Submission: New Zealand Methane Target Review

To: The Ministerial Advisory Panel on Biogenic Methane

From: 9(2)(a)

Affiliations: Methane Science Accord member, member of Federated Farmers (Auckland), and researcher of the Greenhouse Gas Effect and Climatic Variability.

This is a personal submission and on behalf of The Methane Science Accord.

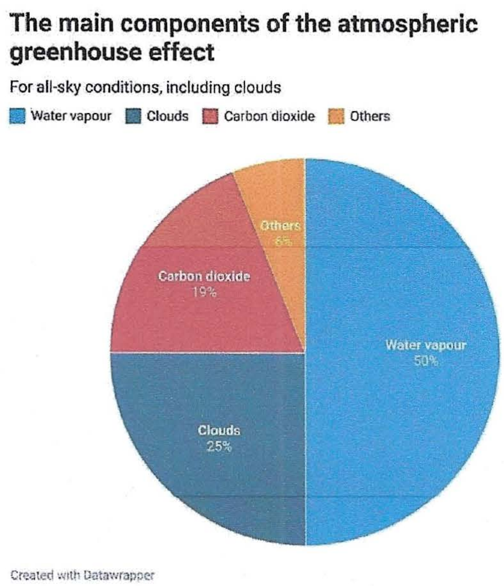
This submission covers generalised points and context for the scientific review of New Zealand's Methane targets.

A summary of the submission is also included.

A Methane Target Review based on measurable, quantifiable warming is welcomed.

Total Global Methane GHG Effect Contribution

It is important to assess natural as well as anthropogenic GHG's when determining warming targets for any greenhouse gas. Natural cycles contribute, and detract from atmospheric concentrations of Greenhouse gases and in particular methane, given methane levels are particularly susceptible to regional rainfall variation. With over 10 sources of methane (natural and anthropogenic) it is essential to quantify each source and its contribution rate (if any) to atmospheric methane levels to determine which methane sources should be targeted



NATURAL AND ANTHROPOGENIC – All Greenhouse gases

Water vapour plays a significant role in Earth's natural greenhouse effect. [Adapted from Trenberth (2022)](), [CC BY-SA]()

It is important to note that water vapour /clouds accounts for around 75% of the Greenhouse Gas Effect, and Carbon Dioxide 19%.

The GHG Effect is a factor of the GHG concentration and its ability to absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds.

Methane, Nitrous oxide, and Ozone combined contribute (scientific papers vary) around 6% to the GHG Effect.

If Methane is 66% [1] of the combined "Others"6% **then methane is 4% of the overall natural and anthropogenic GHG Effect**, with Carbon Dioxide 19%.

- **Methane (natural and anthropogenic) globally contributes approximately 4% to the overall Greenhouse Gas Effect.**

New Zealand's Methane GHG Effect Contribution

GHG PROFILE	Global % GHG Effect	Ruminants Source %	NZ's % of global ruminants [3]	**NZ Ruminants % of the GHG Effect**
Methane	4%	14.00%	**1%**	0.0056%

Assumes that all sources of methane are contributing equally to increaseing atmospheric CH4 levels

The focus for NZ's target is the increase (delta change) in methane relative to a set date, not the cumulative 0.0056%.

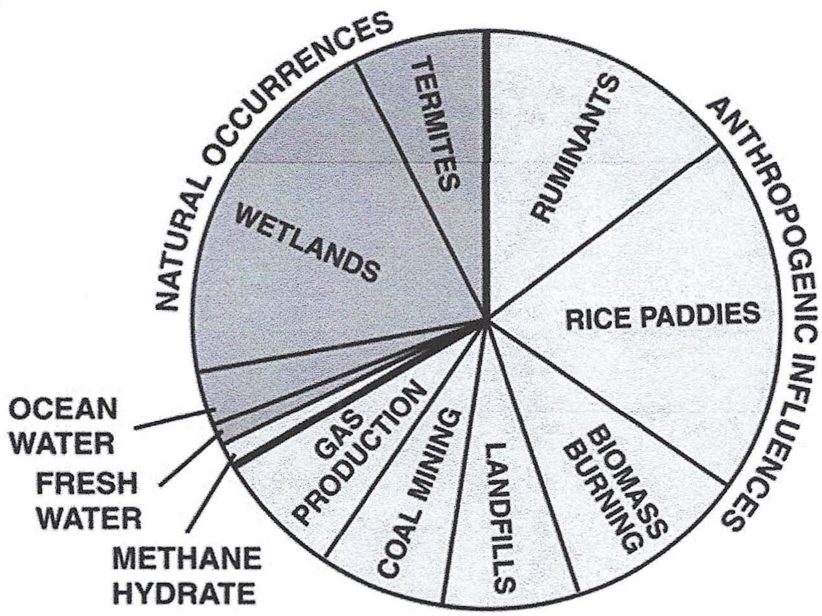
- **New Zealand's methane emissions make up less than 0.006% of the global GHG effect.**

New Zealand's Unique Biogenic Methane Profile

- Globally, methane comes from 11 different sources and these vary from natural sources through to anthropogenic (natural cycle based) and anthropogenic (fossil fuel based).
- Identifying which of these sources are contributing to atmospheric increases, and assessing the ability to influence specific sources, such as leaks from oil and gas fields, is essential for robust policy
- No other GHG has such a variety of sources.

Sources of total methane emissions into the atmosphere: Natural and Anthropogenic

https://www.giss.nasa.gov/research/features/200409_methane/



Globally Ruminants are estimated to be between 10% and 14% of global methane emissions. (or 21% of Anthropogenic Methane emissions).

