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The Geothermal Opportunity of the Gippsland Basin, Australia

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ABSTRACT

The onshore portion of the Gippsland Basin covers about six thousand square kilometers of the state of Victoria, Australia, to the southeast of Melbourne. Most of that area is underlain by the highly productive Lower Tertiary Aquifer (LTA). Recent mapping by the Geological Survey of Victoria has confirmed that thick layers of brown coal within the Gippsland Basin sequence act as a thermal blanket to elevate the temperature of significant segments of the underlying LTA to as high as 75°C at less than 1,000 m depth.

The hot aquifer was first identified by a government geologist in 1962, but in spite of some early uses of the hot water there has been little incentive to understand its full extent because of extensive local reserves of cheap natural gas and brown coal. The economic and environmental costs of those fossil energy sources are now on the rise, and the Gippsland Regional Aquatic Centre (GRAC), opened in 2020 in the town of Traralgon, became the first new user of the geothermal aquifer in several decades. The Latrobe City Council chose geothermal energy over natural gas to heat the GRAC based on cost, and the GRAC has now proven the potential of the aquifer as a source of cheap and reliable renewable heat—about AU$30 billion worth of heat at today's natural gas price.

The Latrobe Valley Authority and the University of Melbourne are working together to raise awareness of the economic potential of the aquifer and to identify other potential end users. We have recognized that geothermal sources in the same temperature range as the Gippsland Basin aquifer already provide sustainable, low emissions heat to a wide range of residential and industrial consumers in many other parts of the world. In most of those locations, the geothermal source is much deeper than in the Gippsland Basin. When compared to geothermal systems around the world, the natural hot water in the Gippsland Basin represents a truly world class geothermal energy resource that has, until now, been largely overlooked.

Developing the Gippsland Basin geothermal resource could provide many socio-enviro-economic advantages to the region. It could deliver residential and industrial heat at a cheaper and less volatile price than natural gas; it could encourage the growth of new industries to re-employ skilled workers displaced from coal and power industry jobs; it could displace or avoid particulate pollution and greenhouse-gas emissions from fossil fuel combustion; and it could lead to a proper appraisal of the potential for geothermal power generation from much deeper, undrilled reservoirs in the Gippsland Basin. Importantly, geothermal energy with reinjection could provide all these advantages without putting additional pressure on regional aquifers.

1. INTRODUCTION

1.1 Gippsland

The region of Gippsland covers 35,200 km^2 (Britannica, 2012) of gently rolling hills, alpine regions, forests, lakes and agricultural land in the southeast of the state of Victoria, which is itself in the southeast of Australia (Figure 1). DJPR (2022) reported that Gippsland has historically been known as a center for coal mining and electricity generation, with important economic contributions from the construction, healthcare & social assistance, agriculture, forestry & fishing, natural gas production, water, and waste services sectors. The region supported a population of 291,000 in 2020 (DJPR, 2022), divided amongst six local government areas (Bass Coast, Baw Baw, South Gippsland, Latrobe, Wellington, and East Gippsland) with their main administrative centers at Wonthaggi, Warragul, Leongatha, Morwell, Sale and Bairnsdale, respectively (Figure 1).

Several established industries in the region are now under pressure as Victoria moves to meet CO_2 emission reduction targets announced in May 2021; namely a reduction of 28–33% of emissions by 2025, 45–50% by 2030, and net zero emissions by 2050 (Acting Premier, 2021). The industries under most pressure are those that directly contribute to greenhouse gas emissions (notably coal mining, coal-fired power generation, and natural gas production), and those that have historically relied on cheap local power and fuel (including food processing, protected cropping, and some elements of healthcare and recreation.) This is driving a search for new sources of low emission energy, and for new industries to replace those under pressure.

