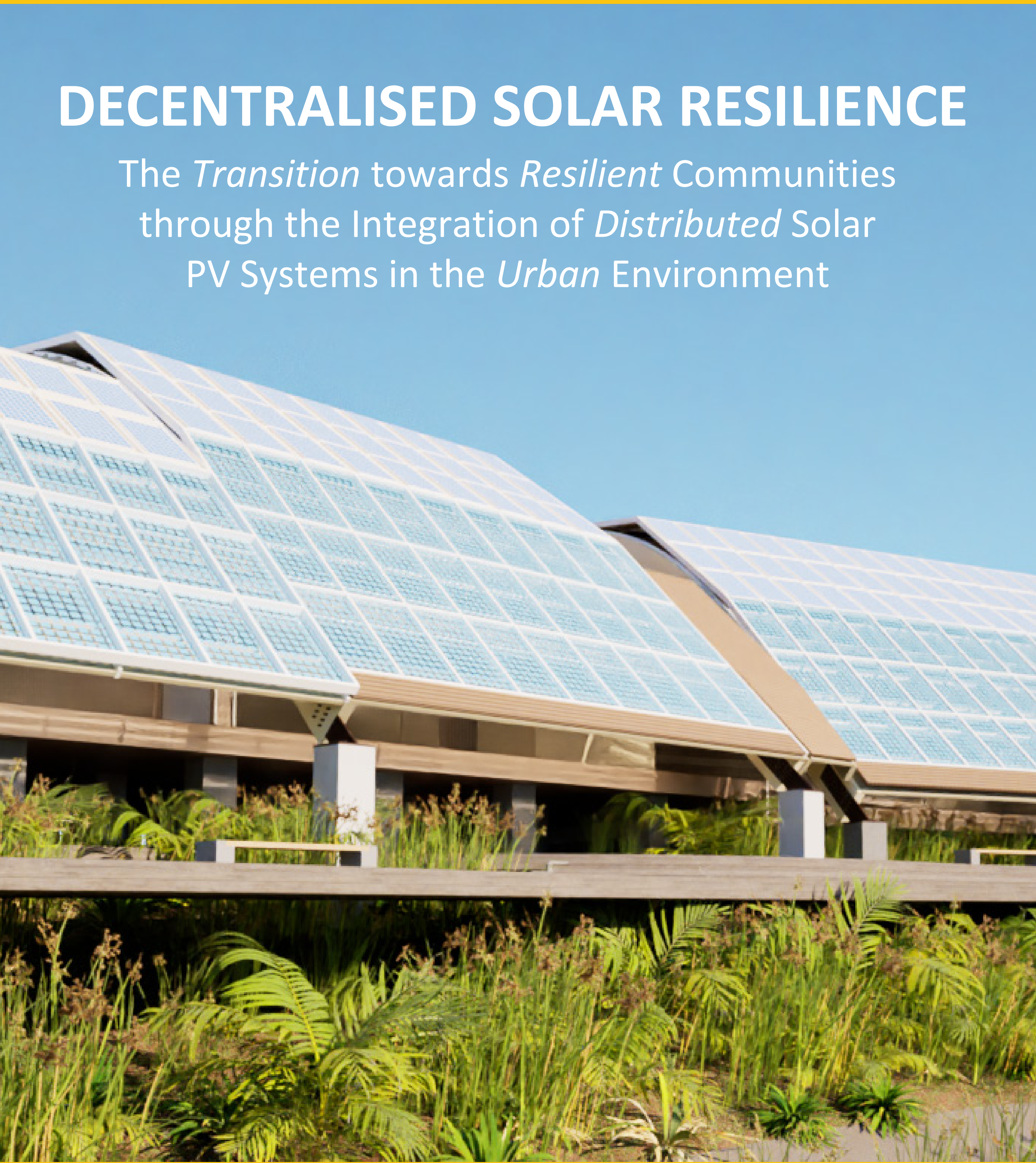
DECENTRALISED SOLAR RESILIENCE

The *Transition* towards *Resilient* Communities through the Integration of *Distributed* Solar PV Systems in the *Urban* Environment



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Faculty of Design and Creative Technologies, School of Future Environments

ABSTRACT

This design-led research, Decentralised Solar Resilience, explores the possibility of solar power generation integrated into communities and cities in Aotearoa. The design proposal is in response to the ongoing climate crisis of this century as an act to be resilient while mitigating its damaging effects. The centralisation of solar was discussed with its current implementation of solar farms in New Zealand, however, the decentralisation of these systems favoured a more integrative approach within the urban environment. Thus, the strategy was adopted within the design proposal, a solar station, to host these systems and become a central link for an interconnected system for energy storage, generation and distribution, as well as a disaster relief centre.