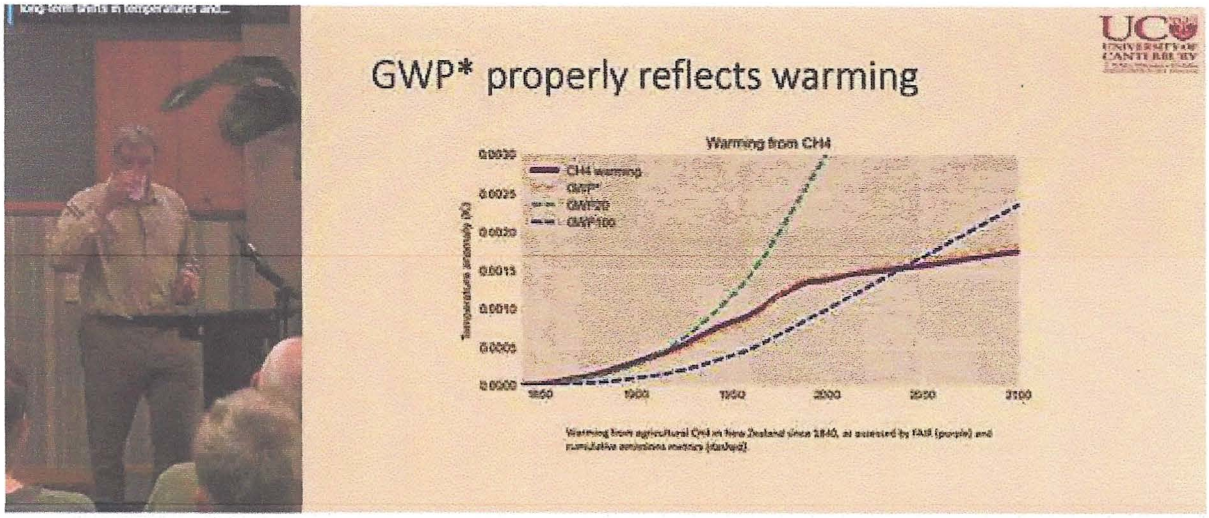
Rice paddies are 20%, and natural wetlands 21% with coal mining and gas production being a combined 15%. [2]

New Zealand is estimated to have about 1% of the world's ruminant population. [3]

New Zealand's agricultural emissions are dominated by Enteric (Ruminant) Methane based on a biological process (methane can only be emitted if CO2 has been sequestered), and produces high quality food, contributing significantly to New Zealand's GDP.

Prof David Frame has stated warming from NZ ruminants from 1850 to 2000 (150 years) was *"1.5 thousandth of a °C "* 0.0015°C/150 years That equates to *"1 thousandth °C /100 years"*, which equates to 10 millionth °C per year. This is immeasurable.

- Future warming [4] from NZ ruminants is expected based on GWP* at 4 millionth °C per year based on the graph below. This is immeasurable and a target cannot be statistically relevant.

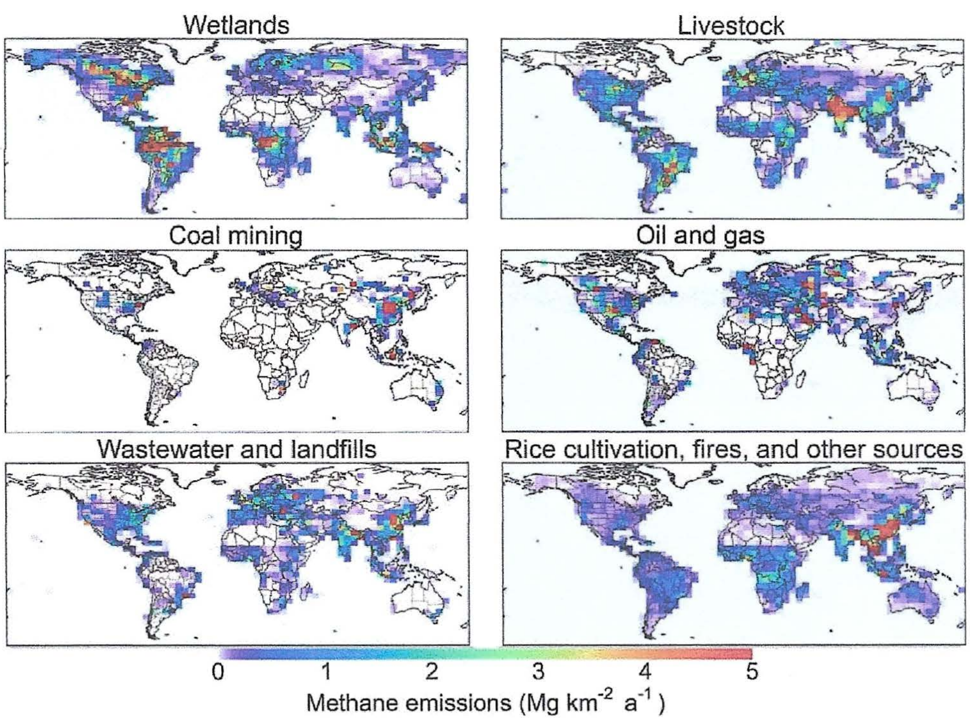


BY FARMERS. FOR FARMERS

Emissions pricing with Professor David Frame

https://beeflambnz.com/knowledge-hub/video/emissions-pricing-professor-david-frame-lets-talk-about-what-science-means-our