1.2 Geothermal Innovation Group and the Geothermal Opportunity

This paper reports on activities carried out by the Geothermal Innovation Group (GIG) of the Gippsland Smart Specialization Strategy (G3S) coordinated by the Latrobe Valley Authority (LVA) in the state of Victoria, Australia. The LVA is a regionally-based government department in place to assist in the transition away from coal electricity generation towards renewable energy. The LVA is focused on a whole-of-region response, concentrating its efforts across the Energy, Food & Fiber, Health & Wellbeing, and Visitor Economy sectors. The GIG is a network of some 60 individuals from over 40 organizations collectively pursuing development of a 'geothermal economy.' The GIG works with government, industry, academia, and community to understand how government policy and regulation, industry capability, technology, workforce, and regional capacity can unlock Gippsland's competitive advantage.

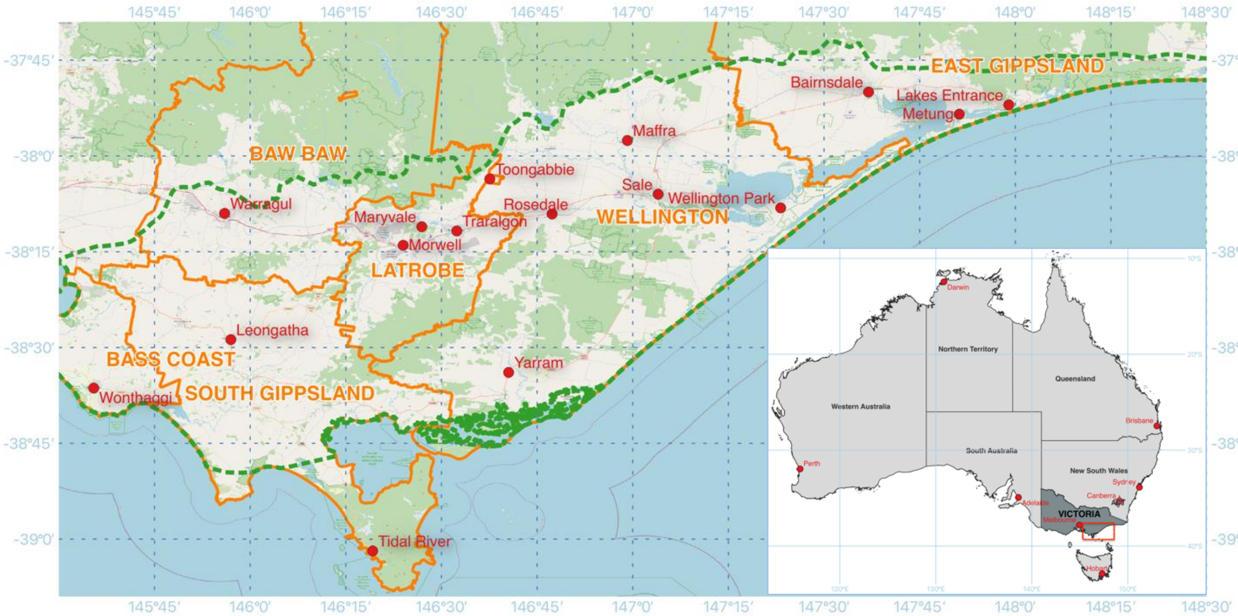

Figure 1: Location of Gippsland in Victoria in southeast Australia, showing cities and towns (red dots), local government areas (orange), and the onshore extent of the Gippsland Basin (dashed green outline).

Members of the GIG recognize that extensive, accessible and world class hot aquifers (described below) provide Gippsland with a competitive advantage in the form of geothermal energy as an alternative to natural gas for heating public, commercial or agricultural projects. Low-emissions sources of industrial heat to displace the combustion of natural gas are uncommon. Bio-gas, wood, bio-diesel, bio-methane (Table 1), and geothermal energy are some of the few options for low-emission baseload heat. Compared to the options in Table 1, geothermal heating systems drawing on natural hot water and incorporating heat exchangers and 100% reinjection emit effectively zero greenhouse gases, although McCay *et al*. (2019) estimated the range of lifetime emissions (due to fossil-fuel powered drilling and construction as 2.7–3.9 kg.CO_2-e per GJ_t) for 'deep geothermal' heating systems.

