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Explainer: What does net zero geothermal emissions actually mean?

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ABSTRACT

Many Indigenous groups are embracing geothermal energy and exploring indigenous-led clean energy projects to promote economic development and self-determination. In Aotearoa New Zealand, Māori are participating in brownfield and greenfield geothermal developments, as landowners, equity partners and, increasingly, co-developers and operators of geothermal projects, providing substantial financial returns and wider social benefits for whanau, hapu and iwi with commercial interests in these developments. Also, local communities are critical for geothermal developments having a social license to operate. However, there is a lot of jargon and technical information in this rapidly changing technological landscape, particularly in the management of greenhouse gas emissions.

While geothermal energy is considered a low-carbon energy source, geothermal plants release greenhouse gases that are naturally present in the Earth's crust and travel to the surface with the geothermal fluids. Changing social expectations, regulations and financial incentives, are driving both existing and new geothermal developments towards net-zero carbon emissions. So, what does net-zero carbon actually mean for a geothermal operation? How is it different to zero carbon, carbon free and carbon neutral? Where do the emissions come from, and what is the natural baseline? Why are gas levels different between geothermal fields, and how do they change over an operations lifetime? What are the options for managing, reducing or utilizing these emissions?

We address these questions, and more, using examples from New Zealand geothermal developments. We apply a Te Ao Māori (Māori world view) lens to this assessment, including how different options for managing geothermal greenhouse gas emissions align with Māori values and aspirations. Achieving global climate targets and reducing reliance on fossil fuels requires adoption of renewable energy and deployment of carbon dioxide removal technologies. Geothermal energy, and indigenous resource owners, have a key role to play in this energy transition.

1 INTRODUCTION

Renewable geothermal energy has a key role to play in achieving global climate targets and reducing reliance on fossil fuels. However, while geothermal energy is considered a low-carbon energy source, geothermal plants do release some greenhouse gases. This paper overviews how this process works, and what it means, in a way that is, hopefully, understandable for a non-technical lay person. It is the intention of the co-authors to deliberately avoid the use of geothermal industry jargon and acronyms so that the information is accessible to a wider range of audiences.

1.1 Terminology

We are in a world where a range of carbon-related terms are being used interchangeably—by politicians, businesses, scientists and other experts driving climate conversations. There are often conflicting definitions and contradictory usages of terms depending on what the user seeks to accomplish. For example, *net zero* tends to be favored by those setting long-term targets (like governments and political bodies), while *carbon neutral* tends to be used for operational, shorter-term targets (like for the carbon emissions of businesses and organizations).

First, here are some basic terms that are used in other definitions.

Gross vs Net

Gross emissions are the total amount of greenhouse gases released by human activities.

Net emissions are the gross emissions minus the amount of emissions removed from the environment.

Life cycle emissions

Life cycle carbon emissions include the total emissions associated with a product or service throughout its entire lifespan, from raw material extraction, through all operations, and including end-of-life disposal. Gross carbon free life cycle emissions is impossible in our society.

Operational emissions

Operational emissions are those released from/during the use and ongoing operation of a building, product, or system. They are a sub-set of life cycle emissions.

Emissions intensity

Emissions intensity is the ratio of produced emissions compared to the useful output produced by a system – in the case of geothermal energy this is the ratio of emissions to electricity generated. It can be measured and presented in terms of life cycle or operational emissions intensity.

Q. What does net-zero carbon mean? How is it different to zero carbon, carbon free and carbon neutral?

Carbon neutral / carbon neutrality

Carbon neutrality is a short-term goal that seeks the removal and reduction of CO_2, by balancing CO_2 emissions with an equal amount of carbon removal. This means no net carbon emissions are released into the atmosphere from a given activity, process, or organization.

Carbon negative

This is when more carbon dioxide (or carbon-based emissions) is removed from the atmosphere than it emits. It is a step beyond carbon neutrality (and is also, confusingly, sometimes called 'climate positive').

Carbon free / carbon zero / zero carbon

Zero carbon usually refers to the operational emissions, not the full life cycle emissions. It means producing no carbon dioxide (or other carbon-based) greenhouse gas emissions during operation (e.g. for a source of energy or a technology in use). This usually refers to net zero carbon, not gross zero carbon (which is a lot more difficult to achieve).