The solar station is integrated into communities not only to provide energy security and resilience on and off-site but also the transition to a new norm within the electrical infrastructure. It functions as a place for energy services and a space for communal activity, serving dual purposes of electrical and social regeneration. Like a tree, the intervention will be planted in Manukau; a suburb in south Auckland and grow into a rooted interconnected urban environment, being part of the community's infrastructure and beginning of an energy-resilient city.

This architectural integration was landed by investigating the question, *"How can solar photovoltaic systems be implemented to adapt and migat e against climate change for more resilient communies? "*. A literature review was carried out to evaluate the current standings within the global and local solar industry. This revealed the need for action within New Zealand against climate change through its lack of movement towards decentralised solar energy. Analysing existing solar PV implementations and integration within the community for a solar transition; presented a building, the solar station. This proposal was refined through design-led research of mapping, calculative simulation and precedent studies through an energy-resilient framework.

Key words: Decentralisation, Solar photovoltaics, Solar PV system, Urban environment, Resilience, Architecture.

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed
Kyle Paala

February 2025

Some images have been removed due to copy right issues*

ACKNOWLEGDEMENTS

Special thanks to my supervisors Dr Priscila Besen and Dr Andrew Burgess for their efforts in guiding this research paper to produce a quality piece of work. I'm also grateful for the collaboration with the Aurecon Group, Yasmin Tapiheroe and Damian McGhahan for providing expert insight into renewable energy influencing the topic of this research.

POSITIONALITY STATEMENT

Studying Architecture at Huri Te Ao School of Future Environments moulded my aspirations to pursue sustainability and regenerative design. Both terms extend to multiple aspects of architecture, whether it is manufacturing the materials of the building or how the project itself affects the built environment through people and the surrounding context. The Mauri Ora compass influenced these views as an action tool for urban generation through Maori values, with research supported by AUT. Within this umbrella, renewable energy has been a recurring theme among my projects with the idea of self-sustaining in green energy and giving more than it takes. This positions myself in collaboration with the Aurecon Group to explore implications and integration of more renewable energy projects in communities and the environment.

Self-sustainability can be taken further by distributing the energy to multiple destinations like the proposed Solar Station. It is this thrive to achieve more than just an equilibrium but revitalisation through a project, is fundamental to reach a successful project integration.

It is crucial to practice this mindset with the rise of climate awareness, the effects of climate change have become more frequent and severe. Thus, resilience is key to adapting to the climate crisis and reducing its overwhelming damages by mitigating its effects with the inclusion of renewable energy towards climate regeneration away from emergencies.

GLOSSARY

PPA – Power Purchase Agreement

DER – Distributed Energy Resources

VPP – Virtual Power Plant

FIT – Feed in Tariff

PV – Photovoltaic

BIPV – Building Integrated Photovoltaics

W – Watts

WH – Watts per Hour

KW – Kilowatts

KWH – Kilowatts per Hour

KWP – Kilowatts peak

MW – Megawatts

MWH – Megawatts per Hour

GW – Gigawatts

INTRODUCTION

Solar power generation has been around for the past 70 years, evolving in each decade to be more efficient and evoke innovation. However, has it maximised its integration for resilience? The matter in question is the implementation of solar photovoltaic (PV) systems in today's urban landscape. What is it now? Just a luxury purchase? Just panels on the roof? Just to exceed the standard? Unfortunately, that is what has become in Aotearoa. Do not be mistaken, these descriptions of its status are not intended to be adverse but to reveal that it can be more than just an installation. To move forward and innovate what is next for solar PV systems in the urban environment.

