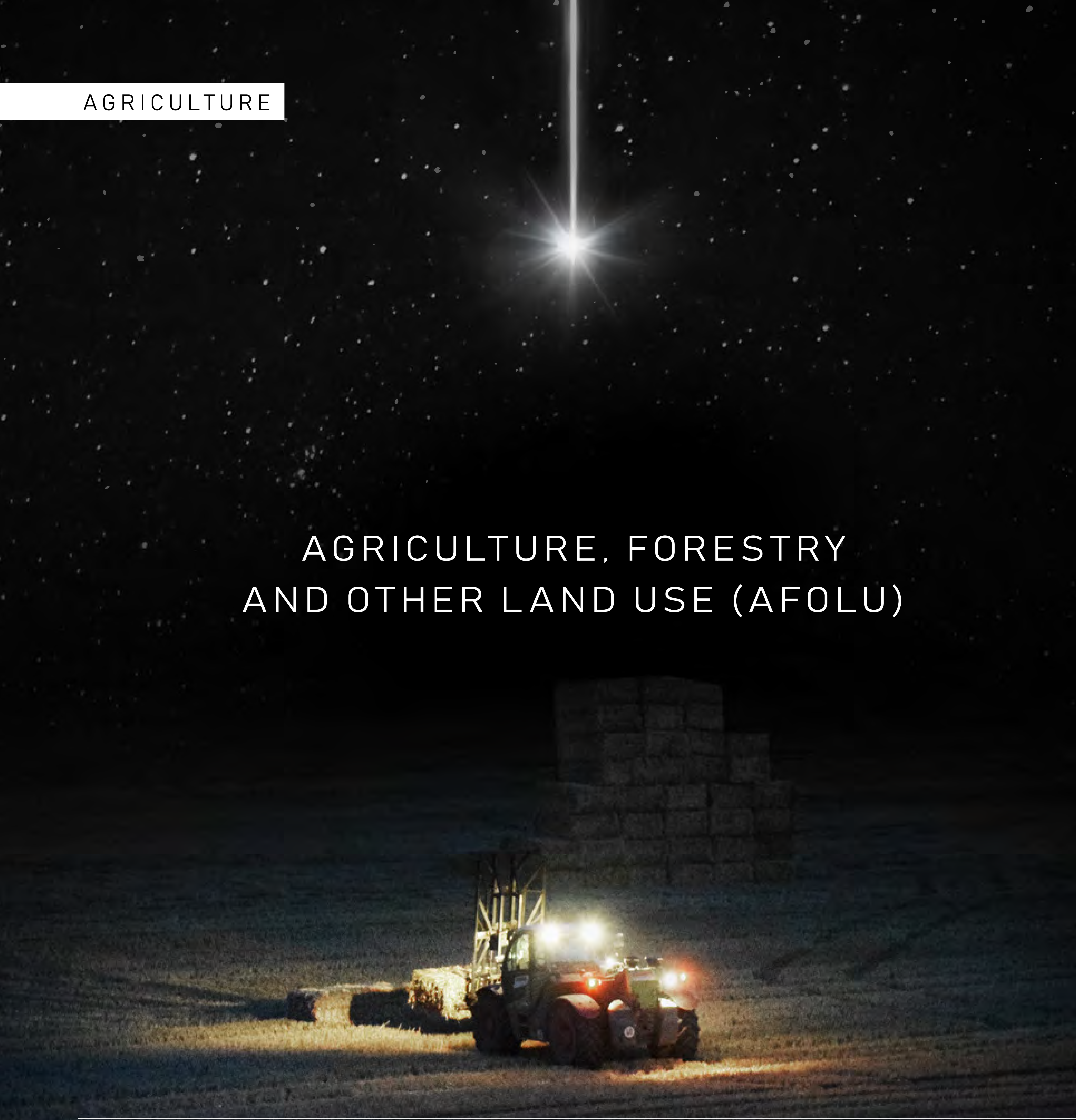
03

This covers nascent technologies at the forefront of energy transitions that are not yet based on satellite communications technology. These new energy systems are AI-driven energy optimisation methods, where the core of innovation is represented by the application of AI to the grid[16].

A nascent satellite communications-based technology scenario was not found for the Electricity and Heat sub-sector. However, considering the above information, Teff's lower limit is 9% (from scenario 2) and nascent technologies would be above this value.

Achievable reduction (%) > 9%

Satellite communications reduction > 1.3 Gt CO_2



AGRICULTURE, FORESTRY AND OTHER LAND USE (AFOLU)

In brief

How we manage the land beneath us is vitally important – from our food stocks to the health of the forests that absorb the world's CO_2. Considering its fundamental role in all our lives and the ancillary benefits it bestows, decarbonising this sector is essential.

Currently, technologies enabled by satellite communications allow the removal or avoidance of up to 300,000,000 tonnes (0.3 gigatonnes) of CO_2 according to the study. Precision agriculture and forest management enables decarbonisation through a number of different technologies, from tractor routing and yield mapping to forest fire early warning.

If universally adopted, **these satellite-enabled technologies could amount to 1,900,000,000 tonnes (1.9 gigatonnes) of carbon avoided or removed.**

Current impact on global emissions

Carbon impact – expressed as a percentage of total global emissions – for AFOLU sub-sectors are as follows.

Sub-sector	Main use cases	% of total global emissions
Farming	Input reduction	6%
Forestry	Fire prevention	5%