Zero carbon and carbon neutrality has the same end result – removing harmful emissions from the earth's atmosphere – but the scale and kind of emissions removed are different (Figure 1). Net zero is a substantially more ambitious goal than neutrality. Zero carbon means cutting emissions at the source and removing unavoidable emissions from the atmosphere (using technologies such as carbon capture), as well as offsetting emissions.

Net zero

Net zero is a long-term strategy that achieves an equal balance between all emitted greenhouse gases (not just CO2) and those removed from the atmosphere. As noted above, net zero doesn't mean no emissions at all (gross zero is virtually impossible as our society needs to make some emissions) and is a substantially more ambitious goal than neutrality.

Carbon offset / credits

After reducing emissions as much as possible, the remaining emissions are offset through measures like carbon capture and storage or reforestation. Carbon offsets / credits provide tools to negate emissions that are challenging to remove. They allow for funding of sustainability projects and encourage the development and innovation of greenhouse gas reducing technologies. Offsetting projects often include planting trees to form forests which are carbon sinks (they remove carbon from the atmosphere), as well as renewable energy projects (like wind farms or solar power plants), methane capture projects, energy efficiency improvements and

technologies to capture and store carbon. Carbon offsetting can be a key component to achieving carbon neutrality and net zero.

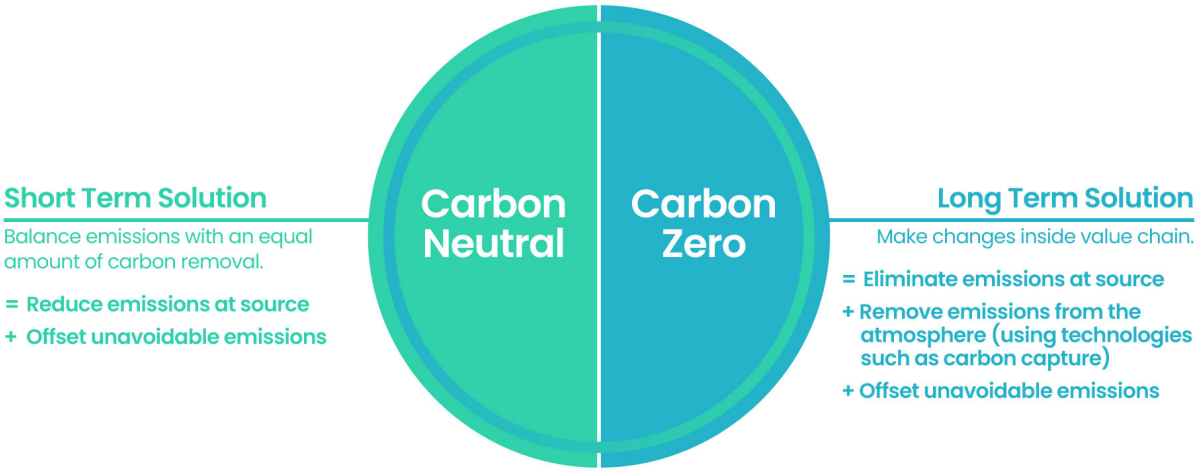

Figure 1: Carbon zero and carbon neutrality has the same end result – removing harmful emissions from the earth's atmosphere – but the timeline and scale are different.

1.2 Geothermal greenhouse gases

Q. What are greenhouse gases and where do they come from?

Greenhouse gases (also referred to as GHGs) trap heat in the Earth's atmosphere through their interaction with incoming or reflected solar radiation. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) and fluorinated hydrocarbons. Greenhouse gases come from natural and human-caused sources. The main cause of the current rapid increase in greenhouse gases is from human activities, including the burning of fossil fuels (coal, oil, and gas) for energy, electricity, and transportation, as well as agriculture (livestock and fertilizers), deforestation, waste from landfills, and industrial processes. Greenhouse gas emissions are commonly reported in 'CO_2 equivalent' (CO_2e), with non-CO_2 gas emissions converted based on their atmospheric impact.

Q. Where do *geothermal* greenhouse gases come from, and how much gas is the natural baseline?

Undeveloped geothermal systems naturally release gases from heated soils, steaming ground and surface features, such as fumaroles. In New Zealand, these gases can be traced back to shallow (6+km deep) magma interacting with groundwaters. Gases from the magmatic sources dissolve in the circulating groundwater and rise up to the surface in the hot fluids (Figure 2). These dissolved gases include carbon dioxide (CO_2 – the most abundant), hydrogen sulfide (H_2S), methane (CH_4), ammonia (NH_3) and nitrogen (N_2), only some of which are greenhouse gases.

