Application of the United Nations Framework Classification for Geothermal Projects in the Waikato Region

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ABSTRACT

This paper presents an energy assessment and classification of all geothermal projects in the Waikato Region, New Zealand, using the new Geothermal Specifications for the United Nations Framework Classification (United Nations, 2020). The assessment includes major potential projects and existing projects that generate electricity and heat within the region but excluding Protected Geothermal Systems and small Geothermal Systems. The work has been sponsored by the Waikato Regional Council as part of their obligations to report on the geothermal energy resources available within the region.

To evaluate each project, a standard template has been developed and populated with publicly available data and data provided by project owners, capturing a simplified description of the Project and Energy Source and the key factors that are needed to assess classification on the E-axis, F-axis, and to assess energy production with uncertainty represented on the G-axis. Furthermore, the assessed projects are categorized according to their status within the UNFC framework.

This assessment/classification is probably the most comprehensive application to date of the UNFC system to any geothermal region and provides a robust view of the present and near-future geothermal energy potential of the region. The present status of projects includes some already in long-term operation, in active development, undergoing major re-development with new plants, direct heat use projects, and undeveloped opportunities with no known development plan. As such, this represents a good example of how UNFC can be applied to all stages of development. Observations and suggestions regarding further application of UNFC to geothermal are provided. The major geothermal developer/operators in the region have participated in the work and are assessing how they may be engaged or use UNFC in future.

1. INTRODUCTION

The United Nations Framework Classification for Resource (UNFC) is a robust framework for assessing energy development projects, which considers the technical feasibility and socio-economic viability for a project to progress, and confidence level for future quantities being available in a project (United Nations, 2020). An update to the UNFC in 2019 intended to accommodate the application of the framework to all resources, allowing geothermal projects to be compared to other renewable projects using the same framework.

1.1 UNFC Nomenclature

The language of UNFC (United Nations, 2022) is specific and distinguishable from that used in New Zealand's Resource Management Act (RMA). Some key UNFC terms include but are not limited to: **Project** – a defined development or operation that can be used as a basis for environmental, social, economic, and technical evaluation and decision-making, such as an electricity generation project or a direct use project; **Sources** – such as geothermal, solar, wind, etc. are the feedstock to resource projects from which products can be developed; **Products** – electricity, heat, hydrogen, minerals, etc. may be bought, sold, or used; and **Resources** – cumulative quantities of products that will be extracted from a source throughout a project lifetime.

1.2 UNFC Axis System

The UNFC utilises a three-axis system (United Nations, 2019) to assess energy projects comprising the **E-axis** – environmental-socio-economic viability; **F-axis** – technical feasibility; and **G-axis** – degree of confidence (Figure 1). Each axis has a distinctive evaluation scoring system detailed in Table 1.

Table 1: UNFC E-F-G Axes of evaluation and their grading systems (United Nations, 2019; United Nations 2022).

Axis	Description	Evaluation Scores
E	Environmental-socio-economic viability	1 – 3
F	Technical Feasibility	1 – 4
G	Degree of Confidence	G1: high confidence estimate G2: most likely/best estimate G3: low confidence estimate

The outcome of evaluation is used to categorise projects into different Primary Classes: viable, potentially viable, non-viable, and prospective projects. The class of a project may change with time as the project matures, or variables change over time.

Total Products	Produced	Sold or used production			
		Production which is unused or consumed in operations[a]			
		Class	Minimum Categories		
			E	F	G[b]
	The project's environmental-socio-economic viability and technical feasibility has been confirmed	Viable Projects[c]	1	1	1, 2, 3
	The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed	Potentially Viable Projects[d]	2[e]	2	1, 2, 3
		Non-Viable Projects[f]	3	2	1, 2, 3
	Remaining products not developed from identified projects[g]		3	4	1, 2, 3
	There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility	Prospective Projects	3	3	4
	Remaining products not developed from prospective projects[g]		3	4	4

a. Future production that is either unused or consumed in the project operations is categorized as E3.1. These can exist for all classes of recoverable quantities.

b. G categories may be used discretely, or in cumulative scenario form (e.g. G1+G2).

c. Estimates associated with Viable Projects are defined in many classification systems as Reserves, but there are some material differences between the specific definitions that are applied within different industries and hence the term is not used here.

d. Not all Potentially Viable Projects will be developed.

e. Potentially Viable Projects may satisfy the requirements for E1.

f. Non-Viable Projects include those that are at an early stage of evaluation in addition to those that are considered unlikely to become viable developments within the foreseeable future.

g. Remaining products not developed from identified projects or prospective projects may become developable in the future as technological or environmental-socio-economic conditions change. Some or all of these estimates may never be developed due to physical and/or environmental-socio-economic constraints. This classification may be of less value to renewable resource projects but can still be used to indicate the amount of unrealized potential. It is emphasised that the remaining products are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.).