Table 1: Emission intensity of combustion of different fuels. Data (excluding geothermal) from DCCEEW (2022).

Fuel	Emissions intensity *(kg.CO_2-e per GJ_t)*
Natural gas	51.53
Fuel oil	18.00
Landfill or sludge biogas	6.43
Wood	1.20
Bio-diesel	0.28
Bio-methane	0.13

2. THE LOWER TERTIARY AQUIFER

We refer those readers to Powell et al. (2020) for a detailed description of the structure and stratigraphy of the Mesozoic-aged Gippsland Basin (see Figure 1 for the onshore extent of the basin.). For the purpose of this paper, it is sufficient to note that Tertiary-aged formations in the shallowest parts of the basin underlie much of Gippsland, resting unconformably on underlying Early Cretaceous rocks. The total thickness of Tertiary formations is about 750 m around Morwell, Maryvale and Traralgon, increasing to 1,200 m and deeper at the coast. The Tertiary formations include thick brown coal seams and several sandstone aquifers. Figure 2 presents the hydro-stratigraphy of the Gippsland Basin as defined in the Victorian Aquifer Framework (SKM, 2012). Some of the aquifers are interleaved with the coal seams, while others lie at deeper levels. The natural porosity and permeability of the aquifers can support production rates from individual bores of at least 100 liters per second, as demonstrated by numerous coal mine dewatering bores. The Lower Tertiary Aquifer (LTA) underlies about 6,000 km^2 of Gippsland and is the deepest (and therefore hottest) of the Tertiary aquifers.

A state government geologist first tabulated "many occurrences of high temperature waters [in boreholes] in East Gippsland" more than 60 years ago (Jenkin, 1962), including one notable observation of 70°C water at 525 m depth at the town of Maryvale. The LTA was the source of 70°C water at Maryvale, and the Gippsland Regional Aquatic Centre at Traralgon (see below) draws 68°C water from the LTA. The thick and shallow brown coal deposits are primarily responsible for the elevated temperatures in the LTA by providing a thick layer of thermal insulation, as modelled by Rawling et al. (2013). Temperature logs from bores which penetrate the thick coal seams into the LTA (e.g. Figure 3) provide compelling evidence to validate the models, invariably revealing extremely high temperature gradients through the insulating coal seams. The resulting elevated aquifer temperatures today make the LTA an attractive geothermal energy target.

Aquifer/aquitard	Hydrogeological units	Lithology
Upper Tertiary Quaternary Aquifer (UTQA)	Haunted Hill Formation, Eagle Point Sand.	Sand
Upper Tertiary Quaternary Aquitard (UTQD)	Boisdale Formation (Nuntin Clay)	Clay
Upper Tertiary Aquifer Fluvial (UTAF)	Boisdale Formation (Wurruk Sand)	Sand
Upper Tertiary Aquitard (UTD)	Hazelwood Formation, Yallourn Formation, Jemmys Point Formation, Sale Group	Coal
Upper mid-Tertiary Aquifer (UMTA)	Alberton Formation, Balook Formation, Cobia Subgroup, Gurnard Formation, Morwell Formation, Morwell M1-2 aquifers, Turrum Formation, Yarragon Formation	Coal/sand
Upper mid-Tertiary Aquitard (UMTD)	Giffard Sandstone Member, Gippsland Limestone, Lakes Entrance Formation, Seaspray Group, Tambo River Formation	Limestone
Lower mid-Tertiary Aquifer (LMTA)	Morwell 2 Coal Seam aquifer – (Rosedale, Lake Wellington Depression, Seaspray Depression, Traralgon Syncline) and Seaspray Group sands	Coal/sand
Lower Tertiary Aquifer (LTA)	Burong Formation, Childers Formation, Honeysuckle gravels, Latrobe Group, (Morwell 2 Coal Seam aquifer – when basal aquifer), Traralgon seams and aquifers, Yarram Formation	Sand/coal

Figure 2: Hydro-stratigraphy of the Gippsland Basin from the Victorian Aquifer Framework. From O’Neill et al. (2022).