No two geothermal reservoirs have the same composition or behavior. Some New Zealand geothermal reservoirs have naturally high levels of CO_2, such as Rotorua, Ohaaki and Ngawha, and others have naturally low levels, such as Mokai and Wairakei (NZGA, 2022; McLean et al., 2019). It is incredibly challenging to determine exactly how much CO_2 and other gases come naturally out of a geothermal system – it can be calculated using a combination of measurements and modeling, however datasets are limited. Further, the development of geothermal reservoirs can affect these natural emissions, making comparisons complicated.

As one example, a survey of Rotokawa (Bloomberg et al, 2014), a developed field in New Zealand, found total natural emissions through surface features and soil of ~441 t/d CO_2. For comparison, the published emissions from approximately 174 MW of generation from the Rotokawa field were approximately 233 t/d CO_2e in 2023.

Q. What happens during geothermal operations, and how much gas is released?

Geothermal electricity generation does not create additional CO_2, as there isn't any combustion like in fossil fuel power plants. However, during geothermal operations under the conditions of a power plant, some dissolved gases do not stay condensed (dissolved) in the liquid phase (mostly because the pressure is lower at the surface than underground). These gases are known as 'non-condensable gases' ('NCG's) and are removed from condensers (or the binary plant equivalent: vaporizers) and released into the atmosphere ('vented'), so that they do not build up and prevent the efficient operation of the plant.

Harnessing the geothermal energy alters the rate of emissions, which would eventually end up in the atmosphere anyway via natural surface features. But this means that geothermal operations do affect climate warming.

The gas emissions from geothermal plants varies depending on the design of the power station, as well as the reservoir conditions. A series of papers (e.g. McLean et al., 2019, 2020, 2021, 2024; Montague et al, 2022, 2023; Richardson & Webbison, 2024) has overviewed geothermal emissions data and trends from New Zealand's fifteen geothermal electricity generation plants. This has shown that the total CO_2e (CO_2 + methane converted into an equivalent amount of CO_2) emitted was about half a million tons each year. That's about 0.6% of NZ's emissions from human activities (MfE, 2025). If the same amount of electricity were to be generated using gas or coal, around 10 to 15 times more greenhouse gases would be produced.