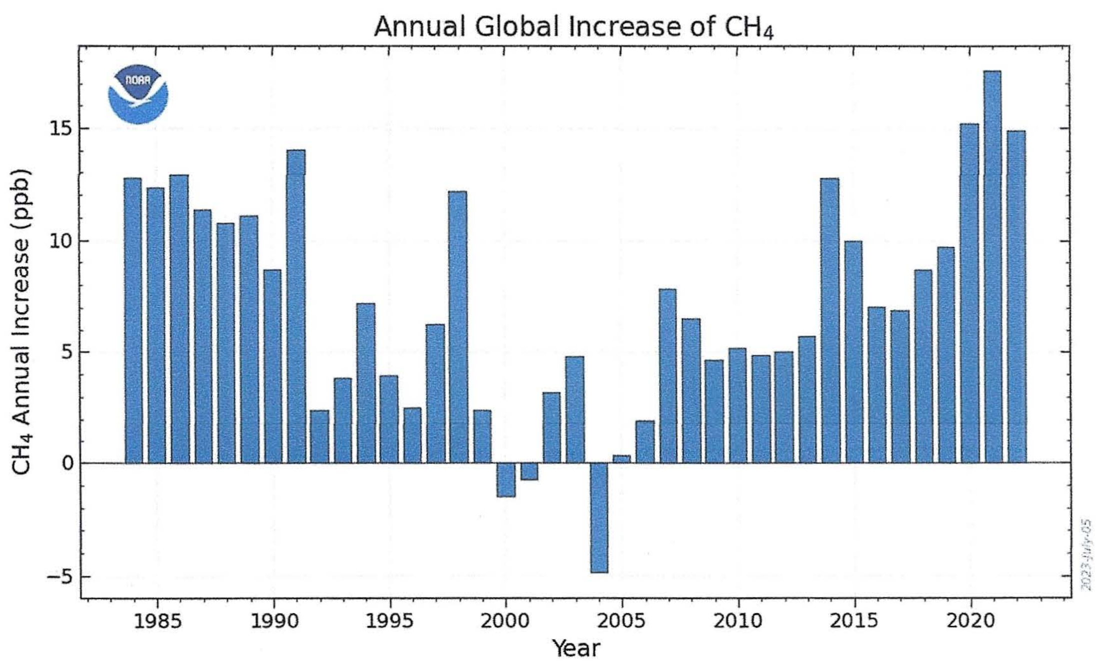
Globally each source of methane varies geographically, making quantification by source or geographical area complicated.



Global distribution of methane emissions, emission trends, and OH concentrations and trends inferred from an inversion of GOSAT satellite data for 2010–2015

To set targets it is important to quantify:
Whether the current increase is natural or anthropogenic.
Which of the individual sources are responsible for methane levels increasing.
Differentiate between anthropogenic emissions that are biological (Enteric/Ruminant) and Fossil fuel based.
Global contribution by country. (NZ's contribution).
The ability to decrease emissions without affecting food production. (Article 2(b) Paris Accord)

<u>Recent atmospheric concentration of methane. Image taken from NOAA.</u>



- Methane (CH_4) increases and decreases are not linear. The NOAA has reported fluctuations in atmospheric concentrations, with periods of decline and acceleration in recent years. These variations are heavily influenced by natural weather patterns, especially precipitation, and anthropogenic sources (source not specified).

"**The observed 2010–2015** growth in atmospheric methane is attributed mostly to an increase in emissions from India, China, and areas with large tropical wetlands."
https://acp.copernicus.org/articles/19/7859/2019

During 2019, emissions related to large positive rainfall anomalies from Sudd wetlands in South Sudan were found to be over a quarter of the growth in global emissions.
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Methane_levels_surged_in_2020_despite_lockdowns

The positive rainfall anomalies over South Sudan and Uganda **continued into 2020**. In addition to large amounts of precipitation, there was a high rate of dam releases from Lake Victoria resulting in increased water flow into the White Nile which feeds the Ugandan and Sudd wetlands.
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Methane_levels_surged_in_2020_despite_lockdowns

- **Increasing evidence shows that rising atmospheric GHG levels may also be driven by thermally-induced emissions, not just anthropogenic sources.**

"Like carbon dioxide emission, also CH4 emission increases with temperature (Fig. 12). It too is emitted by biomass (Fig. 6), chiefly through anaerobic processes that operate in well-irrigated regions like wetlands, and those influences magnify CH4 emission particularly from tropical land, where biomass and precipitation are abundant. The simultaneous intensification of CO2 emission and CH4 emission is precisely what is expected from observed warming in the tropics. ***Therefore, this single physical mechanism provides a unified understanding of the joint increase of these greenhouse gases, one that follows naturally from thermally-induced emission."***
Microsoft Word - Salby-Harde-2022-Theory-of-Increasing-GHG-Part-III.docx (scienceofclimatechange.org)

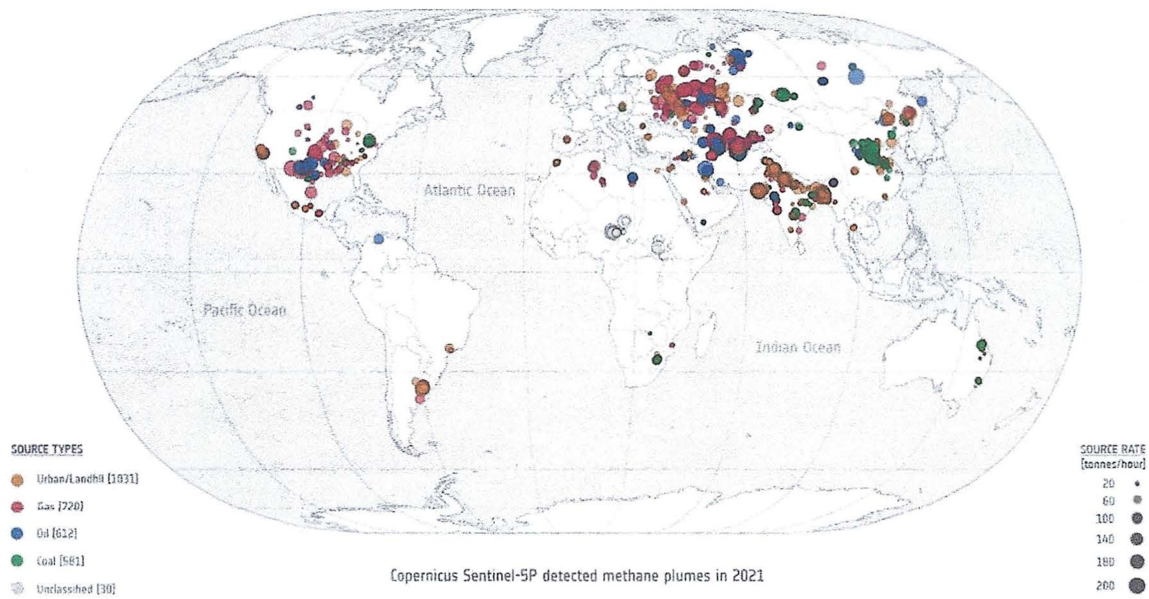
- **There is growing focus on identifying "anthropogenic super emitters" of methane, typically industrial facilities, such as oil and gas operations, coal mines, or even landfills.**