Architectural resilience is the ability to withstand, recover and sustain against extreme natural events (Jia & Zhan, 2023). This concept will embed itself into how solar PV will be integrated within buildings, progressing towards the next evolution of its implementation. Aotearoa's recent introduction of solar batteries has made it possible to deliver the goal of architectural resilience in solar PV. Thus, solar PV can be a solution for both adaptation and mitigation simultaneously. It promotes adaptation by providing reliable power during extreme weather events and works on mitigation by generating renewable energy reducing carbon emissions. Integrating with architecture allows to exceed equilibrium from sustainability to electrical regeneration beyond the building itself.

This thesis, *Decentralised Solar Resilience: The Transition towards Resilient Communities through the Integration of Distributed Solar PV Systems in the Urban Environment*, merges different international approaches to solar into a communal and national strategy for Aotearoa. It begins as a building in a site central to Manukau, Auckland, a seed to sprout for solar resilience in the urban environment. With initial research to advance solar power integration, it is taken further to support the question "*How can solar photovoltaic systems be implemented to adapt and mitigate mitigate against climate change for more resilient communities?*". Conducting this design-led research in a New Zealand context, revealed several issues of solar integration. This includes a predominant centralised system and lack of government incentives for solar delaying the progression towards communal resilience.

The thesis then synthesises this research into an architectural outcome to promote and support communities with the benefits of decentralised solar systems. First, the architecture tests how the urban environment could transition into integrating distributed solar PV systems. Where and who will host these systems first and become a catalyst for the strategy? Second, is the merging of different resources and systems into one site, being an energy hub, a place for recreation and disaster relief. Finally, it creates a new medium to support the existing infrastructure and well-being not only within its community but reaching towards the region and nation. The outcome led to more than just energy security through decentralisation, but climate resilience through its integration with the urban environment.

The climate crisis is the result of immoderate greenhouse gas emissions with carbon dioxide (43.7%) made up of transport (38%), manufacturing/construction (19.1%), public electricity and heat production (13.4%) in New Zealand, 2020 (Stats NZ, 2022). The proposal addresses the public electricity sector in its integration through community connections for renewable energy

Aotearoa has recently experienced a one in a 200-year weather event of cyclone Gabrielle. (Morton, 2024). The country declared a state of national emergency when the cyclone hit Hawkes Bay and Napier in February 2023. Mass flooding, landslides and severe winds resulted in evacuation, community displacement and isolation of access and electricity (IDMC, 2024). Certain areas were cut from power for days and even a week from damages caused by debris and flooding disabling electrical infrastructure (Tan, 2023). As a climate response, the proposal of the Solar Station integrated within communities aims to promote resilience for adaptation but also mitigation against climate change. Solar PV generating renewable energy allows this multiplicity, providing multiple benefits from one technology, a necessity in this climate emergency.

SOLAR APPROACH

SOLAR PHOTOVOLTAICS

The first silicon photovoltaic (PV) cell of what we see today was created in the United States in 1954, converting the sun's energy to electricity. (Energy Efficiency & Renewable Energy, 2002). Since then, these cells have been implemented into various products and projects like satellites in the 1960s, and rooftops of homes and commercial buildings through different incentives and policies. Solar photovoltaic (PV) has been made a marvel and has spread throughout the globe with countries utilising its benefits differently. As the technology has continued to improve and increase in production, it has seen a significant decrease in price over the last two decades, making it more affordable for homeowners to purchase and install. The addition of solar batteries and their recent introduction in New Zealand has changed the scale of integrating solar PV panels in the consumer sector.

As solar PV panels have become cheaper and more affordable Figure 1 (IRENA, 2023), so are solar batteries. Lithium-ion batteries are commonly paired with solar PV systems, with its price per kWh shown to decreased by more than half in the past decade (Ritchie, 2021). Although solar batteries are getting cheaper, the upfront costs are still expensive over NZD 10,000 (Wells, 2023). This results in a longer return of investment period with the addition of the battery, leaving buyers reluctant to install until prices begin to attract in its trend for decline.

The global market price for solar PV has drastically decreased over the past decade (IRENA, 2023). Corresponding with the New Zealand market for the price of a 3KW solar power system (MySolarQuotes, 2024). The price increase in 2022 was due to freight costs during the pandemic (Wells, 2023), however, it will continue to drop in 2024.