SATELLITE TECHNOLOGY CURRENTLY DECARBONISES 'AFOLU' BY UP TO

0.3

GIGATONNES OF CO_2

ADOPTED GLOBALLY, SATELLITE TECHNOLOGY COULD REMOVE/AVOID

1.9

GIGATONNES OF CO_2

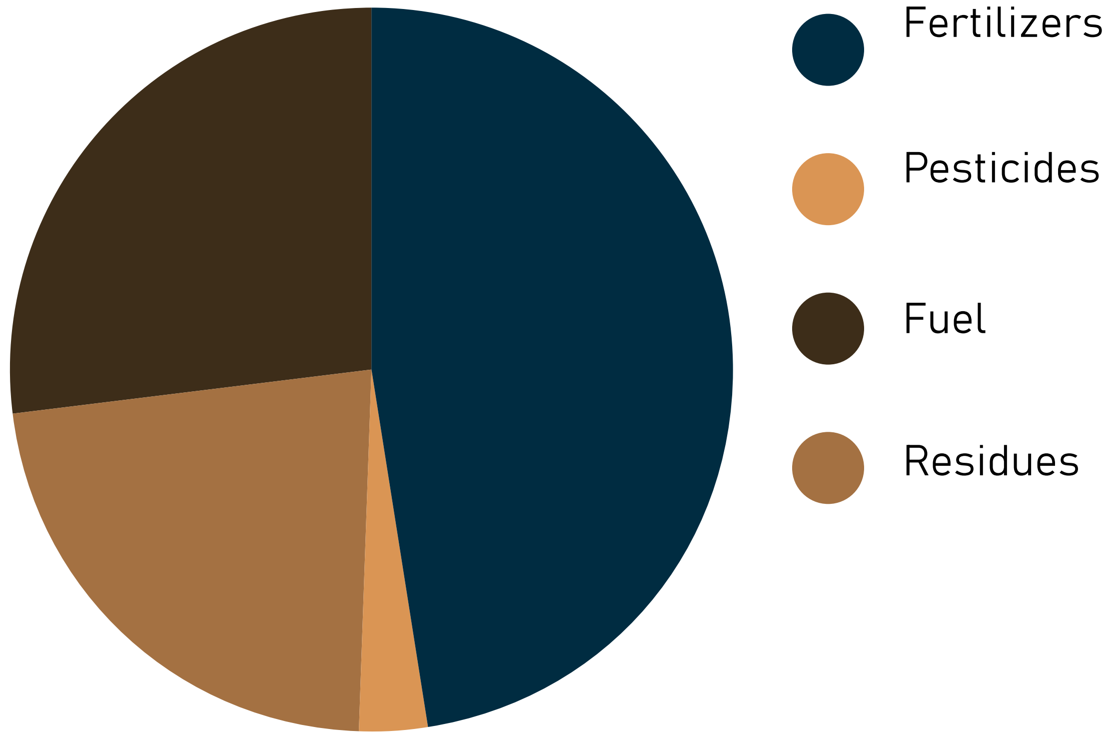
FARMING

THE CHALLENGE: CURRENT ESTIMATIONS OF WORLD CROPLAND AND LIVESTOCK EMISSIONS RANGE BETWEEN 5.3 AND 6 GIGATONNES CO$_2$E[1] [2]. CROPLAND EMISSIONS CONSTITUTE ABOUT HALF OF THAT FIGURE, AT SOMEWHERE BETWEEN 2.7 AND 2.9 GIGATONNES CO$_2$E[3] [12].

Cropland cultivation is highly dependent on fertilisers, fuels, machinery and pesticides. Sources of emissions include those from the production and use of synthetic fertilisers and pesticides, as well as emissions from generated residues and fuel consumption. On average, fertilisers, fuel and pesticides represent 47.7%, 22.5% and 3.1% respectively of total GHG emissions in Farming[4] [14].

The Food and Agriculture Organisation estimates that harvested areas will continue to grow, reaching at least 1.500 million hectares by 2050[15].

Average emissions for crop farming[14].



The solution

Precision agriculture enables accurately localised crop production management via several different technologies, mostly based on GNSS correction services and telemetry. These technologies allow farmers to micro-manage seed, fertiliser and pesticide applications[7].

Key decarbonising technologies

- **IoT technologies** reduce waste and increase productivity using smart sensors and machines that automate many tasks – from precision irrigation systems and self-driving tractors to automated crop-scouting drones[17].
- **Variable rate (VR) technology** ensures the optimum application of pesticide or fertiliser according to real-time crop needs and conditions.
- **GNSS** provides driver assistance and machine auto-guidance – ensuring maximum efficiency and minimum emissions.

THE FOOD AND AGRICULTURE ORGANISATION ESTIMATES THAT HARVESTED AREAS WILL CONTINUE TO GROW, REACHING AT LEAST 1.500 MILLION HECTARES BY 2050[15].

Addressing the issues

Tractor guidance systems mainly use GPS – including yield/soil mapping – and VR applications. These technologies provide farmers with the data they need to adjust production practices to current field conditions.

VR technology applications instruct machinery – such as sprayers and seeders – to automatically control flow rates. For example, there are two VR pesticide technologies. The map-based VR pesticide application uses a GPS receiver to identify the field position and alter input concentration as the sprayer moves through the field. Then the real-time sensor-based VR pesticide application changes the rate and even the direction of spray, according to the pests, foliage characteristics and conditions identified by an array of advanced sensors.

Input	Emissions reduction due to technologies adoption (%)	Range
Fertilisers	18	4-46
Pesticides	45	25-77
Fuel	8	6-10

Looking forward to achievable efficiencies

Nascent technologies for precision agriculture focus on yield enhancement and input reductions – such as driving down emissions by using mechanical means for weed control rather than chemicals[16]. You can see how they are forecast to perform in the scenarios below.

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

Scenario 3:

Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

Uses current GNSS-enabled technology: namely variable rate application, soil mapping and guided systems/controlled traffic farming. Likely global technology adoption for the combined three technologies is 50%[7, 8, 11, 18, 20].

Solution	Average adoption level	Range
US & Canada	68%	23%-100%
South America	61%	20%-100%
Europe	24%	17%-50%
China	25%	12%-25%
Oceana	71%	60%-90%
Average	50%	-

Satellite communications market share is estimated at 49%[19]

T_{eff} = 11.5%

T_{adop} = 50%* 49% = 24%

Emissions excluding satellite communications = 2.9/(1-2.8%) = 3.0 Gt CO_2e

Achievable reduction (%) = 24% * 11.5% = 2.8%

Cropland emissions = 3.0 Gt CO_2e

Satellite communications reduction = 3.0 Gt CO_2e * 2.8% = 0.1 Gt CO_2e

Agriculture emissions = 6 Gt CO_2e

Sub-sector reduction = 0.1/6 = 1.7%

02

Same technologies, 100% technology adoption

Achievable reduction = 11.5% Cropland emissions = 3.0 Gt CO_2e

Satellite communications reduction = 0.3 Gt CO_2e 17

Sub-sector reduction = 0.3/6 = 5%

03

Nascent technology, 100% technology adoption

GNSS-enabled technology: variable rate application + soil mapping + guided systems/controlled traffic farming + agbots for weed control

Based on above descriptions, 100% pesticide reduction could be achieved, rising technology efficiency from 11.5% to 13%.

Achievable reduction (%) = T_{adop}%*T_{eff}% = 100% * 13% = 13%

Satellite communications reduction = 0.4 Gt CO_2e

Sub-sector reduction = 0.4/6 = 6.7%

FORESTRY

THE CHALLENGE: CO_2 EMISSIONS ARE DIRECTLY RELATED TO BURNING BIOMASS WITH FOREST FIRES ACCOUNTING FOR 1.5 GIGATONNES CO_2E[1 3]. A GLOBAL ANALYSIS OF FOREST FIRES BETWEEN 2003 AND 2012 IDENTIFIED APPROXIMATELY 67 MILLION HECTARES BURNT ANNUALLY[2].

In 2022, fanned by climate change, the frequency and extent of wildfires has increased worldwide, with the number of hectares burnt annually rocketing to circa 113 million.

The solution

Satellite communications technologies that play a role in early fire detection substantially improve the probability of detecting, containing and stopping those fires.

Key decarbonising technologies

Navigation and communications systems for enhanced aerial observation, as well as lookout towers, patrols and automatic fire detection using infrared cameras and satellites[6 9], are the current key contributing technologies to emissions reduction.

A standard forest fire early warning system is composed of the forest area control centres, wireless transmission systems and front-end monitoring points. The front-end monitoring points have all-weather infrared (thermal) cameras. Real-time images of each monitoring point can be transmitted to the monitoring centre via a wireless transmission system.

Fire detection using satellite observation is based on the satellite's ability to detect energy differences between fires and background areas[6]. The result is global monitoring with a fire detection efficiency of 100%[8].

Addressing the issues

The European Union target is to reduce 55% of emissions from wildfires by 2050[10]. The Intergovernmental Panel on Climate Change (IPCC) identifies REDD+ (the framework created by the UNFCCC Conference of the Parties to reduce emissions from deforestation and degradation) as having the greatest potential for reducing AFOLU emissions in that time – estimated at 0.4 - 5.8 gigatonnes CO_2e[11].

Looking forward to achievable efficiencies

The future looks likely to include early detection and fire-fighting systems that are based on current technologies but also incorporate autonomous uncrewed aerial vehicle (UAV) fleets equipped to extinguish fires[14 15 16 17 18]. These will also be used for fire monitoring – improving detection via AI[19 20 22] and accelerating deployment. Indeed, speed is of the essence. The faster you get to a fire the easier it is to extinguish[21].