"While methane emitters refer to any source of methane ranging from natural processes like wetlands or human activities such as agriculture, methane "super-emitters" release a disproportionately large amount of methane compared to other emitters.

These are typically found amongst industrial facilities, such as oil and gas operations, coal mines, or even landfills, that have equipment or infrastructure issues leading to significant methane leaks.

These super-emitters are the low-hanging fruits in our quest to cut emissions. Fixing these super-emitters does not require complex or expensive solutions. In many cases, relatively simple repairs can result in significant climate gains.

Global Overview showing the location and magnitude of all 2974 methane super-emitter plumes detected in 2021 using the [Copernicus Sentinel-5P](https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Trio_of_Sentinel_satellites_map_methane_super-emitters) Tropomi instrument.
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Trio_of_Sentinel_satellites_map_methane_super-emitters



Copernicus Sentinel-5P detected methane plumes in 2021

Country-Specific Data?
Methane concentrations in the atmosphere are fairly uniform globally because methane mixes relatively quickly in the atmosphere. Country-specific **emissions** can vary dramatically, but **concentrations** are influenced by broader atmospheric circulation patterns and do not vary significantly on a national scale. Monitoring stations and satellites measure global and regional concentrations that are representative of broader areas rather than specific *countries*.
In summary, while atmospheric CH_4 concentrations are globally or regionally measured, they aren't typically presented country by country. Instead, you can find regional and global maps or rely on emissions data to understand each country's methane contribution to the atmosphere.

- **MethaneSAT (Future)**: Once launched, MethaneSAT will provide detailed measurements of methane emissions from specific sources, including country-level estimates of methane emissions, but this will still focus on emissions rather than concentrations.

- **Effective methane reduction targets require accurate quantification of sources and their contributions. Current data is argued to be insufficient for this purpose.**

Measuring New Zealand's Agricultural (methane/greenhouse gas) net contribution to emissions

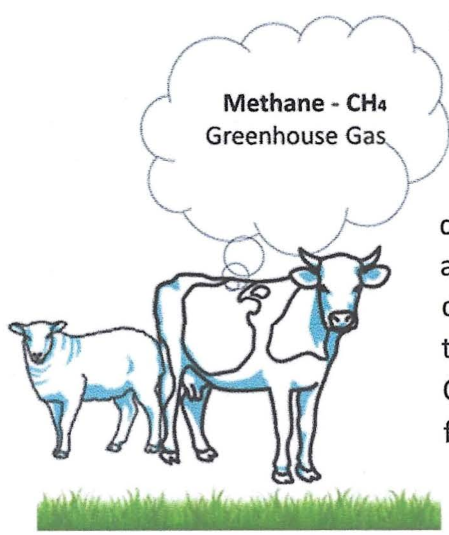
The importance of Biogenic Methane

New Zealand's agricultural emissions are dominated by Enteric (Ruminant) Methane based on a biological process (methane can only be emitted if CO2 has been sequestered), and produces high quality food, contributing significantly to New Zealand's GDP.

There needs to be a Complete Carbon Accounting: NZ pasture-based farms should, like any other company, account for all inputs and outputs, not just methane emissions. Currently, the focus is primarily on methane output from enteric fermentation, ignoring other significant factors like animal growth, progeny (which adds carbon to the animals), and the export of high-quality milk, protein, hides, and wool.

Methane emissions occur because cows consume grass, which sequesters CO_2. Therefore, for every tonne of methane produced, a proportionate amount of CO_2 should be accounted for. The current view, focusing solely on methane emissions, oversimplifies this complex carbon cycle.