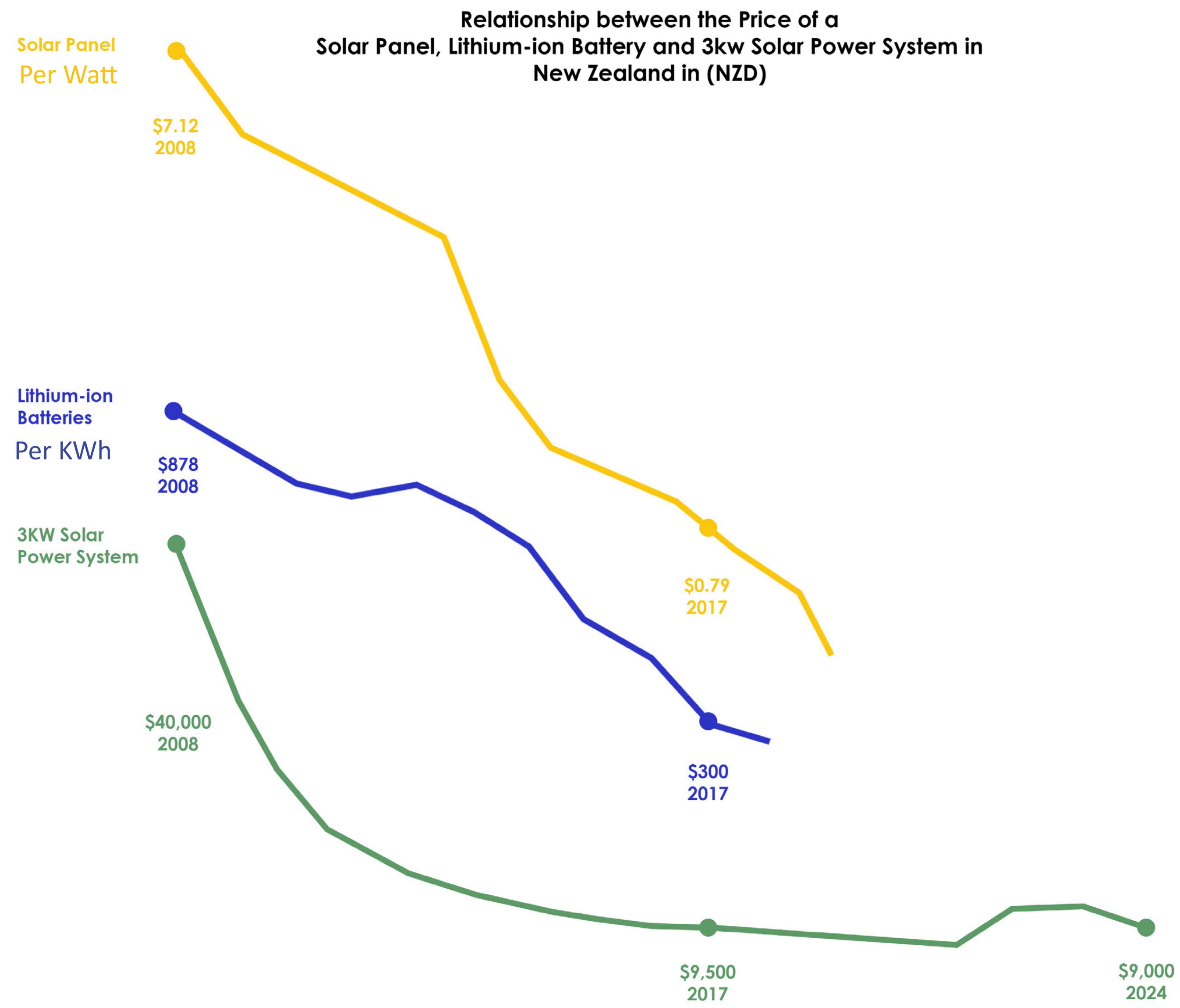