UNDERSTANDING THE SCENARIOS

Scenario 1:

Quantifies the current reduction in emissions using existing satellite communications technologies.

Scenario 2:

Calculates the untapped potential of existing satellite communications technologies assuming full market adoption.

Scenario 3:

Forecasts the future decarbonisation impact of nascent satellite communications technologies at full adoption.

Scenario:

01

Technologies: mobile broadband satellite communications services[23], forest early warning systems.

T_{eff} = 90%[2]

T_{adop} = 14%[7]

Emissions excluding satellite communications = 1.5 Gt CO_2e / (1-14%*90%) = 1.7 Gt CO_2e

Achievable reduction = 12%

Satellite communications reduction = 0.2 Gt CO_2e

02

Attains the highest decarbonisation and savings numbers in AFOLU

T_{eff} = 90%[2]

T_{adop} = 100%

Emissions excluding satellite communications = 1.7 Gt CO_2e

Achievable reduction = 90%

Satellite communications reduction = 1.5 Gt CO_2e

03

T_{eff} = 100%

T_{adop} = 100%

Emissions excluding satellite communications = 1.7 Gt / (1-100%*100%) = 1.7 Gt CO_2e

Satellite communications reduction = 1.7 Gt CO_2e (100%)

COP27

A GAUGE OF THE CHALLENGE AHEAD

Many commentators have stated their frustration at COP27's lack of progress. It's something that climate activists highlighted before the event, accusing COP of being a space for "Greenwashing"[1].

A mix of political, technological and economic upheaval has clearly had an effect at COP. As technologies evolve and non-fossil fuels develop to help reduce CO_2 emissions, that very piece of progress poses a threat to those nations where fossil fuels are an economic cornerstone. A Saudi Arabian delegate who said "we should not target sources of energy; we should focus on emissions. We should not mention fossil fuels," [2] was not a lone voice.

To complicate matters further, there is the polarising international scene. The war in Ukraine and troubling global economic situation have diverted attention and put up barriers to change.

This distracting background of mistrust and insecurity not only affected what the climate change talks could accomplish, but also put existing commitments at risk, as witnessed by the calls to weaken the wording around the 1.5°C commitments.[3]

What's more, as seen through our research earlier in the year, COP illustrated the education gap, or at least the awareness gap, as to what satellite communications could achieve in terms of decarbonisation.

However, even though COP27's lost momentum and glaring omissions gave significant cause for concern, it also gave clarity to the challenge ahead and the key role that the space sector must now play.

THE PERCEIVED ROLE OF SPACE TECHNOLOGY

One thing the space sector might not be comfortable with is the airtime given to satellite technology at COP27 – it did not feature heavily. And when it did make an appearance, it was under the title of 'Loss and Damage', where satellites are seen as a tool for monitoring carbon emissions and measuring damage caused by extreme weather.

In other words, space technology is currently only viewed as a passive way of observing what has happened, rather than as an active means of decarbonisation. Which explains why, on COP27's 'Decarbonisation Day', satellite communications were barely mentioned.

This is not to play down the importance of space technology's role as a climate change observer. The launch of The Methane Alert and Response System (MARS) is, as US Special Climate Envoy John Kerry said, "critical" to climate efforts.

Nonetheless, it's only half the story of what the technology can achieve.

Hence, there is a vital job to do: to create awareness of the full – both passive and active – potential of satellite-enabled technologies.

Decarbonisation Day's missing link

On COP27's Decarbonisation Day, space-enabled technologies such as these should be acknowledged:

- Performance-based navigation
- Continuous climb operations (CCO)
- Continuous descent operations (CDO)
- Ship automation
- Ship autonomy
- GPS-based route optimisation
- Speed management
- Fleet management
- Teleworking / telecommuting

Why? Because such technologies are contributing now to the current 1.5 gigatonnes of satellite communications-enabled decarbonisation. And, as our study shows, they possess the potential to do much more in the global battle to actively reduce carbon emissions.

The challenge is, of course, easier to say than do. But it is achievable if a collective effort across the space sector is made to make everyone aware of space's full potential. We must share our successes. We must show our progress every step of the way. We must wake up the world to what this amazing technology can do. Before it's too late.

MARS' LAUNCH ANNOUNCED

As part of a new initiative to encourage companies and governments to curb GHG emissions, the United Nations Environment Programme (UNEP) announced on the 11 November 2022, the launch of a public database of global methane leaks detected by satellites.

The Methane Alert and Response System (MARS) will build on the Global Methane Pledge signed in 2021 by 119 countries to cut methane emissions by 30% this decade.

MARS will use existing space satellites to spot methane plumes around the globe and identify the company or government responsible.

The initiative is to be funded by the United States and European Union governments, as well as private organisations, including the Bezos Earth Fund and the Global Methane Hub.

NET ZERO BY 2050

UNDERSTANDING THE TRUE VALUE OF SATELLITE COMMUNICATIONS

The question at the heart of this report is simple: **how much CO_2e can be avoided, restricted, or reduced using satellite communications-enabled technology?**

We applied that question to three sectors that together are responsible for circa 60% of all current global emissions and put it in the context of three different scenarios:

- **Scenario 1:** quantifies the current reduction in emissions using existing satellite communications technologies.
- **Scenario 2:** calculates the untapped potential of existing satellite communications technologies assuming full market adoption.
- **Scenario 3:** forecasts the future decarbonisation impact of nascent satellite communications technologies, at full adoption.

In simple terms, our analysts ascertained **'the present', 'the possible' and 'the potential' value of satellite communications in the race to meet Net Zero by 2050.**

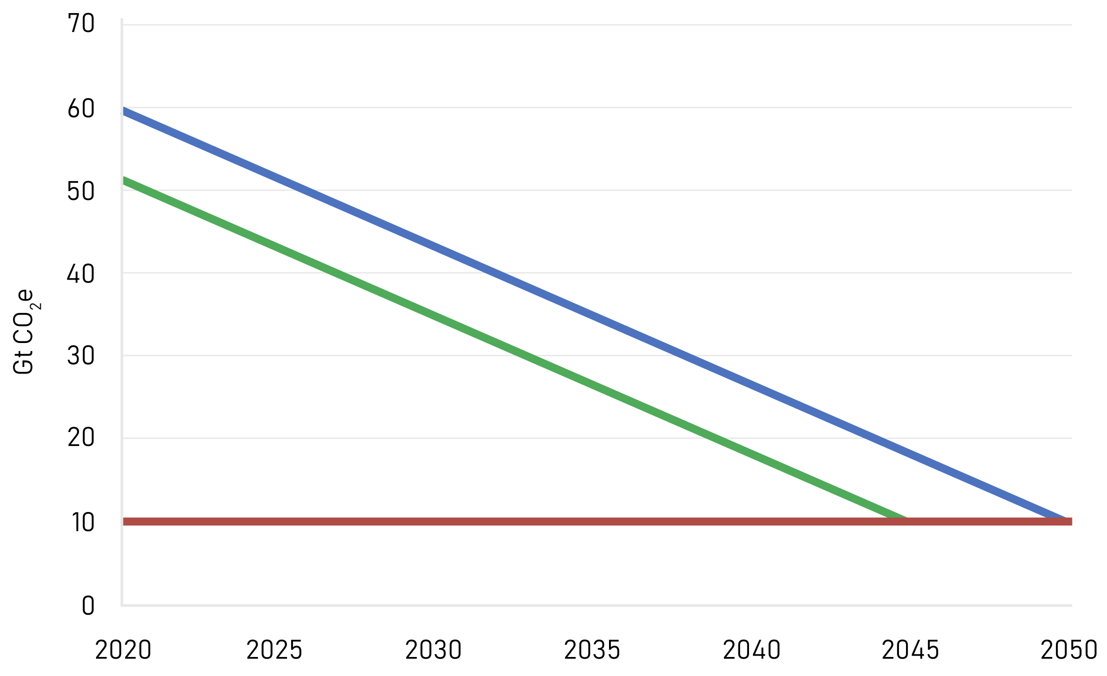
They established that:

- Today's satellite communications-enabled emissions savings represent **2.5% of total GHG emissions.**
- Further deployment of current technologies would make it possible to achieve **9% reduction** of these emissions.
- Widespread adoption of current and nascent technologies could **cut emissions up to 18%.**

Those three percentages show the substantial impact of satellite communications technologies on the global process of decarbonisation between now and 2050. But what does that mean in terms of measurable progress?

HOW TO BEAT NET ZERO BY 5 YEARS

When the gigatonne savings explored in our study are applied to the IPCC's projections, quite a startling narrative unfurls. The full adoption of technologies in scenarios 2 and 3 would allow us to step up the pace and gain time on the road to decarbonisation, beating Net Zero 2050 targets by about five years, as shown by the green line in the graph below.



🔵 The decarbonisation rate required to meet IPCC's 'best scenario' to meet Net Zero by 2050.

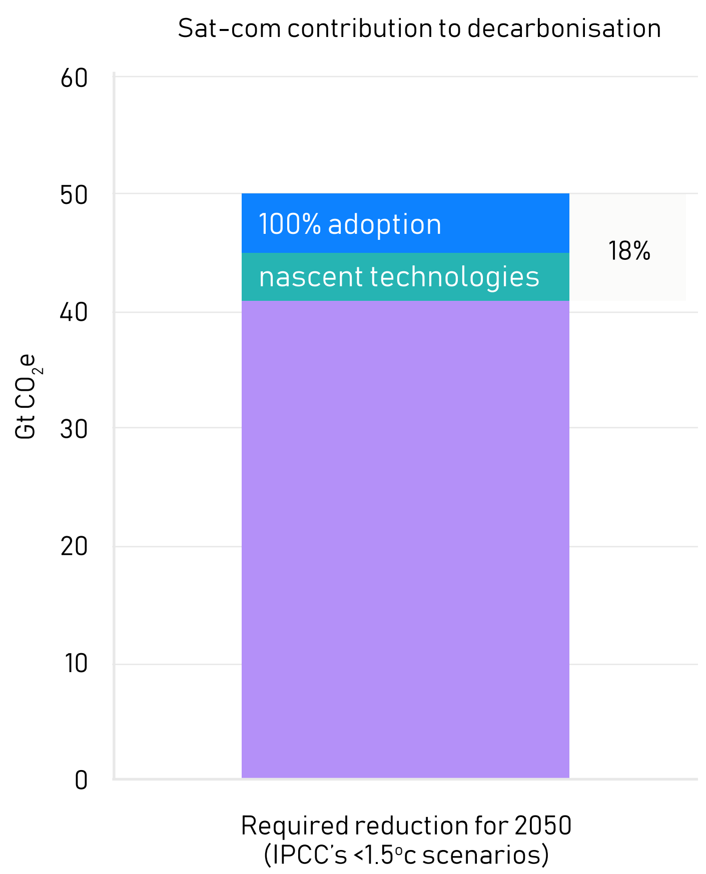
🟢 The enhanced decarbonisation rate in scenario 3, whereby satellite communications technologies accelerate decarbonisation by five years.

🔴 The median of the irreducible amount of carbon in 2050. Global net emissions estimated by IPCC's < 1.5 ° C scenarios for 2050 are between 1 and 15 Gt CO$_2$e with a median value of 9 Gt CO$_2$e.

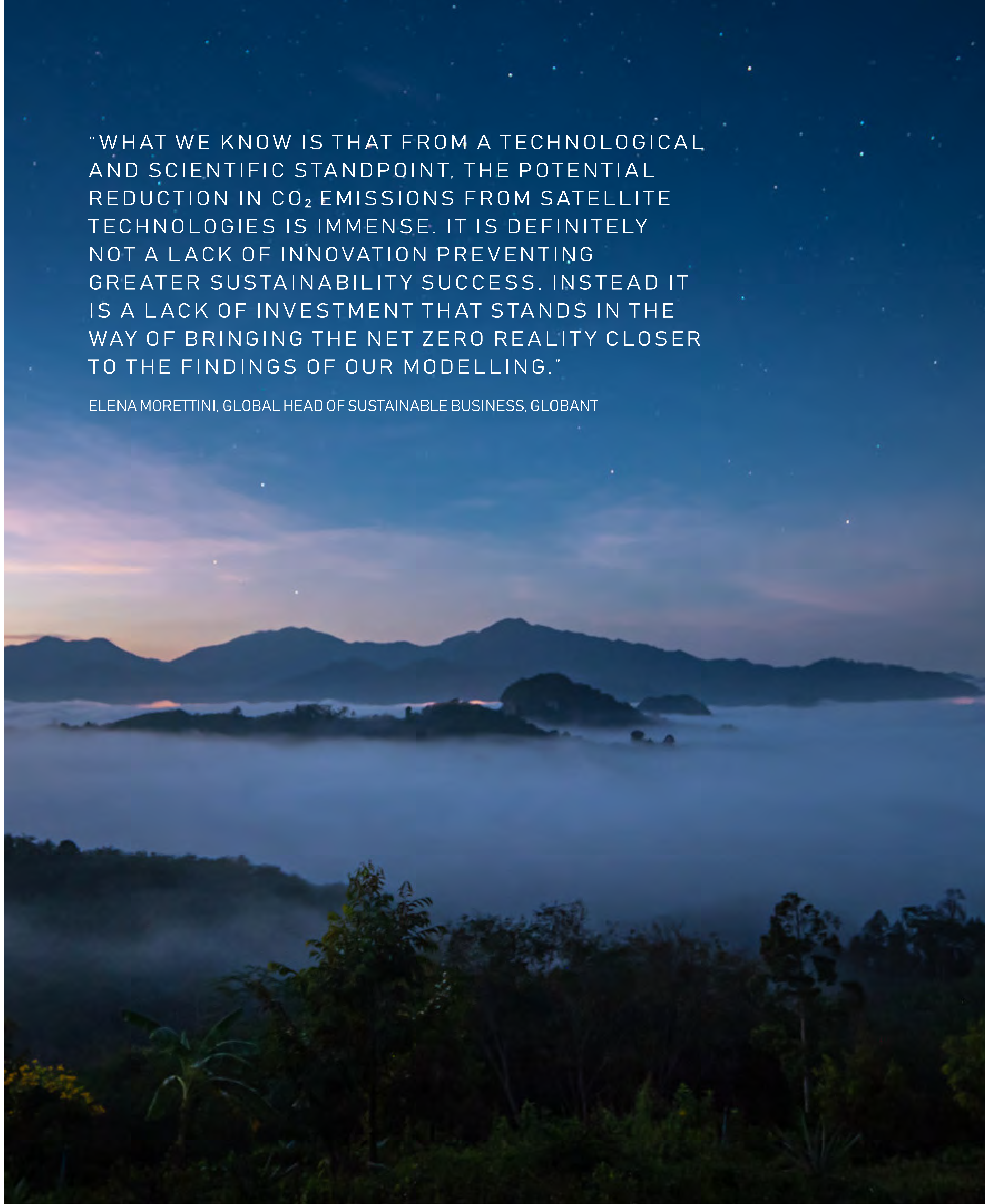
But the good news doesn't stop there. In scenario 3, 8.8 gigatonnes is avoided, that is 18% of the reduction that is needed to limit global temperatures to 1.5C.