Current Output View

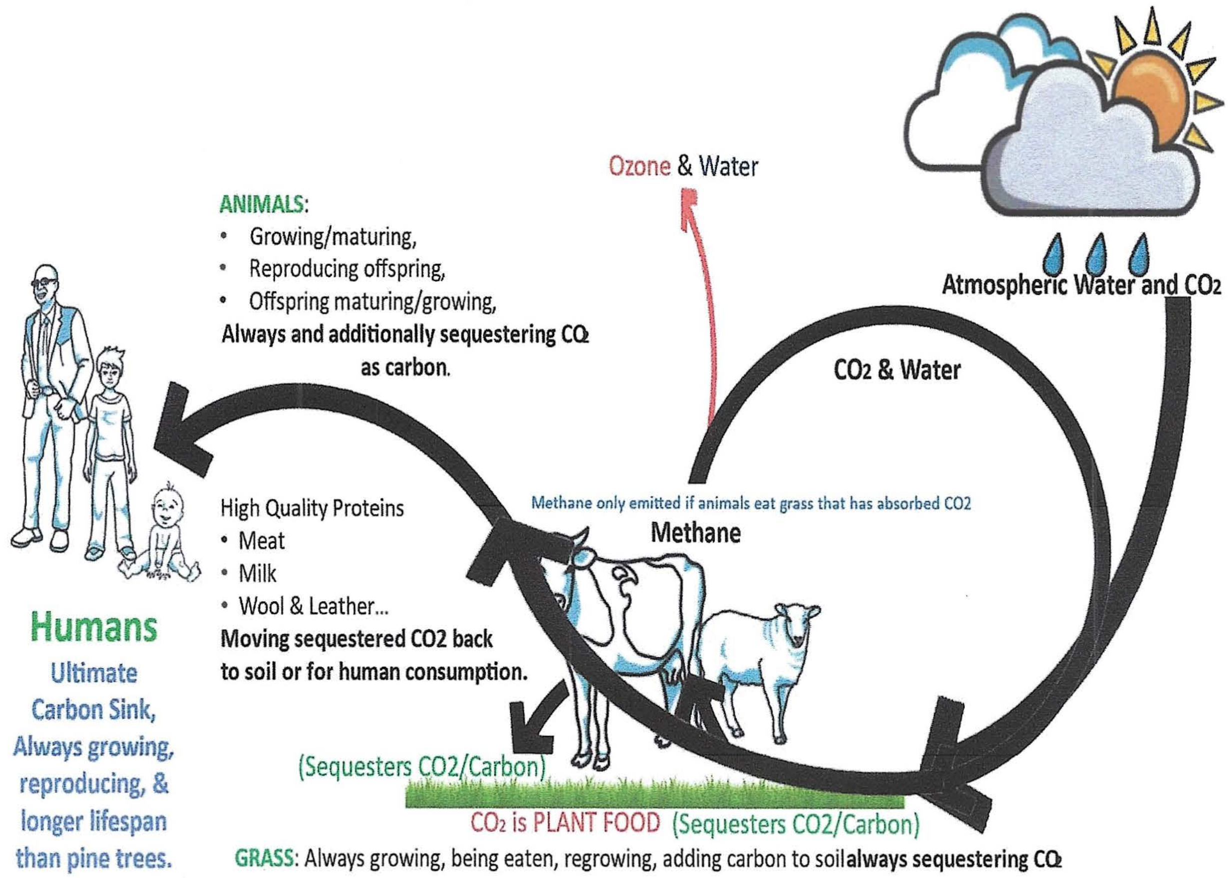


Currently the focus is simply the output of methane emissions of animals. This ignores the simple fact that Methane can only emitted if animals eat grass which sequestered CO_2.

Methane production occurs only because the rumens digestive microbe's breakdown grass that generates hydrogen and CO_2 in the rumen. The hydrogen combines with carbon dioxide (CO_2) to form methane (CH_4). Therefore, for every tonne of methane produced, an equivalent input amount of CO_2 must be accounted for. In practice, one could consider if for every tonne of methane produced, 2.75 tonnes of CO_2 should be subtracted from the inventory.

Complete Input and Output View

- **The current approach of focusing solely on methane emissions from livestock is overly simplistic and does not capture the full environmental impact of New Zealand's pasture-based farming system. Like any other New Zealand company, our farming entities should be evaluated based on all inputs and outputs in their carbon accounting.**



Grass and Photosynthesis: Grass, like pine trees, grows through photosynthesis, a process that sequesters carbon dioxide (CO_2) from the atmosphere, incorporating it into the plant's biomass and roots. This process not only contributes to soil carbon (sequestration) but also provides a crucial food source for grazing animals. As cows consume a portion of this grass, they are essentially partaking in a cycle that starts with the sequestration of atmospheric CO_2. The grass then regrows so sequestering additional CO_2 on an ongoing basis through time.

Animal Digestion and Carbon Sequestration: Once the grass is consumed, it undergoes fermentation in the cow's rumen (stomach), where microbes break down the plant material. This process allows the cow to absorb nutrients necessary for its maintenance, growth (sequestration), and production of offspring (sequestration). During this digestive process, some of the carbon from the grass is stored in the cow's body, effectively sequestering it as part of the animal's biomass.

Methane Production and the Carbon Cycle: As a byproduct of this fermentation, cows the rumen microbes produce hydrogen and CO_2, which must be expelled from the body. Methane-producing microbes in the rumen convert Hydrogen into methane (CH_4) by adding CO_2, which is then released primarily through burping, with a minor amount expelled through flatulence. Crucially, this methane originates from CO_2 that was initially captured by the grass during photosynthesis. Therefore, the emission of methane is part of a broader carbon cycle that begins and ends with atmospheric CO_2, as the methane emitted oxidises back to CO_2 and water. This is circular and net zero.

Net Sequestration Through Livestock: While methane is released during digestion, a significant portion of the ingested carbon is utilized for the cow's maintenance, growth, and the production of high-quality food products such as milk, meat, and fibre. These products, when consumed by humans, continue the carbon sequestration process, as the carbon becomes part of the human body or is stored in durable goods. Thus, livestock, particularly pasture based ruminant systems, act as intermediaries in the carbon cycle. They effectively transfer atmospheric CO_2 via grass growth, animal ingestion, animal production of progeny and food products to the carbon sink being humans. The New Zealand pasture based ruminant system contribute to a net carbon sequestration rather than merely emitting greenhouse gases.

Soil Enrichment: Moreover, cows contribute to soil carbon levels through their dung, which enriches the soil and promotes further grass growth. This creates a feedback loop where additional CO_2 is ongoingly captured from the atmosphere, enhancing the carbon storage capacity of the pasture and soil.

Scientific Perspective: Dr. Kevin Trenberth, an IPCC scientist, underscores this cyclical nature of methane emissions from livestock: "It appears to assume that the methane emissions from dairy and meat count, but they do not because they come from carbon dioxide that was already in the atmosphere and was taken up by grass in photosynthesis. Any methane decays on a decade timescale back to carbon dioxide. It is circular."

- **The reality is New Zealand's pasture-based farming system sequesters more greenhouse gases than it emits, making it a net absorber of GHGs. This approach should be recognized accordingly.**

- **This understanding raises an intriguing question: If our current livestock practices already result in net sequestration, how much more CO_2 could be captured if we were to increase herd sizes? This could potentially enhance New Zealand's role as a global leader in sustainable agriculture, with a significant positive impact on carbon sequestration.**

Data reliability:

New Zealand's Original Methane Target

- **New Zealand's 2050 methane target of a 24-47% reduction below 2017** levels appears to have been based on **an average** of **four widely varying scenarios/pathways [5]**, using 2010 as the reference year. If either the "business as usual" option or more aggressive reduction strategies was used NZ's original methane targets would have been lower.