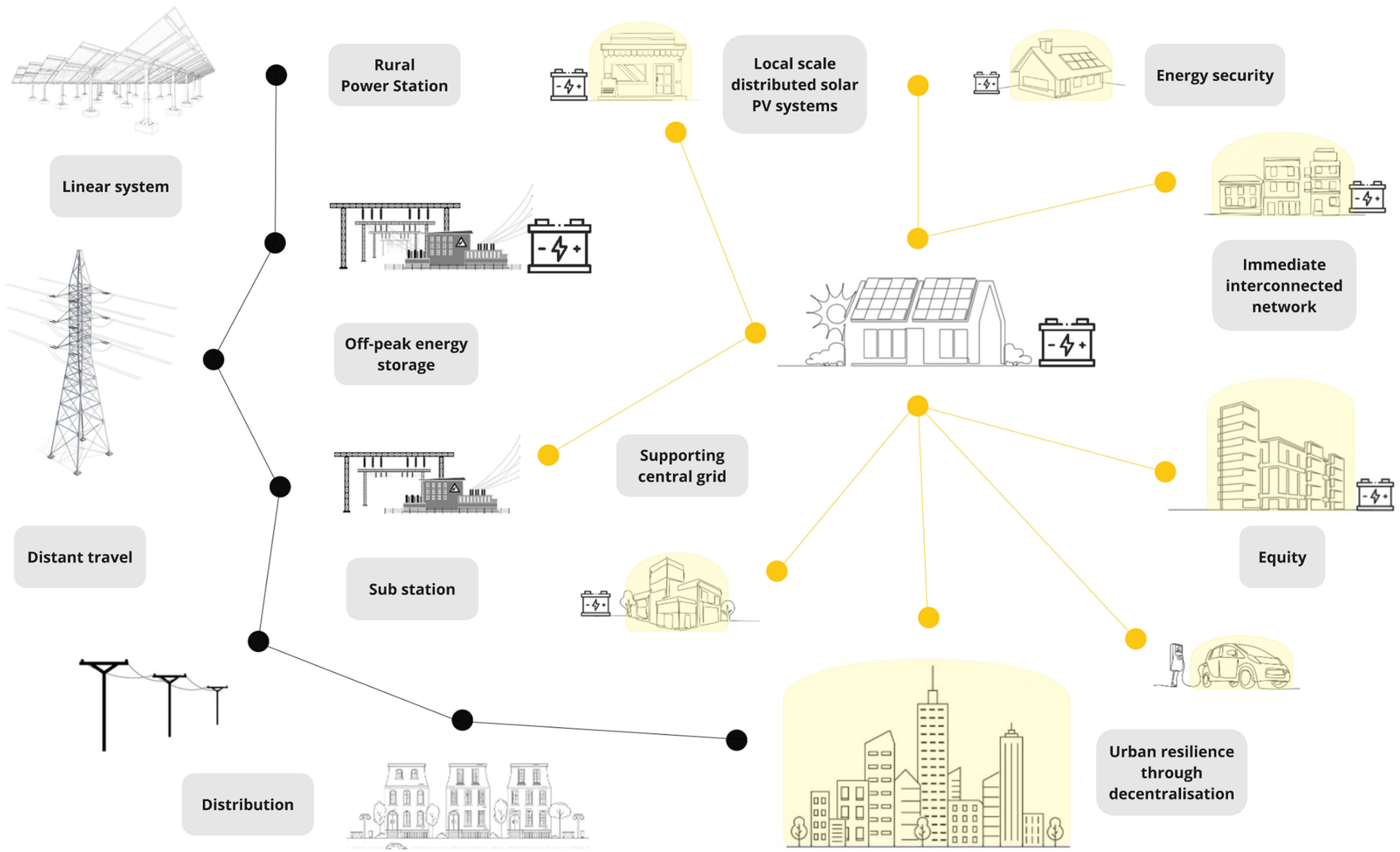