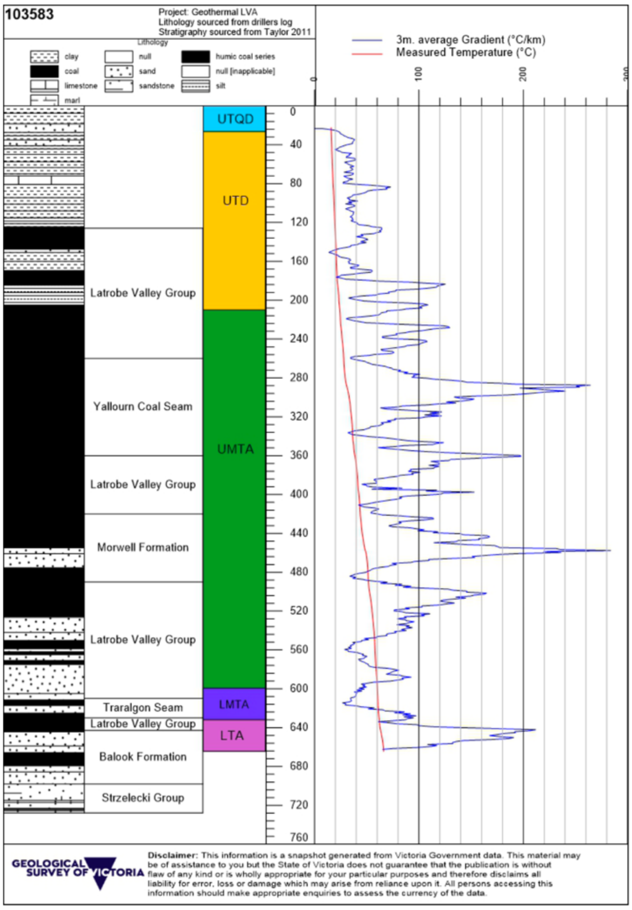

Figure 3: Temperature (red) and derived temperature gradient (blue) with depth to 660 m in the bore Winnindoo-46 (38° 06’22”S, 146°43’48”E) between Rosedale and Toongabbie. ‘Normal’ temperature gradient ~35°C/km is observed in sand and limestone layers, while coal corresponds to gradients up to 200°C/km or higher. From O’Neill et al. (2022).

As part of a recent collaboration between the University of Melbourne and the Geological Survey of Victoria, supported by the Latrobe Valley Authority, O’Neill et al. (2022) produced a new series of maps of the geothermal energy properties of the LTA and other Tertiary-aged aquifers in Gippsland. The maps were based on new compilations and interpretations of pre-existing data sets, and new temperature data measured in boreholes (e.g. Figure 3). Figure 4 shows a subset of the maps; namely the depth and temperature at the top of, and the transmissivity and salinity within, the LTA. The maps provide a solid foundation from which to investigate the technical and commercial feasibility of geothermal development projects.