Figure 1: Abbreviated version of the UNFC classification with Primary Classes and grading categories for E-F-G axes. Source: United Nations (2020).

1.3 Project Objective and Scope

The primary objective of this study is to provide a large-scale regional assessment of geothermal projects in the Waikato Region covering existing, planned, and potential development projects. In the long term, WRC intends for UNFC reports to be assimilated into the System Management Plan (SMP) reported to them by geothermal Resource Consent Holders.

We have undertaken assessments of several geothermal projects located in major geothermal systems within the Taupō Volcanic Zone (TVZ). The scope of our assessments includes projects categorized as Development Systems, Limited Development Systems, and Research Systems (Table 2). Protected Systems, and small systems within and outside of the TVZ are excluded from our study. We also arbitrarily set a threshold of 10 MW for projects to be included in our assessment.

Table 2: Geothermal systems included within the scope of this report.

WRC Classification	Geothermal Systems
Development Systems	Horohoro, Mangakino, Mokai, Ngā Tamariki, Rotokawa, Ohaaki
Limited Development Systems	Atiamuri, Tokaanu-Waihi-Hipaua
Research Systems	Reporoa

1.4 Data source

Only information available in the public domain are used for developed and undeveloped projects. Assessments on developed projects relating to sites operated by Mercury NZ Limited are completed in collaboration with Mercury NZ Limited. For the Ohaaki Project, Contact Energy Limited provided their assessment following the Jacobs UNFC template.

2. METHODOLOGY

2.1 Defining Projects

Within the geothermal context, the UNFC definition of a *Project* refers to extracting heat from the earth and delivering it to a point of sale or use in form of useful energy. For this study two main project categories are set: electricity and heat projects.

2.2 General Assumptions

System type and development technology: Only conventional geothermal systems are covered (e.g. high temperature and high permeability reservoirs with <3 km depths; excludes future energy sources including but not limited to supercritical fluids and development of outflow zones using pumps.

Treatment of "foreseeable future": The term "foreseeable future" is approximately 5 years under the Geothermal Specification (United Nations, 2022). For this study, speculative projects and projects without any Resource

Consents are considered as unlikely to proceed in the foreseeable future.

Project life: The maximum Resource Consent life of 35 years is applied to new electricity projects and projects requiring consent renewal. The project life of operating projects refers to the remaining Resource Consent life but can be extended with Resource Consent renewal and facilities refurbishment. For projects near the end of their existing Resource Consent (e.g., <5 years), this study assumes that the project life will be extended by the expected period.

Energy Estimates: The range of energy estimates for projects is recommended to be presented as G1-G2-G3 or G4 (for Potential Projects) in the UNFC (Figure 1). For practical purposes, this study presents these values via assessing the Low, Best, and High estimates for each Project.

The methodology for calculating energy estimates is covered in Section 2.5 (General Calculations). The energy estimates are not equal to P10-P50-P90 resource areas (Cumming, 2016) often used in defining conceptual models and resource sizes.

2.3 Assumptions for Undeveloped Projects

Project start: As all the projects in the Waikato Region require Resource Consents under New Zealand's RMA, time frames for all new Projects are assumed to begin after the Resource Consents are granted. For low-best-high estimates in new electricity projects, a range of 5-10-15 years is assumed as required for project set-up and construction before the Project is considered operational and are based on a likely time frame to complete all pre-operational stages. Heat or direct use Projects are given a low-best-high estimate of 1-1-5 years upon Resource Consent approval and assumes that heat projects may become fully operational in relatively shorter time to electricity projects.

Project size: The size of a Project is based on the developable area of the Source intended for production, and not based on the full reservoir area available for a given geothermal source. For example, in developed projects the project area will be the production or fluid take area and exclude the injection areas. The project size takes into consideration existing infrastructure, terrain conditions, land status, and any other environmental or social factors that may impact on physical access to the Source. In undeveloped projects, the estimated area is based largely on resistivity data and may result in relatively larger project size compared to developed projects due to having more uncertainties. Only projects with an arbitrary minimum threshold of 10 MW are included in this study.