When we start to look at the effect of making that reduction sooner rather than later, the picture evolves.

If technologies in scenarios 2 were fully deployed before 2030 and technologies in scenario 3 were fully deployed before 2040, **we could reach Net Zero by as early as 2040 – 10 years ahead of schedule**. While that is highly ambitious, it demonstrates the magnitude of effect satellite technology can have on CO$_2$ emissions. It demonstrates that with investment and commitment, climate change can in theory be fought effectively.



To meet IPCC's <1.5 °C goal by 2050, current emissions must be reduced by 50 Gt CO$_2$e by 2050. Together Scenarios 2 and 3 enable 8.8 GtCO$_2$e (18%) of the required reduction.



> "WHAT WE KNOW IS THAT FROM A TECHNOLOGICAL AND SCIENTIFIC STANDPOINT, THE POTENTIAL REDUCTION IN CO$_2$ EMISSIONS FROM SATELLITE TECHNOLOGIES IS IMMENSE. IT IS DEFINITELY NOT A LACK OF INNOVATION PREVENTING GREATER SUSTAINABILITY SUCCESS. INSTEAD IT IS A LACK OF INVESTMENT THAT STANDS IN THE WAY OF BRINGING THE NET ZERO REALITY CLOSER TO THE FINDINGS OF OUR MODELLING."
>
> ELENA MORETTINI, GLOBAL HEAD OF SUSTAINABLE BUSINESS, GLOBANT

THE RESEARCH REVEALS WE NOT ONLY ALREADY HAVE THE TECHNOLOGY NEEDED TO ACCELERATE PROGRESS TOWARDS OUR 2050 GOALS, BUT ALSO THAT WE CAN BEAT THEM.

Qualifying the calculations

The ability to hit these percentages is based on the assumption of the 'full deployment' of scenarios 2 and 3. **There are three considerations that could counter that assumption:**

1. The infrastructure necessary to fully deploy nascent technologies doesn't currently exist.
2. The study assessed 60% of global emissions for 2019. The base error for calculation is plus or minus 11%. In other words, the figures could be better than calculated. But they could also be worse.
3. It's unlikely that any sector will achieve 100% deployment.

Recognising the real benefits

Nonetheless, even if we accept all those caveats and take a much more conservative estimate of 50% deployment, the resulting emissions reduction would be 9%.

That would still be very good news. Because now we not only know that we've got the technology needed to accelerate progress towards our 2050 goals, but also that we can beat them. Furthermore, we know that there's innovative new satellite technology on the way that can deliver more reductions at even greater speed.

So, however you look at the figures, the value of space cannot and must not be ignored. **Satellite-enabled decarbonisation is a key driver in reaching our climate goals**. Which is why satellite communications technology should be protected from everything – from a lack of investment to an abundance of space debris – that might impede its progress.

THE CHALLENGE: MAINTAINING A HEALTHY ORBIT

For satellites to enable these decarbonising technologies, they must be able to operate in Earth's orbits over the long term. Therefore, the health of Earth's orbits is a key consideration, and on our current course we are placing it in jeopardy.

As we edge into the era of a new space race, humanity is accelerating its expansion into space. There are around 100,000 launches already proposed as part of active projects up to 2030.

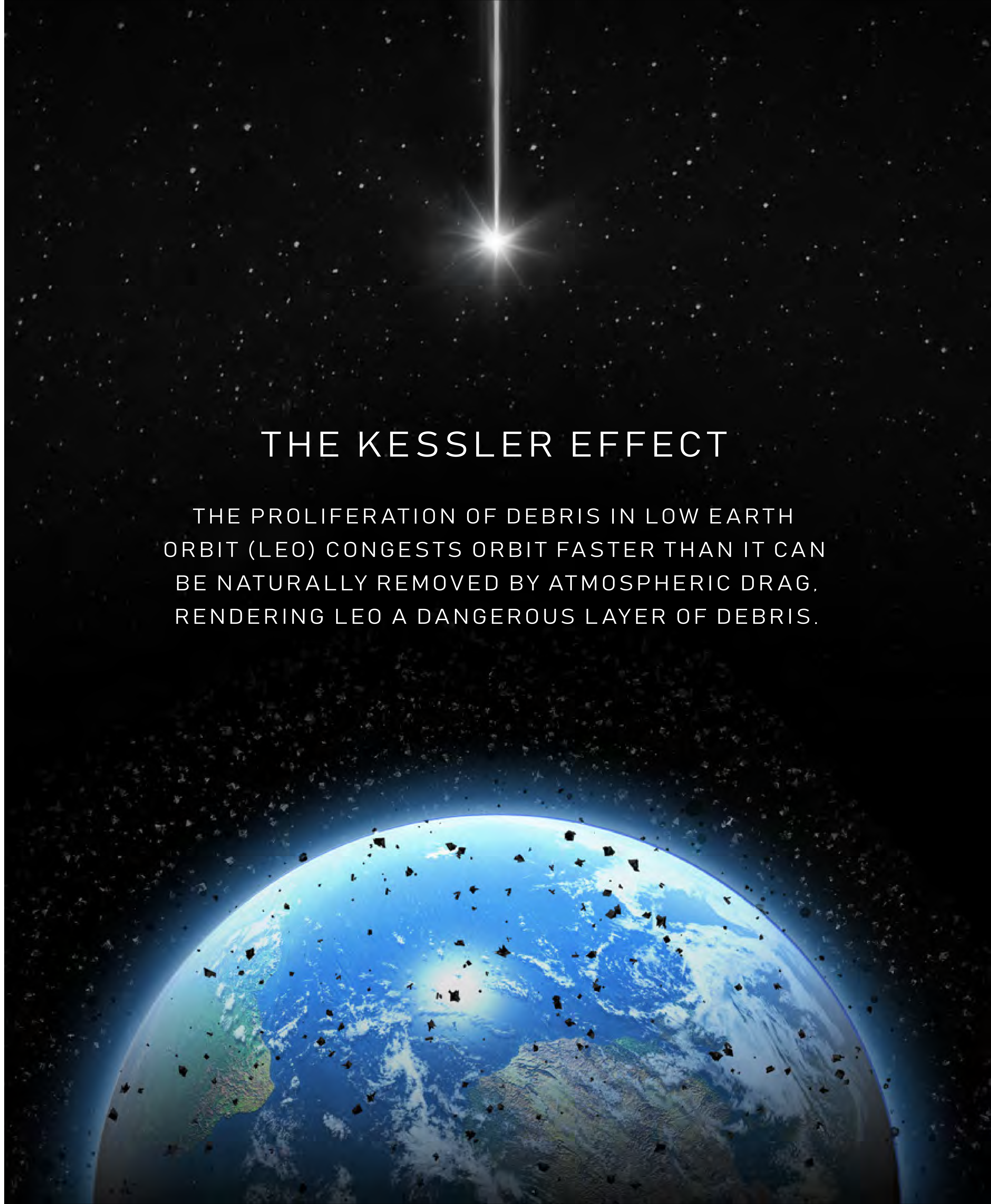
The lack of co-ordinated regulation, monitoring and management could lead to a level of expansion that might change space from an enabler of Net Zero on Earth into yet another threat to our environment.