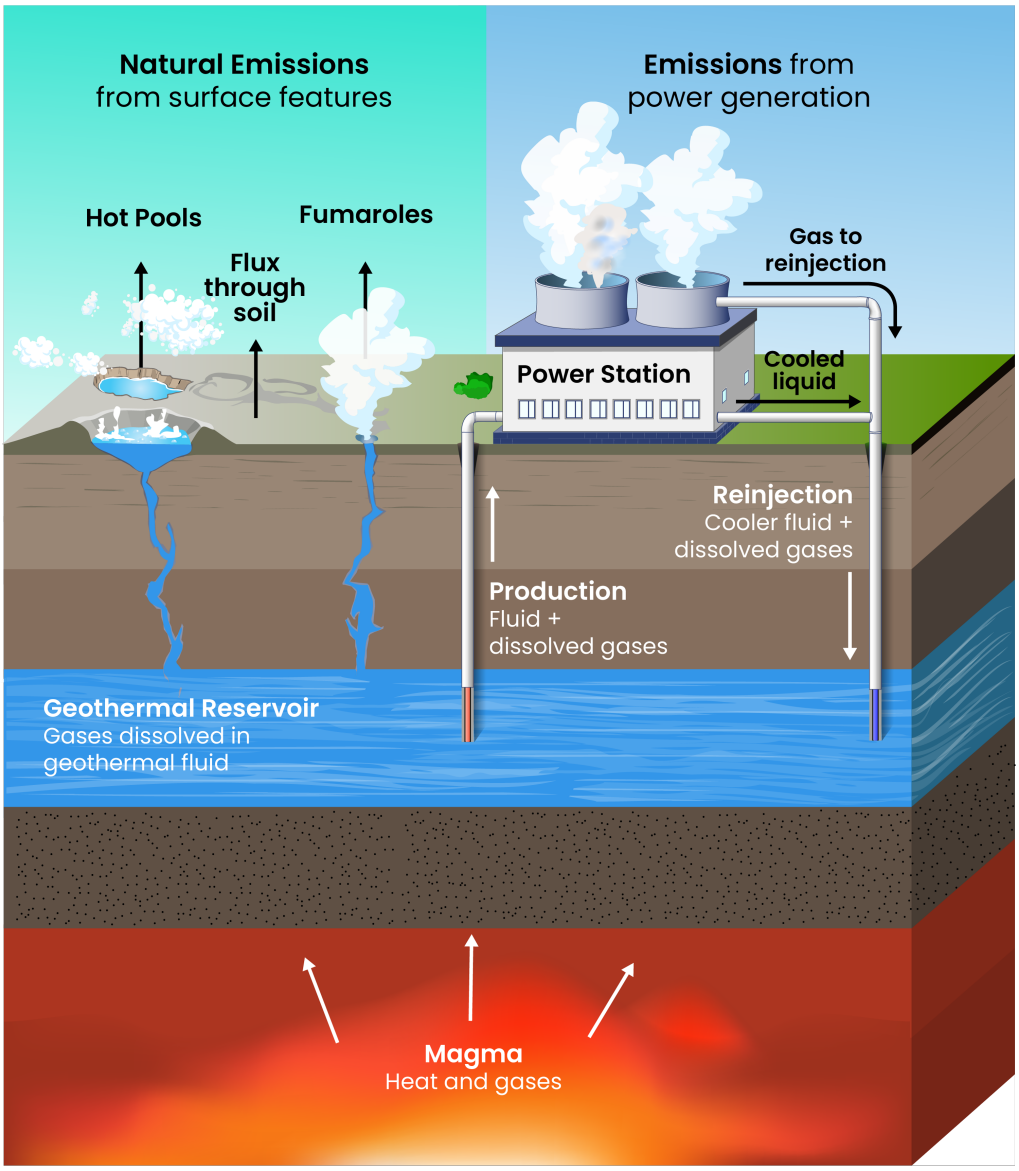

Figure 2: Schematic of a geothermal reservoir and gas emissions.

2 REDUCING GEOTHERMAL GREENHOUSE GAS EMISSIONS

2.1 The cost of gas emissions

Q. What is driving operators to reduce geothermal gas emissions?

Non-condensable gas emissions pose environmental and economic challenges for geothermal operations as their emissions are closely regulated. The legislation requires that both CO2 and methane are measured and reported as one CO_2-equivalent number (CO_2e). The introduction in 2008 of the NZ emissions trading scheme (ETS; MFE, 2009), and its applicability to geothermal operations in 2010, has been a key driver for change and innovation in emissions management within the NZ geothermal sector. The New Zealand model taxes emissions similar to other jurisdictions, where carbon taxation follows trading mechanisms and other cap-and-trade type

initiatives. In recent years, the price has fluctuated around an average of NZ$50 per ton—so 500,000 tons of CO_2 has a cost to the NZ geothermal industry of about $25M per year.

2.2 Managing geothermal greenhouse gases

It is important to note (re. McLean et al, 2024) that the total greenhouse gas emissions could be reduced simply by reducing the amount of power generated by the plant (i.e. less generation means less steam use which means less emissions). But simply reducing the power generation undermines the purpose and viability of the enterprise - to use renewable geothermal resources as an energy source to displace fossil fuels. Thus, the goal is to monitor the emissions intensity – this is the amount of greenhouse gases (primarily carbon dioxide) released per unit of electricity generated. Producing no (net) carbon / greenhouse gases requires a combination of technological innovation, policy changes, and behavior shifts across industries.

Q. What are the options for managing, reducing or utilizing gas emissions?

Due to its dominance (i.e. ca. 95% of geothermal gases), CO_2 is the primary focus for greenhouse gas management. Methane is a secondary focus because, despite being emitted at lower rates (typically <1.5% of geothermal gases), it is a highly potent greenhouse gas. Note: hydrogen sulfide gas and ammonia gas (<0.5%) are not greenhouse gases but must also be managed during geothermal operations because they are toxic and corrosive and can pose risks to human health and industrial operations.

2.2.1 Reinjection

Not all non-condensable gases are vented. Geothermal reinjection involves pumping used geothermal fluids back into the underground reservoir. This is undertaken routinely, to manage produced fluids, sustain the geothermal reservoir and prevent land subsidence. In some plants, a significant amount (up to ~20%) of 'non-condensable' gases do in fact remain dissolved in the geothermal fluid and are reinjected (called "passive reinjection"). In certain plant designs and geothermal fields, pressure can be maintained high enough throughout the system that all gases remain dissolved, resulting in no gas emissions.