Project Generation Potential: Generation potential of undeveloped projects are estimated using the power density method and assumes a power density factor of 10 MW/km^2 for all projects with limited information available, as suggested by Grant (2015).

2.4 General Calculations

Some of the equations used in the assessment:

Generation Potential (for undeveloped projects):
Power plant capacity (MWe) =
accessible source area (km^2) × power density factor (MW/km^2)

- A power density factor of 10 MW/km^2 is used (based on Grant, 2015) for the low, best, and high estimates.

Annualized generation (MWe) (for existing projects) = power plant capacity (MW) × plant availability (%)

MW years = Annualized generation × project life

The energy estimates are considered as follows:

- G1 is the Low estimate,
- G2 is the difference between Best and Low estimates (Best – Low),
- G3 is the difference between the High and Best estimates (High – Best).
- G4.1, G4.2, and G4.3 are applied for Undeveloped Projects.

The different **estimate classes** can be mathematically expressed as follows:

- Low estimate = G1
- Best estimate = G1 + G2
- High estimate = G1 + G2 + G3

PJ (e) = MW(e) years X 0.03154 PJ

2.6 UNFC Reporting Template

The primary unit for reporting classifications (E1-3, F1-4) and energy quantities (G1-3 or G4) under the UNFC is PetaJoule (PJ). The UNFC requires the project description and assumptions used to be recorded for every project, but does not prescribe a specific methodology for this assessment. To address this requirement, we created a template for consistent assessment of different projects, which is designed to capture (but is not limited to) the following information: general information (effective date of evaluation, evaluator – a "qualified person"), project information (location, history, Source summary, project description, development plan, project lifetime, product type), E-axis (environmental-socio-economic viability), F-axis (technical feasibility), and G-axis (energy production and degree of confidence). Classification of the E, F, and G-axes are justified using the key factors considered. For undrilled Projects, the probability of discovery is described considering factors including but not limited to favourable temperature, permeability, and chemistry, and the reporting entity is set as the regulator (WRC in the Waikato Region). Quantities for electricity projects are expressed in MegaWatt-years electric (MWe Years) and PetaJoule electric (PJe), and for heat projects MegaWatt-years thermal (MWt Years) and PetaJoule thermal (PJt) are used. All information sources from the public domain are recorded as references; for projects assessed by the project owner (or developer), the recording of internal data as references is not required.

Table 3: Summary of the UNFC classifications for Waikato geothermal projects, excluding projects estimated to be less than 10 MW and projects located in the Wairakei-Tauhara Geothermal System.

#	Geothermal System	Project	Product	MWe Best Est.	MWt Best Est.	E-axis	F-axis	G -axis
1	Horohoro	Horohoro	Electricity	23	-	E3	F3.3	G4.1 – G4.3
2		Horohoro Direct Use	Heat	-	191.7	E1	E1	G1 – G3
3	Mangakino	Mangakino	Electricity	15	-	E3	F2.2	G4.1 – G4.3
4		Mangakino Direct Use	Heat	-	125	E3	F2.2	G4.1 – G4.3
5	Mokai	Mokai I & II*	Electricity	104	-	E1	F1	G1 – G3
6		Mokai Direct Use*	Heat	-	14.5	E1	F1	G1 – G3
7	Ngā Tamariki	Ngā Tamariki OEC 1 – 4*	Electricity	79	-	E1	F1	G1 – G3
8		Ngā Tamariki OEC 5*	Electricity	37	-	E2	F1.3	G1 – G3
9	Ohaaki	Ohaaki**	Electricity	36	6	E1.1	F1.1	G1 – G3
10	Rotokawa	Rotokawa RGEN & NAP*	Electricity	160	-	E1	F1	G1 – G3
11	Atiamuri	Atiamuri	Electricity	15	-	E3	F3.3	G4.1 – G4.3
12		Atiamuri Direct Use	Heat	-	125	E3	F3.3	G4.1 – G4.3
13	Tokaanu-Waihi-Hipaua	Tokaanu-Waihi-Hipaua	Electricity	100	-	E3	F3.2	G4.1 – G4.3
14	Reporoa	Reporoa	Electricity	66	-	E3	F3.2	G4.1 – G4.3

**Assessment and quantities approved by Mercury NZ Limited.*
*** Estimates provided by Contact Energy Limited.*

3. UNFC PROJECT ASSESSMENTS

3.1 List of UNFC Projects

Fourteen Projects were assessed in this study (Table 3), which includes Projects owned or operated by Mercury NZ Limited and Contact Energy Limited (Ohaaki). For Geothermal Systems not presently generating electricity and lacking robust high temperature indicators from preliminary geoscientific surveys (e.g., Horohoro, Mangakino, and Atiamuri), Potential Projects are split into Electricity and a Heat Projects. This is done to showcase how UNFC is applicable for different projects, and to compare which Project is more viable based on the UNFC classification. For Undeveloped Systems with high

probability of discovery and indicators of high temperature (e.g., Tokaanu-Waihi-Hipaua and Reporoa), only Electricity Projects are assessed given historical interests in these Geothermal Systems for electricity generation.