A mega problem

In the last decade, space has seen the uncontrolled growth of new 'mega-constellations' increase the risk of satellite failures and collisions.

Mega-constellations are mass-produced satellites which are quickly becoming the main constituent of the discarded equipment debris that orbits our planet. A dangerous hazard on our course to Net Zero.

This could accelerate the 'Kessler Effect' and render low Earth orbit (LEO) unusable.



THE KESSLER EFFECT

THE PROLIFERATION OF DEBRIS IN LOW EARTH ORBIT (LEO) CONGESTS ORBIT FASTER THAN IT CAN BE NATURALLY REMOVED BY ATMOSPHERIC DRAG, RENDERING LEO A DANGEROUS LAYER OF DEBRIS.

SPACE DEBRIS CAN TRAVEL AT UP TO SIX TIMES THE SPEED OF A BULLET, RESULTING IN HUGE DAMAGE TO SATELLITES, SPACE STATIONS AND MORE.

The wave of new entrants are focused on building LEO mega-constellations, which combined will eventually amount to hundreds of thousands of spacecraft. There is insufficient internal or external pressure on these companies to explain how their satellites can be responsibly disposed of if they fail after launch, in orbit, or when they reach the end of their operational lifetimes.

Although there are movements in the right direction (such as the Space Bureau proposed by the USA's Federal Communications Commission), there are no formal mechanisms or legal requirements for satellite operators to communicate with each other in a crisis. We believe this requires a global approach under the aegis of the UN.

The damage debris can do

Debris is such a huge issue because of its size and speed. Usually, debris is small enough to be almost undetectable – and can travel at speeds of up to 17,000 kph. Compare that to a bullet from a modern rifle travelling at around 2,800 kph. Which means that space debris can travel up to six times faster than a bullet, resulting in huge damage to satellites, space stations and more.

The overpopulation of LEO will see a rise in orbital exclusion, where operational planes of orbit are simply too congested to add more satellites. Overpopulation could even make it too difficult to navigate through one operational plane or to access others beyond it. And that would make it harder to implement and run decarbonising technologies in space.

Satellite operators of all types from various countries are operating with incomplete and inaccurate data resulting from an absence of international standards in object characterisation, cataloguing and broader modelling assumptions.

Consequently, there's considerable concern about the mid to long-term usability and sustainability of Earth's orbits. Current Space Situational Awareness (SSA) and Space Traffic Management (STM) lacks adequate technical capabilities, interoperable standards and regulatory tools.

Bringing sustainable order to space

As it stands, the space community is not a good steward of the domain in which it operates.

This new frontier is essentially a 'Wild West'. New practices, such as monopolising orbits, are putting space operations at risk.

Clearly, the way space – and its relationship to Earth – is viewed must change. Space environmentalism is a cultural mindset that should be at the heart of all satellite operations, with the aim of using this vital domain with consideration for other users and for future generations.

WITHOUT SUSTAINABILITY IN ORBIT THERE CAN BE NO SUSTAINABILITY ON EARTH

However, global regulatory action is moving too slowly on the space issues confronting the sector. New standards are desperately needed. And they are needed now.

The ethos of next-generation orbital management must be grounded in an international approach. Global action between governments and international institutions is required to ensure appropriate policies are developed to enable continued safe, reliable and equitable access to all orbits, for all systems, from all nations.

Think of it as a 'coalition of the willing', established at the highest political level among participating countries, to commit collectively to shared principles, regulations and coordinating mechanisms for safe space operations and orbital development.

If done properly and implemented alongside Environmental, Social and Governance (ESG) principles, space sustainability can expose commercial or governmental operators who might be merely green labelling their activities in orbit.

That's why Inmarsat's position is that, in the long term, the International Telecommunications Union (ITU) should be given a broader mandate and resources to take on space sustainability unilaterally.

At the multilateral level, countries with the largest footprint in space should come together to agree basic standards. In addition, all national regulators should require all operators looking to provide services on their soil to sign up to conduct themselves in a responsible way.

Space environmentalism should be at the heart of all satellite operations, with the aim of using the domain responsibly and with consideration for other users and future generations. Because without sustainability in orbit, there can be no sustainability on Earth.

MAKING A DIFFERENCE WHERE IT MATTERS MOST

We have established that satellite communications make a clear decarbonising impact. A staggering 1,500,000,000 tonnes (1.5 gigatonnes) is being removed or avoided today. What's more, if the same satellite communications-enabled technologies are more widely adopted, a total of 5,500,000,000 tonnes (5.5 gigatonnes) of CO_2 emissions could be avoided. This should be cause for significant optimism.

It is especially notable that satellite communications-enabled decarbonising technologies are available right now, and applicable to sectors that face large challenges to reduce their emissions.

Industries like Maritime, Energy Transmission and Aviation face the challenge of growing to meet demand while reducing their emissions. To this end, there are multiple options – such as sustainable fuels – to pursue. But their time horizons are far in the future. Many do not exist in a commercially viable way and will require investments of hundreds of billions, perhaps even trillions, of dollars to build the new infrastructure needed.

And while satellite communications alone cannot reverse climate change, they do offer us a set of tools to mitigate the carbonising effects of industrial growth. Not *potential* tools, or ones which *may* be useful in future. Tools that exist *today* and ones we know exactly how to use.

Such is the pace of development that there are now nascent satellite communications technologies that can complement the long-term drive towards Net Zero. Together with 100% adoption of existing technologies, these nascent technologies could remove 8,800,000,000 tonnes (8.8 gigatonnes) of CO_2.

In the meantime, what can we all do to deliver progress?

This report has set out several agendas to help the private sector approach our most important climate change-related challenges. Crucially, they explain why we must help keep IPCC targets from slipping and fill the gap where governments cannot coordinate action, as was made apparent at COP27.

Although the scenarios we gave for 2050 were illustrative, they show that – even given the most conservative estimates for technology adoption – the value of space as a driver of decarbonisation cannot be ignored. In fact, it is vital.

At COP27 it was clear that, although space technology is not being ignored entirely, it certainly is being underestimated. And therefore under-utilised.

The contribution we can make to Net Zero is much more than decarbonising satellite technology. And it's even more than using that technology to observe GHG emissions and extreme weather events. It's also about how satellite-enabled technology can *actively* help decarbonise operations and processes to a greater or lesser extent across all industries. From telemetry in shipping to optimising flight routes, space has a major role to play. We must tell the world about it.

And we should now act as a united, responsible industry to ensure space sustainability. Without sustainability, all the potential we've shown here could come to nothing, with orbits made unusable by our own space debris. An own goal that must be avoided at all costs.

In short, it is the space sector's job to pursue an awareness campaign for space. One that communicates, clarifies and empowers the decarbonising capabilities of satellite-enabled technology. This is essential if we want to realise the massive potential that this study suggests.

FIVE STEPS FOR THE SATELLITE COMMUNICATIONS SECTOR

1. KNOW OUR NUMBERS

Space sector businesses must work more effectively to gather the data and quantify their potential contribution to customer decarbonisation goals. Clear, credible and consistently articulated evidence will be the cornerstone of customer adoption.