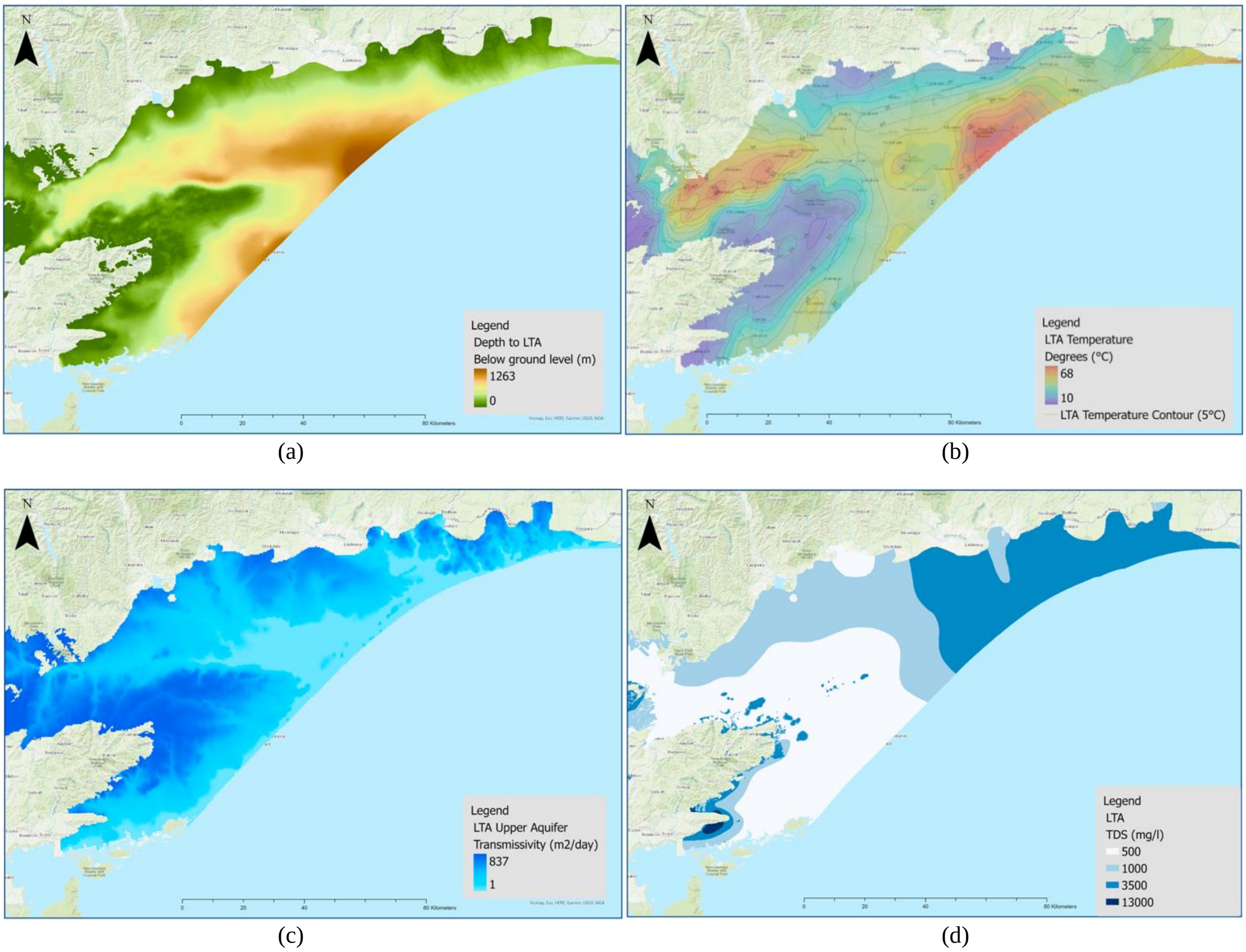

Figure 4: Maps of geothermal source properties of the Lower Tertiary Aquifer. (a) Depth to top of the LTA (m), (b) temperature at top of the LTA (°C), transmissivity of the LTA (m^2/day), (d) salinity of the LTA (mg/l). From O'Neill et al. (2022).

3. GEOTHERMAL ENERGY IN GIPPSLAND

3.1 Global and Local Context

Other regions around the world have embraced the use of geothermal energy from aquifers in the same temperature range as the LTA (30–70°C). In this temperature range, the uses for the geothermal energy as a substitute of low-grade heat commonly supplied by natural gas. While the economics of heat supply are inherently local, Gippsland stakeholders can learn from other regions' experiences. Beardsmore (2021) reported the results of a high level environmental scan which identified and drew lessons from regions exploiting geothermal aquifers in a comparable temperature range to the LTA. The report concluded that the LTA is without a doubt a world-class low-grade geothermal energy resource. It furthermore concluded that regions can specialize in the type of geothermal projects they support; that central governments have a role to provide a coherent, enabling and persistent policy and legislative framework to promote and facilitate secure access to, and sustainable use of, geothermal resources; and that regions in which government, industry, academia and the community collaborate to define and achieve a common goal (such as through the Geothermal Innovation Group coordinated by the Latrobe Valley Authority) are most successful at developing sustainable geothermal economies.