Non-condensable gases can also be reinjected actively, by modifying the plant to dissolve the non-condensable gases into the geothermal fluid in the reinjection line (or at depth in a reinjection well via tubing). Such emissions mitigation through "active reinjection" of non-condensable gases with the expended fluids is increasingly becoming standard practice at many locations to close the emissions loop. This method has also been used in Iceland, Turkey and the USA (Carmichael & Zarrouk, 2023). In this way, greenhouse gases spend a few minutes above ground, contained within the pipelines and the plant, before being returned underground.

Non-condensable gas reinjection projects have been in progress in NZ starting in 2021 and continuing until present day (Mclean et al, 2024). This has so far been achieved at three geothermal power stations – Ngāwhā, Te Huka and Ngā Tamariki (Ruiz, et al., 2021; McLean et al, 2024; Ghafar et al., 2022). Ngawha power station is an example of a zero-carbon operation. The team successfully reduced emissions from the power plant equivalent to 128,000 tons of CO_2e in 2021 to zero by 2023, using 100% reinjection (Cariaga, 2023, McLean et al, 2024). It is a binary plant, which meant that all the gases were still confined within the pipes, making it easier to design a system for reinjecting them back into the brine.

Across the entire NZ geothermal industry, emissions used to exceed half a million tons each year, but that number has been steadily declining as the geothermal reservoirs themselves have degassed to a lower concentration of CO_2.

But 100% reinjection is not a realistic option for many fields. This is due to many factors including the limited capacity of the reservoir to uptake reinjected gases without negative effects on production or scaling in the borehole or near borehole reservoir. And long-term impacts of increased non-condensable gas reinjection and its effects on production is unknown. For active non-condensable gas reinjection, there are also technical challenges (e.g. Siratovich et al, 2024; Ghafar et al, 2022) to overcome such as corrosion of metal pipelines and scaling (build-up of minerals in pipes and wells).

2.2.2 CO_2 production & use

Geothermal operators could add value through creative use of what has previously been regarded as waste byproduct. In addition to mitigation, gas emissions strategies can consider commercial utilization options. By capturing, purifying and selling/using CO_2 from geothermal plants, new industries and supply vectors can be formed (Siratovich et al, 2024). This utilization could be established as a wholesale supply model, and/or a direct use offering in site adjacent new facilities (e.g. greenhouses). Packaging, beverage production, agriculture,

industrial processes, and several other industries rely on carbon dioxide gas — the most abundant non-condensable gas. Also, many efforts are being made globally to leverage CO_2 in the production of chemicals and fuels production (e.g. urea, methanol, aviation fuels). There is also the option of turning gas waste streams into food products through, for example biological transformation (Mitchelmore et al, 2025). These opportunities could create new revenue streams and support the development of low-carbon products and services, as well as displacing more emissions-intensive production methods and the need to produce CO_2 through traditional means.