2. ELEVATE THE SUSTAINABILITY NARRATIVE

Terrestrial sustainability has been a minor sub-plot in the satellite communications sector's commercial narrative. Customer priorities are changing. Net Zero goals are now at the top of global business and government agendas. The satellite communications value proposition needs to reflect this new focus, and the industry needs to do a better job of raising awareness of its handprint role.

3. ACCELERATE A POSITIVE REGULATORY ENVIRONMENT

The industry must work with policymakers and regulators to ensure the context of decision-making is weighted in favour of adopting greener solutions. Commercial goals cannot be allowed to conflict with decarbonising benefits. This may include accelerating supportive regulation or mandating or incentivising adoption.

4. RECOGNISE OUR OWN RESPONSIBILITIES

The ambition to enable customer decarbonisation must be matched by a similar commitment to reduce our own sector's environmental impact. One is simply not credible without the other. This requires investment in identifying, setting, and meeting science-based targets for Scope 1 and Scope 2 emissions[1], audited by creditable third parties and regularly reported.

5. BE BETTER STEWARDS

The space community must be a better steward of the domain in which it operates. To play our part we must be able to operate effectively in orbit. That means behaving responsibly, with common benefit as the shared goal. And it means adopting a more honest and realistic mindset, not wishfully (or even misleadingly) contending everything will work out well. Environmental challenges in outer space have traditionally been assumed to be insulated from environmental problems on Earth. Today we are beginning to understand otherwise. This report establishes, for the first time, the scale of the risk.

INMARSAT'S COMMITMENT TO SUSTAINABILITY

In 2021, Inmarsat CEO Rajeev Suri, called for a 'Net Zero' equivalent for space to ensure the sustainability of the industry and the benefits it brings to people on Earth: "We cannot drive space growth in an unsustainable way. We talk about Net Zero on Earth. I am calling for the equivalent to Net Zero for space."

This will require:

- Improved tracking and data sharing between space operators to reduce the probability of collisions and space debris, making space operations safer and more reliable.
- The implementation of operational norms of behaviour.
- A greater focus by regulators on the impacts on the environment of burning up LEO satellites in the atmosphere and on ensuring responsible space operations in that orbit.

As an organisation founded to deliver life-saving satellite communication services, we have a responsibility to protect the planet through sustainable operations. We take great care to effectively harness the Earth's resources – both on the ground and in space. We continuously seek to further reduce our global CO_2 emissions and energy consumption across all our operations.

The space industry, including Inmarsat, is always innovating and looking at ways to reduce the environmental impact of satellites and launches. Today, many rockets are fuelled by liquid oxygen and liquid hydrogen, which has zero environmental impact on the atmosphere. For example, the rocket used to launch our I-6 F1 satellite in 2021 only relied upon solid combustible fuel for 128 seconds of the rocket's 26-minute journey. In addition, our new generation of satellites feature all-electric propulsion systems for orbit raising. Powered by a non-combustible liquid air propellant called Xenon, it has limited environmental impact on the atmosphere in space.

Our commitment to place sustainability at the heart of our operations means that we are dedicated to finding new and innovative ways to minimise our energy usage and create efficiencies in our business, such as sustainable procurement. Choosing to do business with a sustainably ethical company is not just important to Inmarsat, it is important to our customers and partners too. And we expect the same commitment from them.

Together with our sustainability partner, Carbon Intelligence, we annually quantify emissions from our direct and indirect activities, engaging with the suppliers and customers in our value chain to set meaningful emissions reduction targets.

Inmarsat is the first satellite communications company to have its near-term science-based emissions reduction targets approved by the Science Based Targets initiative. The SBTi is a joint initiative by CDP, the UN Global Compact, the World Resources Institute and WWF.

We have committed to a 1.5°C aligned Scope 1 and 2 target, reducing emissions by 64% by 2030 and reducing our Scope 3 emissions in line with well-below 2°C pathway, by reducing 28% by 2030.

We are also developing a long-term Net Zero target aligned to the SBTi, aiming for emissions reductions of at least 90-95% by 2050.

With the current climate emergency requiring urgent climate action, SBTi is working with companies across the world to halve emissions before 2030 and we welcome their support in helping us set ambitious emissions reduction targets in line with the latest climate science.

> "WE CANNOT DRIVE SPACE GROWTH IN AN UNSUSTAINABLE WAY. WE TALK ABOUT NET ZERO ON EARTH. I AM CALLING FOR THE EQUIVALENT TO NET ZERO FOR SPACE"
>
> RAJEEV SURI, CEO INMARSAT

INMARSAT'S COMMITMENT

Inmarsat is proud to be:

- A founding member of the Space Data Association (SDA), along with satellite operators Intelsat, SES and Eutelsat. By sharing critical data on satellite positions, we aim to reduce the probability of collisions and manage the increase of space debris to make space operations safer and more reliable.
- One of the first members selected for the Commercial Integration Cell (CIC) at the Combined Space Operations Center (CSpOC). Together, SDA and CSpOC are the two main sources of information for tracking debris, collision avoidance and space situational awareness.
- A member of the UK CIC which works with the UK Space Agency to address the needs of civil users of Space Surveillance and Tracking (STT) services through the UK's national capability.
- A member of the Space Safety Coalition (SSC), endorsing and adhering to its 'Best Practice on the Sustainability of Space Operations'.
- A member of Global Satellite Operator's Association (GSOA), working with the satellite industry to deliver sustainable connectivity solutions. Our CEO Rajeev Suri was appointed as Chair of this Association in March 2022.
- Part of the International Organization for Standardization's (ISO) committee for the development of standards for space vehicles and space systems and operations, as well as part of the European Cooperation for Space Standardization (ECSS) Space Debris and Space Traffic Management Working Group.

METHODOLOGY AND CONTRIBUTORS

INMARSAT

Inmarsat delivers world leading, innovative, advanced and exceptionally reliable global, mobile communications across the world – in the air, at sea and on land – that are enabling a new generation of commercial, government and mission-critical services. Inmarsat is powering the digitalisation of the maritime industry, making operations more efficient and safer than ever before. It is driving a new era of inflight passenger services for aviation, while ensuring that aircraft can fly with maximum efficiency and safety. Furthermore, Inmarsat is enabling the rapid expansion of the Internet of Things (IoT) and enabling the next wave of world-changing technologies that will underpin the connected society and help build a sustainable future. And now Inmarsat is developing the first of-its-kind, multi-dimensional communications network of the future, ORCHESTRA.

GLOBANT

Globant is a world leading sustainability tech consultancy. Fast approaching its 20th birthday, Globant work at the confluence of sustainability, engineering, design and innovation – giving them a wide diversity of experience and exposure to ideas, information and insight. Having worked with blue chip clients like Johnson & Johnson, BMW, and T-Mobile along with some of the world's foremost sustainability programmes, they represent a research partner with the experience required to undertake a project of this scale.

OUTLINE METHODOLOGY FOR DECARBONISATION MODELLING

OBJECTIVES AND SELECTED SEGMENTS

The objective of this report is to model and quantify CO_2 equivalent emission curbing and avoidance – expressed in tonnes or gigatonnes – enabled by satellite communications technology adoption and efficiencies, according to three scenarios applied to three industry sectors.

Summary of the three scenarios is as follows:

1. **CO_2 REDUCTION TODAY**
   Quantification of avoided/reduced/curbed tonnes of CO_2 or CO_2 equivalent emissions through the use and application of current satellite communications technologies at current market adoption level.