3.2 Summary of Results

All Projects are assessed using the Jacobs UNFC template as described in Section 2.6. The E-axis, F-axis, and G-axis are given a score based on available information for each axis.

The results of the UNFC assessment are summarised on Table 3. Projects that are presently generating electricity (e.g., Ohaaki, Mokai I & II, Rotokawa RGEN & NAP, Ngā Tamariki OEC 1-4) or supplying heat to end-users (Mokai Direct Use, Horohoro Direct Use) have E1 and F1 scores for the E-axis and F-axis, respectively. This is consistent with the expectation that environmental-socio-economic issues are to be largely addressed when a Project enters its operational stage. Also, existing Projects must be technically feasible to be operational, consistent with the F1 scores given.

The Ngā Tamariki OEC 5 Project has an E2 and F1.3 scores for the E-F axes, respectively. The higher E-axis score reflects the status of the Project which is currently progressing with contract negotiation, feasibility, and Resource Consenting prior to final investment decision. Both reservoir model studies and engineering studies for the Project have been completed (hence the high F-axis score) but further details subject to tendering and contracts after board approval.

Horohoro (electricity), Mangakino, Atiamuri, Tokaanu-Waihi-Hipaua and Reporoa have higher E-F axes scores which mainly reflect the status of these Projects, i.e., mostly

Project Class	PJ (e)		
	G1	G2	G3
Viable Projects	269.9	43.0	32.3
Potentially Viable Projects	24.4	10.4	5.8
Non-Viable Projects	10.0	5.0	5.0
	G4.1	G4.2	G4.3
Prospective Projects	147.0	57.0	80.0
Total	**478.3**	**115.4**	**123.1**

Figure 2: a) Total combined estimated electrical energy (PJe) for electricity projects in the Waikato Region and b) a summary of Electricity Projects. Projects located in the Wairakei-Tauhara Geothermal System are presently excluded.

Project Class	PJ (t)		
	G1	G2	G3
Viable Projects	121.8	75.1	83.4
Potentially Viable Projects	-	-	-
Non-Viable Projects	83.3	41.7	41.7
	G4.1	G4.2	G4.3
Prospective Projects	75.0	50.0	83.3
Total	**280.2**	**166.7**	**208.4**

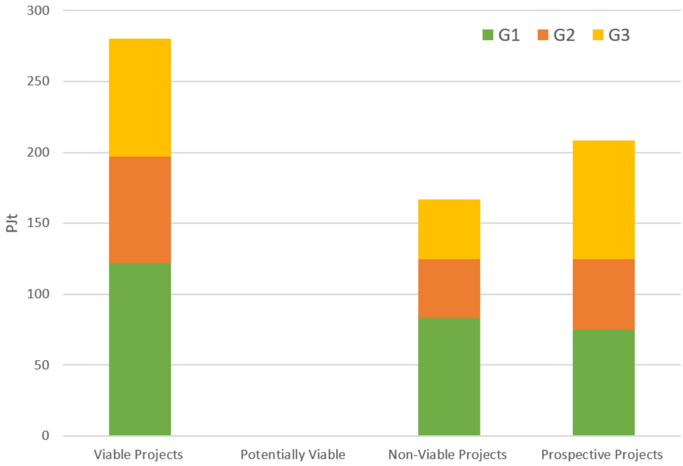

Figure 3: a) Total combined estimated heat energy (PJt) for heat projects in the Waikato Region and b) a summary of Heat (direct use) Projects. Projects located in the Wairakei-Tauhara Geothermal System are presently excluded.

undeveloped, with no known funding for further surface or surface exploration work and requiring more data to confirm the viability of the Source.

The Projects are also further classified into Viable, Potentially Viable, Non-Viable, and Prospective Projects (Figure 1; United Nations, 2020). Figures 2 and 3 show the total combined estimated electrical (PJe) and heat energy (PJt) for Projects in the Waikato Region.