Figure 1: Decreasing Price of Solar Panel, Lithium-ion Battery and 3kW Solar Power System in New Zealand (NZD), Author's own work based on (IRENA, 2023), (Ritchie, 2021) and (MySolarQuotes, 2024).

CENTRALISATION VS DECENTRALISATION

Figure 2: Centralisaton vs Decentralisation, the differences in appraoch.



CENTRALISED SOLAR

Centralised photovoltaic (PV) generation is a large-scale plantation of solar PV built to generate megawatts (MW) of electricity at a rural location (Mustafa et al., 2017). Centralised PV are solar farms that take a large area of land consisting of multiple solar PV arrays typically mounted on the ground and facing the sun. The energy produced from the solar panels is then carried as DC to an inverter to become AC and apply for electrical transmissions to substations and then consumers. Solar farms vary in size - a typical solar farm generates approximately 5000KW (5MW) (Smith & Lane, 2024) producing 6,387,500KWh per annum. Which will be distributed within the central grid through a linear system of transmission lines and power poles to connect thousands of houses, communities, and the city with electricity.

Figure 3: Wairau Valley Solar Farm by Kea Energy (Keaenergy, 2024).

The advantage of centralised PV is its high yield in energy and its cost per watt, between 1.47 to 1.67 NZD as each space is optimised to reach capital gain on-site (Smith & Lane, 2024). This correlates to the large scale of centralised PV projects by having plots of land for the sole massing of solar ground-mounted PV all concentrated at one location. This also benefits when solar PV systems are required for advancements, it will be easier to change or upscale for labourers to execute immediately.

However, a disadvantage is the scarcity of land increases for these projects as location and plot size are not the only factors for implementation (Rathore et al., 2018). Solar farms being in rural areas creates a large distance travelled for energy to reach the consumers.

Figure 4: Kaitaia Solar Farm by Lodestone (Lodestone Energy, 2023).

Hence, energy is lost through resistance and is not utilised at an instance due to travelling between power plants and infrastructure giving a higher chance of disruptions from A to B. Another drawback is the current monofunctional purpose of centralised PV solar farms by having all these materials and components concentrated in one area creating a destructive atmosphere in its local environment both physically and aesthetically. The microclimate will increase in temperature creating a small heat island effect on the plot of land and potential depreciation of the local environment (Nordberg et al., 2021). However, agrivoltaics are on the rise as a synergistic approach to solar farms. An agrivoltaics system is the outcome of merging agriculture, whether it is livestock or orchards with solar farms creating a multifunctional and regenerative environment. Due to large-scale solar farms, maintenance is also a challenge and will be highly labour-intensive as manual work is required to thoroughly clean each solar panel (Shenoy, 2023).

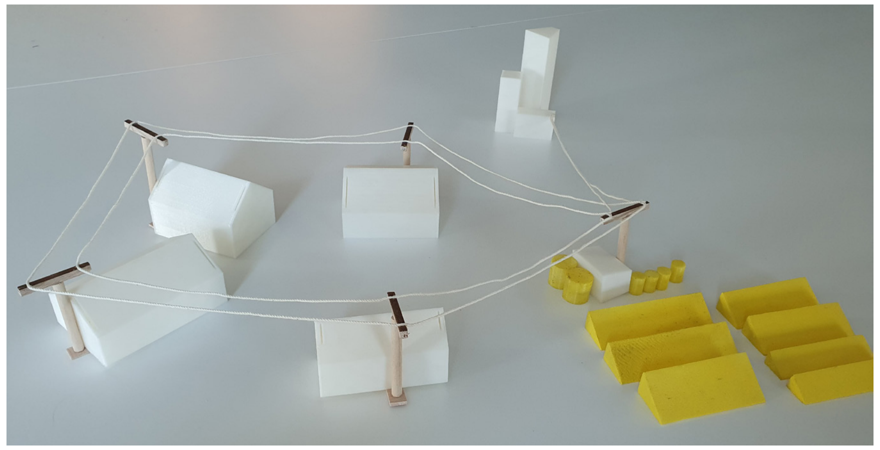


Figure 5: Model demonstration of Centralised Solar.

DECENTRALISED SOLAR

Decentralised PV generation is a local-scale system of solar PV built on existing infrastructure or buildings to satisfy individual energy needs (Rathore et al., 2018). Building-integrated PV is an example of decentralised PV and rooftop solar PVs, on multiple residential buildings it would give a distributed solar power system. Regular solar roof PV systems are solar panels mounted, angled and orientated towards the sun on existing roofs. This is connected to the house, and the energy produced is converted into electricity to power the building. A battery can be added to the solar PV system to store excess or unused electricity for later consumption in addition to an electric car charger. This allows the users to accumulate energy during the day and use it during the night to avoid selling it back to the central grid in an urban setting (D, 2023). Rural buildings are mostly disconnected from the central grid, so they can rely on their battery storage and electrical usage generated from their solar roof PV system.