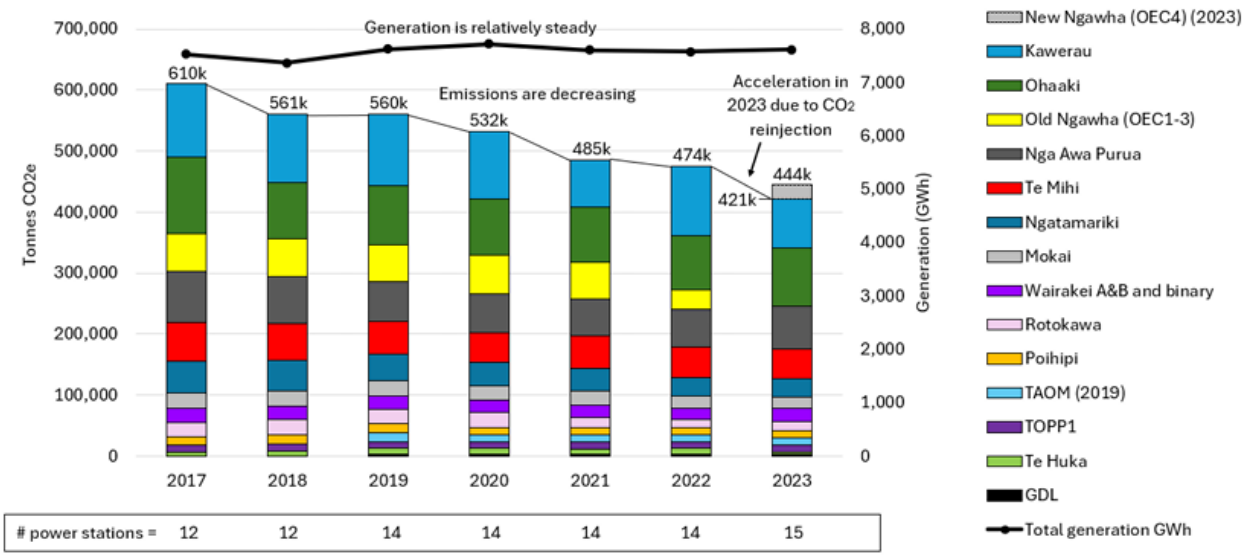

Figure 3: Annual CO_2e emissions stacked from each geothermal power plant 2017-2023 (from McLean et al, 2024).

3 A VALUES-BASED APPROACH TO GREENHOUSE GAS EMISSIONS MANAGEMENT

Indigenous worldviews provide valuable insights for developing geothermal energy in a manner that minimizes environmental impact and maximizes community benefit. In Aotearoa New Zealand, Te Ao Māori is one such worldview: prioritizing long-term sustainability, environmental stewardship and social, cultural and economic outcomes are strong considerations for Māori in their participation in geothermal projects and in decisions about how ambitious to be about emissions reduction.

3.1 Māori & geothermal in New Zealand

Māori traditionally used geothermal hot springs for bathing and cooking, and guided tourists who came to Aotearoa in the 1800s and 1900s for the health benefits of geothermal waters and iconic sights. In recent decades, Māori have participated in geothermal developments, as landowners, equity partners and, increasingly, co-developers and operators of geothermal projects, providing substantial financial returns and wider social benefits for whānau (family groups), hapū and iwi with commercial interests in these developments (Blair et al., 2024 and references therein; Climo et al, 2022). Lovell et al. (2025) provides an overview of the role of the statutory framework for geothermal resources, how Māori have been (and continue to be) affected by these structures, and the interaction of Treaty of Waitangi obligations, local authority responsibilities, environmental planning frameworks, and ongoing legislative reform.

Looking ahead, Māori are also at the forefront of new greenfield geothermal developments on Māori land. In these ventures, decisions about field development, plant design and commercial arrangements are made alongside questions about how far to minimize or reinject greenhouse gas emissions from the outset, consistent with kaitiakitanga (stewardship) and long-term intergenerational aspirations. Recent developments, such as the Taheke 8C geothermal project (EPA, 2024; MFE, 2024), involving Māori landowners of Taheke 8C (a land block that is held as Māori freehold land), illustrate Māori aspirations to exercise mana motuhake over geothermal taonga, while contributing low-emissions renewable generation and local employment. This reinforces the importance of examining geothermal emissions management through a Te Ao Māori lens, rather than treating greenhouse gases as a purely technical or regulatory issue.

3.2 Considering Te Ao Māori (Māori worldviews)

Te Ao Māori is worldview or framework that emphasizes the harmony between people, nature, and spirituality. It embodies respect for the land (whenua), waterways (wai), and all living beings as interconnected parts of a greater whole. This holistic approach promotes sustainability, community and resilience. Māori businesses, trusts and incorporations are not only motivated by financial outcomes, they are also driven by tikanga (values, principles and practices) inherent in Māori belief systems.

Prosperity from a Te Ao Māori approach aims to balance four interconnected outcomes when making decisions about geothermal development and emissions management:

1. Economic – being financially viable and sustainable
2. Environmental – wellbeing of land and water
3. Social – wellbeing of the people
4. Culture – language and customs associated with a thriving community

The following framing uses these four outcomes to examine geothermal development and emissions management through a Te Ao Māori lens.

1. Whakapapa (identity)

He mokopuna ahau, he tipuna ahau
I am a grandchild, I am an ancestor

Te Ao Māori highlights the importance of whakapapa —the genealogical and whanaungatanga (kinship) links that weave individuals into their ancestral lineages, strengthening a sense of identity and belonging. This concept connects all people, the land, and all living things back to the original ancestors and the universe. For tangata whenua, whakapapa also anchors relationships to specific geothermal taonga (treasures), maunga (mountains) and awa (rivers), and underpins obligations to uphold their mauri (life force) across generations.