The energy potential of the hot aquifers beneath Gippsland, and particularly the LTA, has been recognized for over half a century by government geologists and academics (e.g. Jenkin, 1962; King et al., 1987; Driscoll, 2006; Beardsmore et al., 2016; Beardsmore et al., 2017; O'Neill et al., 2022). Public or commercial projects to utilize the energy, however, have until recently been rare. Burns et al. (1995) reported only a single historical use of the geothermal resource in a paper manufacturing mill in Maryvale during the 1950s, prior to the development of the brown coal power industry and the discovery of natural gas in Bass Strait offshore from Gippsland. This has largely been due to a lack of incentive to investigate alternative energy sources. The region has enjoyed an abundance of cheap natural gas and brown coal resources for heat and power.

But the once-stable energy market in eastern Australia is in a state of rapid transition. In Victoria, the three largest coal-fired power stations (Yallourn-W, Loy Yang A, and Loy Yang B; all in Gippsland) are officially scheduled for retirement in 2028, 2035 and 2047, respectively (AEMO, 2023), with no plans to build any new coal-fired plants. At the same time, eastern Australia has experienced a sharp rise in the price and volatility of natural gas since Australia started exporting liquified natural gas in 2016, exacerbated by the global energy market volatility since early 2022 (Figure 5). These factors led to the Latrobe Valley Authority to identify 'Energy' as a growth sector for Gippsland, to identify geothermal energy as a potential competitive advantage for the region, and to support projects aimed at evaluating and demonstrating geothermal energy utilization. The following section briefly describes some of the projects supported by the LVA and other branches of government and some emerging opportunities.

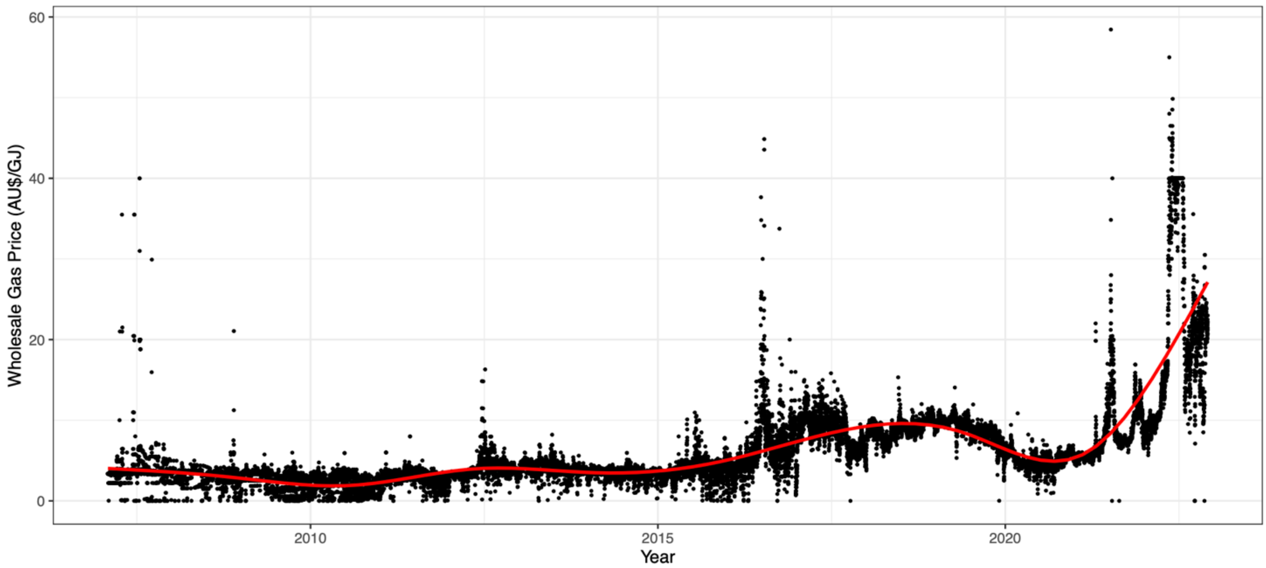

Figure 5. Natural gas wholesale prices in Victoria since records began in 2007. Red line shows a smoothed fit to the data. After Fu et al. (submitted).