The IPCC Figure SPM 3b [5] illustrates these global differences in mitigation strategies and clearly stated they did not represent central estimates, national strategies, or specific requirements. Yet, an average of these figures likely influenced the setting of New Zealand's methane targets.

New Zealand's methane targets should be based on robust scientific data, specifically quantifying the country's methane net emissions greenhouse gas effect (not simply emissions), particularly enteric methane, based on warming impact, rather than an average drawn from a range of scenarios.

Accuracy of NZ GHG Inventory

- **The New Zealand GHG Inventory (1990-2022) data is not ideal for supporting reduction targets due to high uncertainty and annual fluctuations in GHG quantification.**

- **Basing targets or policies on statistically insignificant or fluctuating data is not robust. Warming targets should rely on quantifiable net GHG concentrations and their direct warming effects.**

The NZ Greenhouse Gas Inventory 1990 – 2022 has a 95% confidence interval of ±16% for enteric CH_4 emissions, which is larger than the proposed 2030 reduction targets. This uncertainty undermines the reliability of using these numbers for setting reduction targets.

The NZ GHG Inventory "estimates" are altered such as *"The whole inventory time series, from the base year (1990) to the latest year, is recalculated when the methodology or underlying data change. This means the emissions estimates are only up to date in the latest inventory, and previous inventories are not useful for comparisons."*

The Implication for Decision-Making: Given the large uncertainty relative to both the observed change and the reduction targets, this data might not be reliable for setting or evaluating precise reduction targets like 10% or 47%. It suggests a need for more accurate or robust data before making policy decisions based on these figures.

In summary, the data, as it stands, is not ideal for supporting reduction targets, especially since the confidence interval is so much larger than the observed change. Further analysis or additional data would be needed to have confidence in decisions based on this information.

The NZ Greenhouse Gas Inventory states clearly that the numeric numbers of previous reports have been altered as estimate methodology has changed. To base targets or policies on numbers that are not statistically significant or those that change from year to year is not statistically robust.

On-farm Calculators Statistical Accuracy:

The **wide variability in methane calculators** highlights the challenges in accurately measuring emissions. These calculators often rely on **estimates**, leading to inconsistencies in the data they produce. Currently, the main improvement being proposed is to standardize these estimates, which may bring some uniformity but still falls short of providing the precision needed.

Standardisation may bring conformity but does not bring accuracy or reflect reality.

This raises concerns about using these calculators as the basis for determining methane reductions, let alone as tools for pricing. The accuracy of these calculations is crucial, as any discrepancies can lead to misguided policies and unfair financial impacts on those who are subject to them.

- **Current On-farm Calculators do not accurately reflect actual emissions.**
- **If emissions cannot be measured accurately, they should not be taxed or subject to reduction targets.**

Summary:

- The Methane Review's target based on measurable, quantifiable warming is welcomed.
- Methane (natural and anthropogenic) globally contributes approximately 4% to the overall Greenhouse Gas Effect.
- New Zealand's methane emissions make up less than 0.006% of the global GHG effect.
- Globally, methane comes from 11 different sources and these vary from natural sources through to anthropogenic (biologically based) and anthropogenic (fossil fuel based).

- No other GHG has such a variety of sources.

- Identifying which of these sources are contributing to atmospheric increases, and assessing the ability to influence specific sources, such as leaks from oil and gas fields, is essential for robust policy.

- Globally Ruminants are estimated to be between 10% and 14% of global methane emissions. (or 21% of Anthropogenic Methane emissions). New Zealand is estimated to have about 1% of the world's ruminant population.

- Future warming [4] from NZ ruminants is expected based on GWP* at 4 millionth °C per year based on the graph below. This is immeasurable and a target cannot be statistically relevant.

- New Zealand's agricultural emissions are largely due to enteric (ruminant) methane, which is produced through a biological process where methane is only emitted after CO_2 has been sequestered. This system also produces high-quality food and contributes significantly to New Zealand's GDP.

- Methane sources also vary geographically, making quantification by source or region complex on a global scale.

- Methane (CH_4) increases and decreases are not linear. The NOAA has reported fluctuations in atmospheric concentrations, with periods of decline and acceleration in recent years. These variations are heavily influenced by natural weather patterns, especially precipitation, and anthropogenic sources (source not specified).

- There is growing focus on identifying "anthropogenic super emitters" of methane, typically industrial facilities, such as oil and gas operations, coal mines, or even landfills.

- *Increasing evidence shows that rising atmospheric* GHG *levels may also be driven by* thermally-induced emissions, not just anthropogenic sources.

- Effective methane reduction targets require accurate quantification of sources and their contributions. Current data is argued to be insufficient for this purpose.

<u>Complete Carbon Accounting:</u>

- The current approach of focusing solely on methane (output) emissions from livestock is overly simplistic and does not capture the full environmental impact of New Zealand's pasture-based farming system.

- **There needs to be a Complete Carbon Accounting:** NZ pasture-based farms should, like any other company, account for all inputs and outputs, not just methane emissions. Currently, the focus is primarily on methane output from enteric fermentation, ignoring other significant factors:

- Animal growth, progeny (which adds carbon to the animals), and the export of high-quality (carbon based) milk, protein, hides, and wool.
- New Zealand's already low emissions/kg status
- Paris Accord Article 2(b)
- Carbon leakage

- The reality is New Zealand's pasture-based farming system sequesters more greenhouse gases than it emits, making it a net absorber of GHGs. This approach should be recognized accordingly.