For geothermal, the Te Ao Māori focus is on the underground geothermal reservoir (which has been there a long time and will be there for a long time in the future), not the surface infrastructure (which is temporary). The reservoir is a taonga, and for some perhaps, may be viewed as an ancestor, and the most important thing is the continued health of the reservoir. Decisions about emissions management options, such as reinjection, venting or utilization, are therefore considered in terms of their effects on the reservoir and the wider system for mokopuna (descendants) who will inherit these relationships, not just short-term operational efficiency.

2. Whenua (land)

Ko au te whenua, ko te whenua, ko au
I am the land, and the land is me

Whenua (land) is identity, representing a physical and spiritual connection to whanau (family) and the environment. Whenua is tūrangawaewae—a place of belonging, where people feel safe, comfortable, and can connect with their heritage and future generations. The whenua is seen as a provider of life and nourishment.

For geothermal, land—above and below ground—is key. The well-being of the whenua, in particular the reservoir, but also the surface features, air quality and surrounding environments, is intertwined with the well-being of its people. Māori are generally a place-based people with deep attachments to particular landscapes and geothermal taonga. This means that geothermal development must work with land/resources owners, and use a holistic approach that includes economic, environmental, social, and cultural considerations. Choices about greenhouse gas reinjection, venting or utilization are part of that holistic assessment, alongside effects on visible surface features, wāhi tapu and local livelihoods.

3. Mana Motuhake (self-determination)

Haere taka mua, taka muri; kaua e whai
Be a leader not a follower

Mana motuhake means self-determination, independence, and sovereignty—the right to decide one's path. Mana whenua and mana moana are those who hold tribal rights and authority over land/territory or water, usually due to a whakapapa connection to the area.

For geothermal, mana motuhake means, at a minimum, Māori participation in geothermal projects and strong collaborations to ensure inclusive and informed decision making. It also encompasses the ability of mana whenua to decide whether, how, and under what conditions geothermal resources on their whenua are developed at all, and to set their own climate and emissions ambitions for those projects. Ideally, Māori are leading geothermal development projects, driving investment and ventures that align with community goals. In practice, this may involve Māori-led or co-led governance structures, kaupapa Māori decision-making processes and a willingness to trade off some short-term revenue in favor of long-term environmental and cultural outcomes.

4. Kaitiakitanga (stewardship)

Toitu te marae a Tane, Toitu te marae a Tangaroa, Toitu te iwi
If the land is well and the sea is well, the people will thrive

Kaitiakitanga is about responsibility to care for the environment. People are part of the environment, not superior to it. There is an obligation on tangata whenua (the people of the land) to preserve and safeguard the land and natural resources for future generations. Kaitiakitanga is intended to ensure resource sustainability, by upholding the mauri (life force) and recognizing both the intrinsic value of the taiao (environment) and its role in sustaining people. Exercising kaitiakitanga is a long-term commitment that can also mean securing an asset base, seeking commercial outcomes, developing resources, controlled exploitation, stimulating community development, and managing change.

For geothermal, kaitiakitanga strongly aligns with geothermal reservoir management necessary for long-term (30+ years) sustainable commercial operation, the decarbonization of industrial sectors, and catalyzing economic development and employment opportunities. From a Te Ao Māori perspective, decisions about reinjection, venting and CO_2 utilization are part of exercising kaitiakitanga over the reservoir and associated surface features: good practice aims to reduce net emissions while maintaining reservoir health and respecting cultural values in place. The social benefits of these projects (including electricity security) then extend more broadly to the local communities and the region within which they reside.

4 CONCLUSION

Changing social expectations, regulations and financial incentives, are driving both existing and new geothermal developments towards net-zero carbon emissions. This paper sought to provide introductory, explanatory information about how these technical processes work and the language being used to explain the rapidly changing technological landscape of geothermal development and gas emissions management. A Te Ao Māori approach offers valuable insights for developing geothermal energy in a manner that minimizes environmental impact and maximizes community benefit, and for framing how ambitious geothermal operators and Māori landowners choose to be in reducing or reinjecting greenhouse gas emissions over the life of a field.

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