3.2 Recent Projects and Emerging Opportunities

3.2.1 Barramundi

Supported by Regional Development Victoria, the University of Melbourne led an investigation into the technical and economic feasibility of maintaining a 500 Ha open body of water as a recreational fishery at close to 30°C year round using geothermal energy from hot aquifers. to support a recreational fishery stocked with barramundi for geothermal energy from hot aquifers). The open body of water was the cooling pond of the Hazelwood Power Plant a few kilometers southwest of Morwell, into which the Victorian Government had introduced barramundi (*Lates calcarifer*, or edible Asian sea bass) for recreational fishing a short time before the power plant announced its impending closure with associated cessation of warm water flow into the pond. Beardsmore et al. (2017) concluded that it would be technically feasible, and would provide net economic benefit, to heat 10–30 Ha of the pond. That project did not proceed, but as of January 2023 a company is proceeding with a project to build an aquaculture facility heated with geothermal energy to grow barramundi for the restaurant and export market.

3.2.2 Hot Spring Spas

Metung Hot Springs (https://www.metunghotsprings.com/) opened its first stage of operations at Metung in East Gippsland (see Figure 1) in late 2022, drawing natural geothermal water from the Gippsland Basin for bathing and wellness. While less advanced in development, Nunduk Spa Retreat (https://www.nunduk.com/) at Wellington Park in Wellington is in the process of drilling exploratory wells for geothermal water in early 2023.

3.2.3 Gippsland Regional Aquatic Centre

The Gippsland Regional Aquatic Centre (GRAC) in Traralgon (see Figure 1) is a public recreational facility built and owned by Latrobe City Council (LCC) with financial support from the Latrobe Valley Authority. The AU$57 million facility, which opened in March 2021, contains a fully-equipped gymnasium, group fitness rooms, indoor and outdoor heated swimming pools and aquatic play areas, a wellness center, a café, and a retail store. The GRAC is the first facility of its kind in Victoria to use geothermal energy to heat its swimming pools and buildings, drawing 68°C water from a depth of about 650 m in the LTA. During its first full year of operation, the geothermal system ran at 95% availability, demonstrating the technical feasibility of geothermal heating in Gippsland.

The University of Melbourne analyzed twelve full months of production and running cost data for the GRAC's geothermal heating system, along with capital costs, and completed a robust analysis of the geothermal system's economic performance (Fu et al., submitted). The levelized cost of heat from the geothermal system was found to be substantially lower than the equivalent cost of heating with natural gas. In fact, the GRAC geothermal project was found to have a positive net present value for any natural gas price greater than 10.80 AU$/GJ (7.68 US$/GJ in January 2023). The natural gas tariff paid by LCC at the time of the study was 31.0261 AU$/GJ, indicating substantial cost savings and a pay-pack period less than five years from the geothermal system.

The GRAC has, therefore, demonstrated both the technical and economic viability of geothermal heating in Gippsland. The results have already stimulated interest in developing more geothermal heating systems across the region.

3.2.4 Mapping by Geological Survey of Victoria

As already mentioned above in Section 2, the Geological Survey of Victoria published a suite a new maps of the geothermal characteristics of Gippsland's Tertiary aquifers in 2022 (O'Neill et al., 2022). These maps were generated as a collaborative project with the University of Melbourne, which developed complementary economic assessment algorithms. The maps and algorithms are jointly intended to underpin a future online map-based portal for assessing the technical and economic potential for geothermal energy at any location in Gippsland.