3.3 Discussions

For both Electricity and Heat Projects, Viable Projects contribute to the greatest energy generation or potential, followed by Prospective Projects, with the caveat that projects associated with the Wairakei-Tauhara Geothermal System are not recorded in this paper. The energy estimates show that most of the available geothermal Resources in the Waikato Region may have already been tapped from Sources where development is permitted. Figures 4A and 4B show the cumulative electricity and heat production of Viable Projects over time in the Waikato Region (excluding projects associated with the Wairakei-Tauhara Geothermal System).

Prospective Projects may also have a lower actual energy availability as current 3G surveys are incomplete, resulting in a greater Project Area used for this study. Despite the existing data gaps, Prospective Projects for both electricity and heat products show significant energy being potentially available. Future development of geothermal Sources may be more viable in Geothermal Systems such as Tokaanu-Waihi-Hipaua and Reporoa for electricity projects, and in most available Geothermal Systems for heat projects.

The results summarised on Section 3.2 and Table 3 also highlight the capacity for UNFC to assess the viability of different Products to hold independent Projects within the same Source (within a Geothermal System in the geothermal context). This is demonstrated by the Atiamuri Geothermal System, where an undeveloped system has two potential Projects based on two different Products: electricity and heat. Both Projects share the same E, F, and G-axis categories, however they show two different project potentials. The probability of encountering commercial temperatures of >240ºC (SKM, 2002) is considered low to medium for Atiamuri, resulting in relatively low best estimates for a power generation Project (15 MWe). On the other hand, heat

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Projects have different temperature requirements to electricity Projects; although the required temperature varies depending on Project specifics, generally process heat activities may require temperatures less than expected at Atiamuri. This results in direct use or heat Projects to be more viable than electricity Projects at Atiamuri and similar Geothermal Systems, given the low temperatures predicted. This may help stakeholders in deciding what kind of Project would be most optimal for a given Geothermal System and given varying probabilities of discovery.

Among the electricity Prospective Projects (Table 3), the Tokaanu-Waihi-Hipaua Project has the highest best estimate for generation potential. All electricity Prospective Projects have relatively similar classification scores under the UNFC (E3, F3, G4.1-4.3) except for the Mangakino Project which scores F2.2 on the F-axis as deep wells have been drilled in the Project proving the presence of high temperature albeit in a relatively small area as majority of the wells drilled encountered poor permeability. Despite the more favourable F-axis classification (owing to availability of info from deep wells), the Mangakino Project may be considered less "attractive" than Tokaanu-Waihi-Hipaua when the power potential of the Projects is considered. The Tokaanu-Waihi-Hipaua Project has a power potential (best estimate) of 100 MW whereas the Mangakino Project has a power potential (best estimate) of 15 MW. This example demonstrates how the UNFC assessments can be useful for evaluating multiple Projects and coming up with a priority list of Projects.

4. CONCLUSIONS AND RECOMMENDATIONS

To date, this study provides the most comprehensive application of the UNFC framework to any geothermal region and shows a robust view of the present and near-future geothermal energy potential of the region. Observations and suggestions regarding further application of UNFC to geothermal are provided below.

4.1 Lessons Learned – What Worked Well

- The use of the Assessment template prepared by Jacobs has helped streamlined the evaluation process and provides a uniform standard for assessing different Projects.
- Using a production profile over time (i.e., a plot of annual average production over time showing G1, G2, and G3 estimates), though not a requirement of UNFC, is a useful representation of how a Project or accumulated Projects across a region or nationally may perform over time.
- Collaboration with Project operators ensures that the data included in the assessment is valid and accurate.

4.2 Challenges Encountered

- The limited public info for undeveloped geothermal systems or greenfield Projects makes it difficult to fully understand the geothermal source location and area.
- One geothermal Source may have multiple potential Projects focusing on different Products (electricity and heat).
  - Heat and electricity Projects of Prospective Projects may be mutually exclusive so assessing these may be misleading when considered together, but such assessments can highlight opportunities.
  - Heat requirements for electricity and heat Projects may differ so a more nuanced approach is needed for assessing heat potential than has been possible in this study.
  - Heat can also be a by-product from electricity Projects and there is likely many more opportunities for heat Projects that can be assessed in a similar study.

4.3 Future Recommendations

Socializing the UNFC assessment framework to government and interested stakeholders may help accelerate the development of geothermal Projects as this classification system provides a standardised approach of assessing different electricity and heat Projects across a region or nationally, and hence will be useful for strategic planning for geothermal development.