- This understanding raises an intriguing question: If our current livestock practices already result in net sequestration, how much more CO_2 could be captured if we were to increase herd sizes? This could potentially enhance New Zealand's role as a global leader in sustainable agriculture, with a significant positive impact on carbon sequestration.

Data reliability:

- New Zealand's 2050 methane target of a 24-47% reduction below 2017 levels appears to have been based on an average of four widely varying scenarios/pathways and not on "business as usual" option or a reducing option.

- The New Zealand GHG Inventory (1990-2022) data is not ideal for supporting reduction targets due to high uncertainty and annual fluctuations in GHG quantification.

- Basing targets or policies on statistically insignificant or fluctuating data is not robust. Warming targets should rely on quantifiable net GHG concentrations and their direct warming effects.

- Current on-farm calculators do not accurately reflect actual emissions.

- If emissions cannot be measured accurately, they should not be taxed or subject to reduction targets.

Appendices:

[1] **METHANE AS % OF ALL ANTHROPOGENIC GHG**

GLOBALLY:

GLOBAL Anthropogenic Methane is (currently accepted) 16% of ALL Anthropogenic GHG emissions.

Methane, Nitrous Oxide and F-gases are 24%.

Methane therefore is 16/24% = 66% of GHG's that are not CO2.

Most people assume that Ruminants are the only anthropogenic (Human) source of Methane however analysing the Sources of Methane – natural and anthropogenic would surprise many.

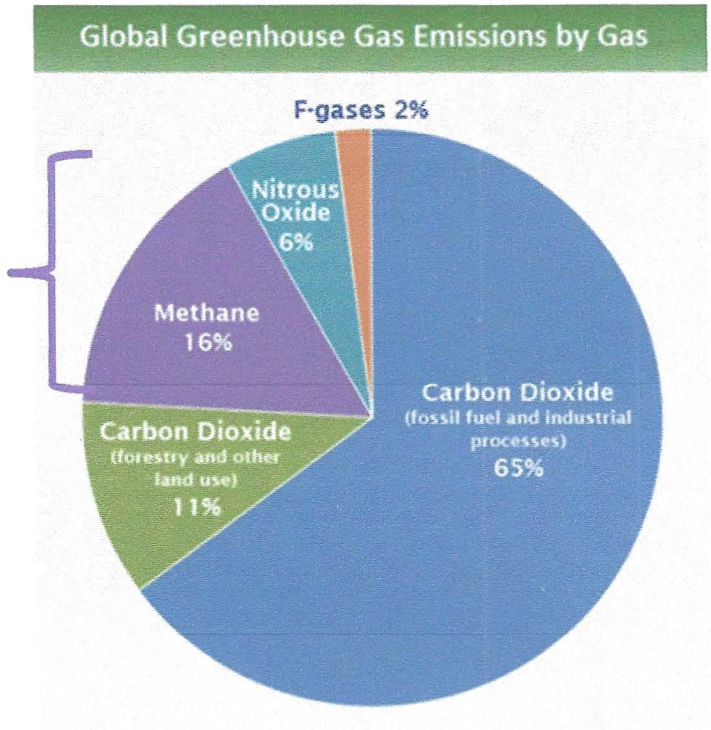
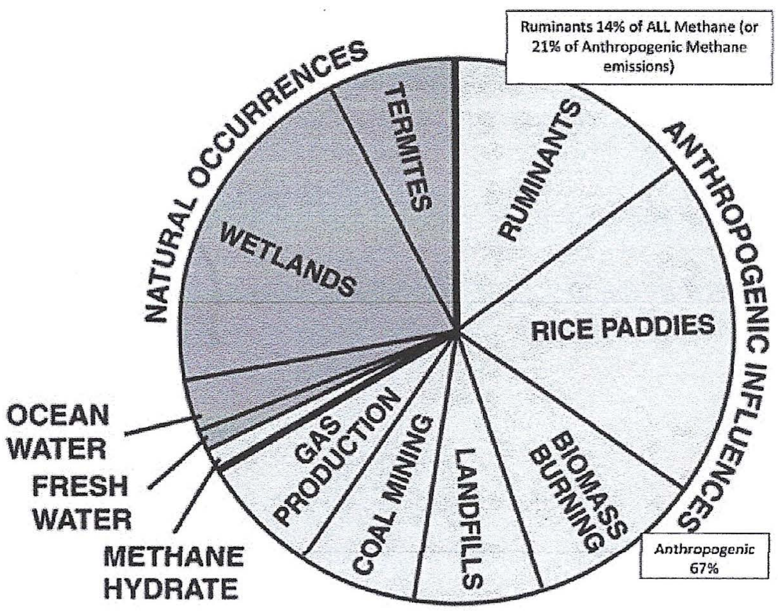


Figure 1: Global Anthropogenic Greenhouse Gas Emissions by GHG.: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

[2]

Sources of total methane emissions into the atmosphere: Natural and Anthropogenic
https://www.giss.nasa.gov/research/features/200409_methane/



TOTAL METHANE		
(0.00018% of Atmosphere)		
Anthropogenic		
Coal Mining	7%	
Landfills	8%	
Gas Production	8%	
Biomass Burning	10%	
Ruminants	14%	
Rice Paddies	20%	
		67%
Natural		
Methane Hydrate	1%	
Fresh Water	1%	
Ocean Water	3%	
Termites	7%	
Wetlands	21%	
		33%
TOTAL METHANE		100%

[3] NZ's % of global ruminants estimated NEW ZEALAND:

World Cattle Inventory: Ranking Of Countries (USDA)