3.2.5 Drill cost estimator

One of the economic assessment algorithms developed by University of Melbourne (with substantial input from drilling consultants) is a tool to estimate the cost of drilling geothermal production and injection bores at any given location in Gippsland. The algorithm takes as its inputs the geology and the characteristics of the geothermal aquifers at the specified location, and the expected thermal power consumption and longevity of the nominated project. The algorithm computes the required flow rate to produce the required thermal power, and from there the diameter and length of the required production (or injection) zone in the aquifer, and the production casing and pump chambers required to complete an appropriate bore. Costs for all the drilling and completion elements are finally estimated for the bore. The algorithm for now remains unpublished.

3.2.6 Smart Geothermal Industrial Loop

Regional Development Victoria is supporting a project led by the University of Melbourne to design and cost a 'smart geothermal industrial loop' (SGIL) for a site near Morwell. The SGIL is intended to be Australia's first geothermal district heating system to sell heat to independent end users. As such, the project entails not just geological and engineering studies, but also an assessment of legislation and regulation that may impact the commercial sale of heat in Victoria; something that is not explicitly addressed in the current legal framework. Interested readers are referred to Cariaga (2023) for more information.

3.2.7 Power generation study

While not the primary focus for development or investigation at present, the University of Melbourne recently completed a desktop investigation into options and economics of geothermal power generation in Gippsland, looking at four specific scenarios. The project concluded that the *prima facie* economics of a hybrid solar PV / geothermal power generation and thermal energy storage project appear compelling enough to warrant further investigation. The findings for now remain unpublished.

3.2.8 Other projects under consideration

The technical and economic success of the GRAC geothermal system has demonstrated that geothermal energy is a viable option for low-grade industrial heat in Gippsland. The local governments in both Wellington and East Gippsland are each now investigating geothermal district heating systems for their main administrative centres. Private companies are investigating geothermal heating for protected horticulture, aquaculture, poultry sheds, and other applications.

3.3 Future Directions

The technical and financial viability of low grade geothermal heating has now been demonstrated in Gippsland, so attention is turning to sustainable management of the geothermal aquifers. A consistent regulatory framework does not yet exist for low grade geothermal energy, with projects largely managed under existing groundwater management rules. Those rules did not envision large-scale reinjection of cooled water, or the possibility of 'thermal pollution' of the aquifers. The result is that applications for licenses for new geothermal projects are currently subject to long delays.

Several parallel lines of activity are suggested to facilitate the sustainable and beneficial development of Gippsland's geothermal energy resource. These can be briefly summarized as follows:

- Continue to improve knowledge of the extent and thermos-physical characteristics of the geothermal aquifers;
- Cultivate a consistent regulatory framework for the sustainable management of the geothermal aquifers;
- Develop pilot projects for specific end-use cases (including power generation);
- Assess the technical and financial performance of the pilot projects;
- Build public awareness of the world class geothermal potential of Gippsland;
- Identify and address possible skill shortages for geothermal development.

4. CONCLUDING REMARKS

The Geothermal Innovation Group coordinated by the Latrobe Valley Authority is working to develop a better understanding of the geothermal energy potential of Gippsland and to define and implement an optimal pathway to sustainably develop the potential. When compared to analogous geothermal energy sources in other parts the world, natural hot water in the Gippsland Basin represents a truly world class resource that has, until now, been largely overlooked. Developing the Gippsland Basin geothermal resource could provide many socio-enviro-economic advantages to Gippsland and Victoria. It could deliver residential and industrial heat at a cheaper and less volatile price than natural gas; it could encourage the growth of new industries to re-employ skilled workers displaced from coal and power industry jobs; it could displace or avoid particulate pollution and greenhouse-gas emissions from fossil fuel combustion; and it could lead to a proper appraisal of the potential for geothermal power generation from much deeper, undrilled reservoirs in the Gippsland Basin. Importantly, geothermal energy with reinjection could provide all these advantages without putting additional pressure on regional aquifers.

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