Also, the methodology used for assessing potential heat Projects in this study may need further review to consider how potential heat as a downstream product or as a direct use can be assessed regionally. Possibly Prospective Projects should not be included in the inventory until there is some indication or plan announced.

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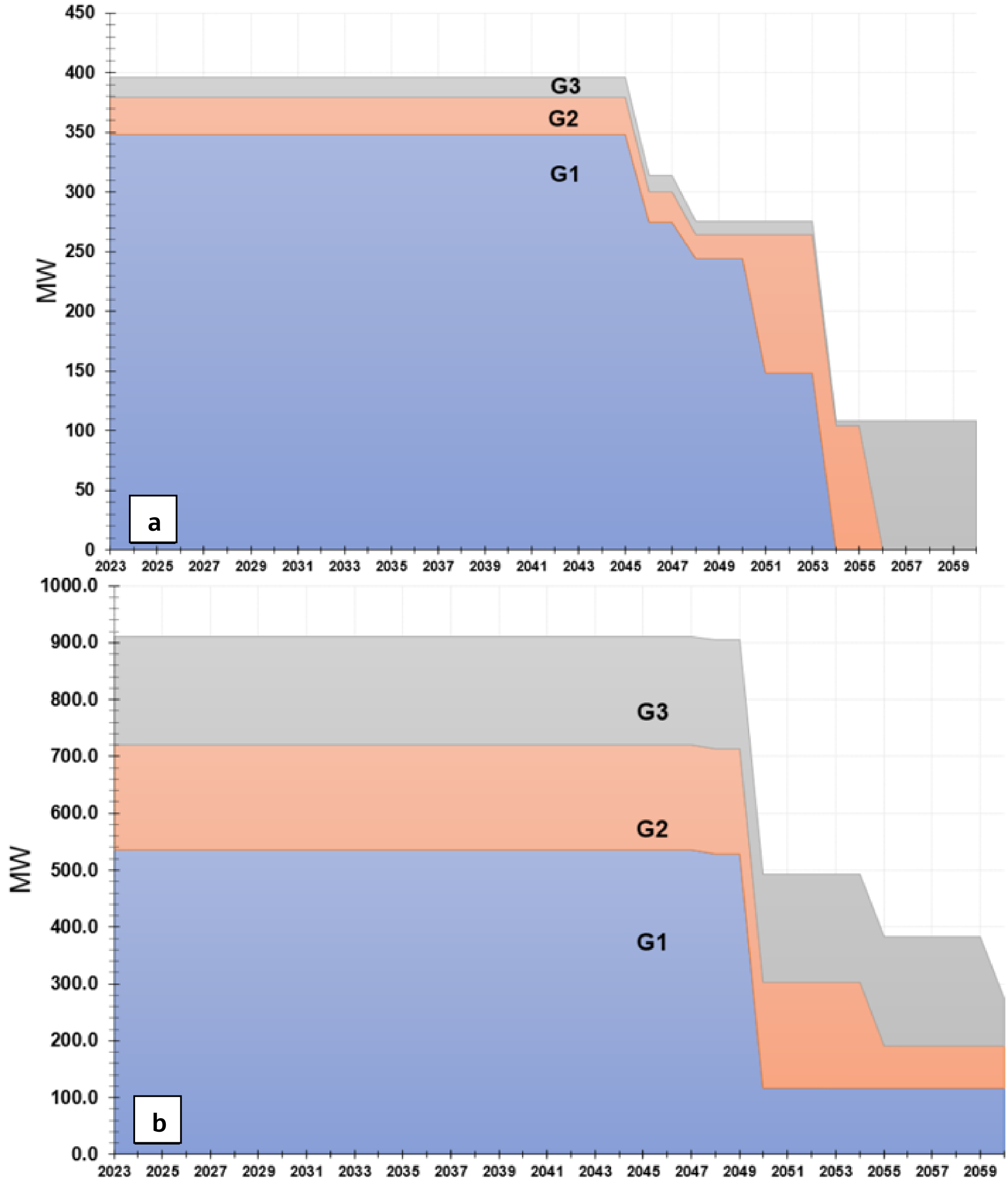

Figure 4: a) Cumulative electricity production of Viable Projects over time in the Waikato Region, and b) Cumulative heat production of Viable Projects over time in the Waikato Region. Projects located in the Wairakei-Tauhara Geothermal System are presently excluded.