2. **POTENTIAL CO_2 REDUCTION**
   Quantification of avoided/reduced/curbed tonnes of CO_2 or CO_2 equivalent emissions through the use and application of current satellite communications technologies at maximum market adoption level.

3. **POTENTIAL CO_2 REDUCTION**
   Quantification of avoided/reduced/curbed tonnes of CO_2 or CO_2 equivalent emissions through the use and application of nascent satellite communications technologies at maximum market adoption level.

Summary of the three industry sectors is as follows:

1. **AGRICULTURE, FORESTRY AND OTHER LAND USE**

2. **TRANSPORT AND LOGISTICS**

3. **ENERGY SYSTEMS**

Altogether, these industries account for around 60% of total global emissions[7], hence providing a relevant selection of GHG emitters to reflect and exemplify satellite communications technology contributions to decarbonisation on Earth for these sectors.

In order to structure quantification efforts and modelling approaches, these three sectors have been divided into sub-sectors, which in turn are detailed according to their most relevant and contributing areas and main use cases for satellite communications technologies.

MODELLING ASSUMPTIONS

Models that quantify emissions reduction for the three selected scenarios are based on the following assumptions:

ASSUMPTION 1: SOURCES OF DATA
In order to estimate reliable and rigorous baselines and base figures throughout the model, a thorough source analysis and selection was conducted amongst the most well established and internationally recognised sources for each industry (e.g. IEA, IPCC, UNFCCC, etc.). This selection is ultimately subject to the authors' decision-making criteria based on expertise and consulted industry experts' inputs and crosschecks.

ASSUMPTION 2: ADOPTION CALCULATIONS
Both Scenarios 2 and 3 push satellite communications technology adoption to the limit; this limit was not analysed in respect to true physical and numerical limits, but rather considered under potential application aspects of the same technology.

ASSUMPTION 3: ADOPTION TIME FRAMES
Scenarios 2 and 3 do not consider time dependency; variables embedded in the calculation of technology adoption level do not include time.

ASSUMPTION 4: BUILDING-UP ERROR
As stated in the introductory paragraph on global emissions, IPCC estimations of net anthropogenic GHG emissions imply an embedded estimation error of 11%. This base error will be carried on throughout model calculations and may not be removed nor mitigated. Moreover, for each sub-sector, the fittest source of information is used for baseline calculations of emission reductions. Such a variety of sources can change the carried-on percentage of error leading to small differences in final results. The IPCC and International Maritime Organization (IMO) estimates for CO_2 or CO_2 equivalent emissions, for example, are different, yet falling within the range of errors previously mentioned. Averaged values will also embed the initial 11%, increasing differently for each sub-sector. For each sub-sector specific ranges of values are always reported.

ASSUMPTION 5: DECIMALS
Numbers are always reported to one significant decimal place. If no decimal places are noted, a 0 is implied, with the exception of the Road and Aviation industries, where two decimals are needed to account for decarbonisation improvements.

ASSUMPTION 6: TOTAL MARITIME FLEET
For Maritime sub-sector calculations, the IMO global fleet was considered, also including passenger transportation and yachts. Nonetheless, non-IMO registered ships fall outside of calculations leading to a potential under estimation of emissions.

ASSUMPTION 7: FUEL CONSUMPTION AND EMISSIONS
CO_2, NOx, SO_2 and CO_2 equivalent emissions are directly proportional to fuel consumption through emission factors. It is assumed that reduction in fuel consumption is equivalent to a reduction in emissions. However, fuel consumption is not the only source of these compounds.

ASSUMPTION 8: TIME UNIT
Where not stated or specified, the estimated tonnes or gigatonnes of carbon reduction will refer to a yearly time unit.

ASSUMPTION 9: GHG EQUIVALENCY
Methane (CH4), nitrous oxide (NOx), sulphur dioxide (SO_2), and CFCs could be expressed as CO_2 equivalents, based on well-established conversion factors.

ASSUMPTION 10: AVERAGES
Satellite communications-enabled technologies may enhance CO_2e reduction in different ways and achieve different efficiencies. In this study, average values were selected for technology efficiency parameters. This could lead to underestimated/overestimated emissions from certain activities.

GENERAL MODEL EQUATIONS

Emissions excluding satellite communications:

Total of CO_2 or CO_2 equivalent emission reduction excluding satellite communications-based technology

Theoretical figures used as baseline for CO_2 reduction comparison, are calculated based on current emissions from each sector as follows :

$$Ews = E + \Delta CO_2$$

$$Ews = E + T_{eff} * T_{adop} * Ews$$

$$Ews = E / (1 - T_{eff} * T_{adop})$$

Ews = *emissions excluding satellite communications (Gt CO_2e/year)*
E = *current emissions (including satellite communications-enabled reductions, Gt CO_2)*
ΔCO_2 = *carbon dioxide emission reduction (Gt CO_2)*
Teff_i = *technology efficiency. Degree of technologies contribution to decarbonization for sector "i". % represents mass to mass ratio of CO_2 or CO_2*
Tadop_i = *combined technologies adoption level or market adoption in sector "i" (%).*

Total satellite communications-enabled CO_2 emissions reduction:

$$\Delta CO_2 = \sum_{i=1}^{N} \delta_i CO_2 = f(T_{eff\_i}, T_{adop\_i})$$

N = *Number of analysed sub-sectors = 7*
δiCO_2 = *satellite communications-enabled achievable reduction of carbon dioxide emission per sector i (Gt/year).*

Sector "i" satellite communications-enabled CO_2 emissions reduction:

$$\delta_i CO_2(t) = E_i(t) * T_{eff\_i} * T_{adop\_i}$$

(simplified expression)

$$\delta_i CO_2(t) = E_i(t) * \left[1 - \prod_{q=1}^{Q} \left(1 - T_{eff_{iq}} * T_{adop_{iq}}\right)\right]$$

(full expression)

Ei = *Sector "i" CO_2 emissions (Gt/year), excluding sat-com reduction.*

The emissions of each sector (Ei) were disaggregated to identify the CO_2 emission reductions specifically enabled by satellites (δiCO_2).

Total satellite communications-enabled CO_2 emissions reduction (ΔCO_2) is the sum of each sector's curbing or avoidance. Also, each sector's maximum achievable reduction is related to the use and/or implementation of different technologies (a Q number of technologies), with different efficiency metrics combined in a parameter named "T_{eff}" under different market adoption levels (parameter named "T_{adop}").

TECHNOLOGY EFFICIENCY

Each technology enables a certain amount of CO_2e reduction. When two or more services/technologies interact by competing to reduce emissions of the same reference activity, their individual effects cannot simply be added. Once one modification has been applied, the next one has only a smaller footprint left to modify, the third one an even smaller one, and so on. The aggregated effect of Q technologies (1, 2...Q) modifying the same reference activity must then be computed via the residual footprint of the original reference activity after applying each modification.

TECHNOLOGY ADOPTION

Each technology adoption by end users differs among analysed sectors. Satellite communications technologies adoption across sectors may be estimated between 30% to nearly 100% [4,5,13]. Specific values for Tadop were selected by our experts based on state-of-the-art literature and trustworthy entities for each sector and sub-sector. The adoption level selected approach and/or calculation procedure is specified for each case. In respect to scenario 2 technology's adoption level, no limitations were considered to the expansion of satellite communications solutions.

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