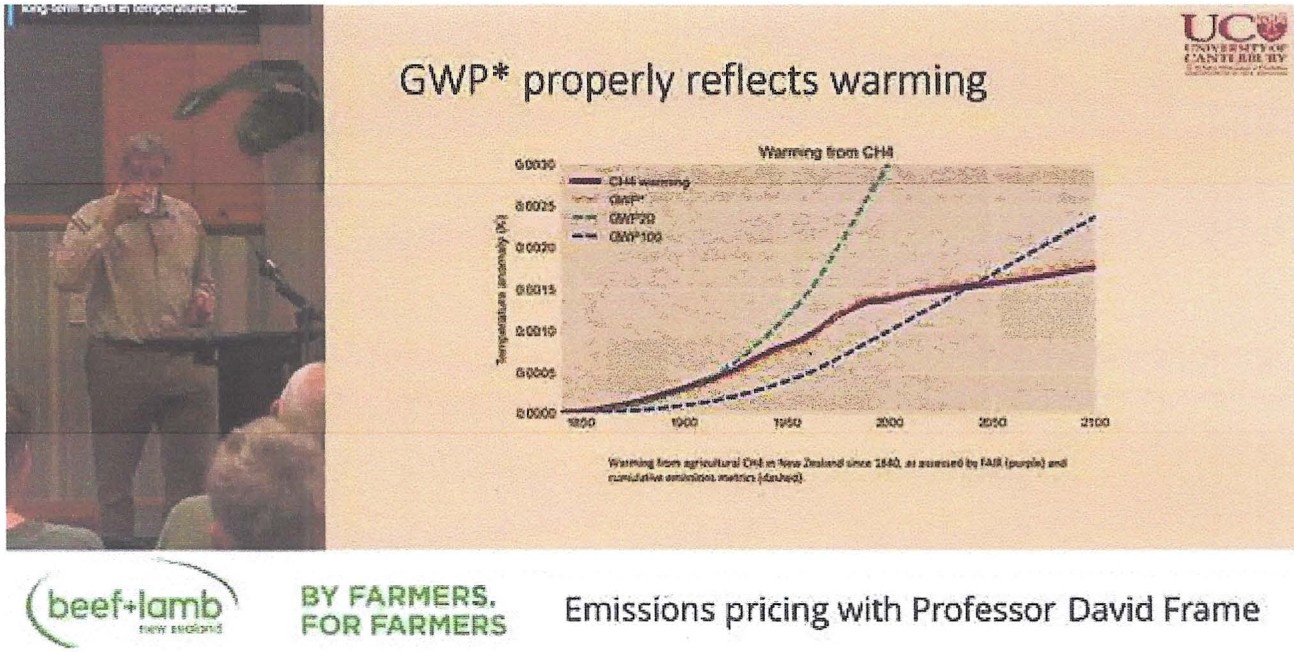
World		998,313,000	
Rank	Country	2017	% Of World
1	India	303,350,000	30.39%
2	Brazil	226,037,000	22.64%
3	China	100,085,000	10.03%
4	United States	93,500,000	9.37%
5	European Union	89,250,000	8.94%
6	Argentina	53,515,000	5.36%
7	Australia	27,750,000	2.78%
8	Russia	18,430,000	1.85%
9	Mexico	16,500,000	1.65%
10	Turkey	14,047,000	1.41%
11	Canada	12,100,000	1.21%
12	Uruguay	11,845,000	1.19%
13	New Zealand	9,903,000	0.99%
14	Egypt	6,995,000	0.70%
15	Belarus	4,320,000	0.43%
16	Japan	3,800,000	0.38%
17	Ukraine	3,780,000	0.38%
18	South Korea	3,106,000	0.31%

Source: FAS/USDA (head)

In 2017 NZ had only 1% of Worlds Cattle Inventory (India 30%, Brazil 22.6%, China 10%). **NZ Ruminant 1% of 2.2% Anthropogenic Methane means NZ contributes less than 0.002% of ALL Anthropogenic GHG Emissions.**

Rough calculations estimate that New Zealand is also approx. 1% of global ruminants.

[4] Professor David Frame GWP*



https://beeflambnz.com/knowledge-hub/video/emissions-pricing-professor-david-frame-lets-talk-about-what-science-means-our

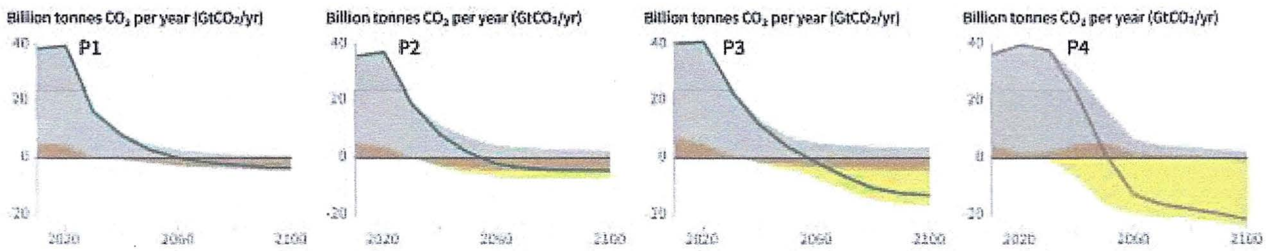
[5] IPCC Figure SPM 3b

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways

Fossil fuel and industry · AFOLU · BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
→ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
→ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
→ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
→ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
→ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
→ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
→ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
→ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
→ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
→ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
→ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km^2)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

SPM 3b

Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure SPM.3a.

These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socio-economic developments, including economic and population growth, equity and sustainability.

A breakdown of the global net anthropogenic CO2 emissions into the contributions in terms of CO2 emissions from fossil fuel and industry; agriculture, forestry and other land use (AFOLU); and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates.

Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements.

For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C.

Pathways P1, P2, P3 and P4 correspond to the LED, S1, S2, and S5 pathways assessed in Chapter 2

(Figure SPM.3a). {2.2.1, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.4, 2.5.3, Figure 2.5, Figure 2.6, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.14, Figure 2.15, Figure 2.16, Figure 2.17, Figure 2.24, Figure 2.25, Table 2.4, Table 2.6, Table 2.7, Table 2.9, Table 4.1}