Figure 6: Rooftop solar PV by Trisolar (Montogmery, 2021).

The advantage of decentralised PV is its location and versatility for implementation within the urban environment. It does not require a rural plot of land but a surface to be mounted on such as existing roofs or walls of residential or commercial buildings compared to centralised solar. The electricity produced will not have to travel kilometres either and lose energy, instead decentralised solar PV will power each building on site one by one (Mustafa, 2017).

Integration can extend to existing shelters on parks, canopies, bus stops and even commercial facades revealing its multifaceted nature (Fitchner, 2024). Depending on the business model of the implemented solar PV system, it can be owned by the contractor or the user; nonetheless, it permits independent usage instead of relying on government infrastructure. Generating and operating independently will lead to user electrical resilience for the building against power outages when the central grid is compromised. Furthermore, this concept can be further built upon to strengthen community resilience by connecting all distributed solar PV into a local system to create a microgrid (ARENA, 2023). This will allow electricity to be stored and then shared communally.

The scale of decentralised PV is at a disadvantage when isolating a single building and its energy production. Although the scale of the concept can grow by creating microgrids amongst multiple buildings and communities, not all can afford or host a rooftop solar PV. As building orientation and adequate sunlight factors, it will not compare to the efficient electrical output of solar farms. Another disadvantage is installing and maintaining a full rooftop solar PV system with a battery. In contrast, the business model of the Power Purchase Agreement (PPA) dismisses this financial challenge by permitting the contracted installer to rent the client's roof space with a fully funded solar PV system instalment and maintenance (Transpower, 2023a). This agreement between the two parties allows the contractor to generate electricity for capital gain and for clients to buy electricity at a discounted price.

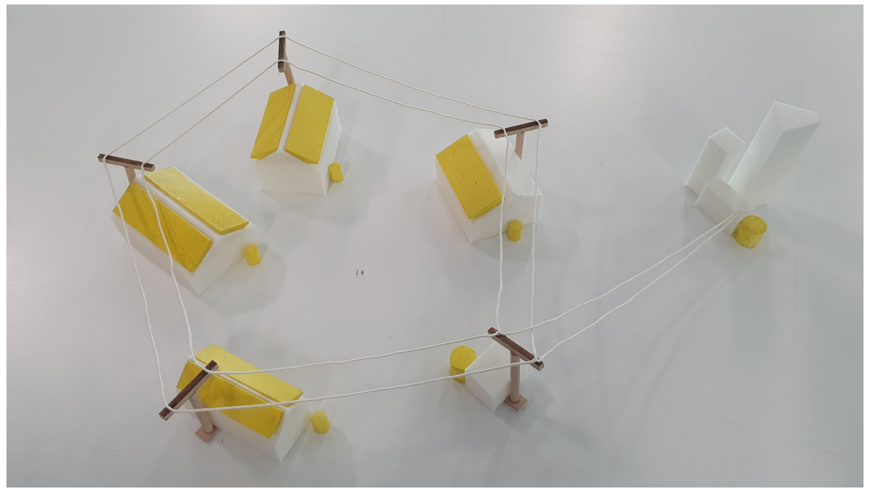


Figure 7: Model demonstration of Decentralised Solar.

The downside of solar PV in general is its peak generation during the day but peak electrical usage during the night. Most people will be at work hence the electricity generated is obsolete without battery storage. The added battery gives a maximum of 10 hours of storage for night-time use (WorldSolar, 2018). However, the current market for batteries is still expensive while the price of solar panels continues to drop (MySolarQuotes, 2024). Hence investors are still waiting for batteries to drop for it to be truly viable. This then raises the issue of seasonal peak generation and usage of summer and winter which is shown in Figure 8 (Gen less, 2024) resulting in consumers buying electricity from the central grid whenever supply does not meet the demand. A normal ion battery or local-scale energy storage cannot hold energy seasonally, which leads to centralised rural-scale energy storage.

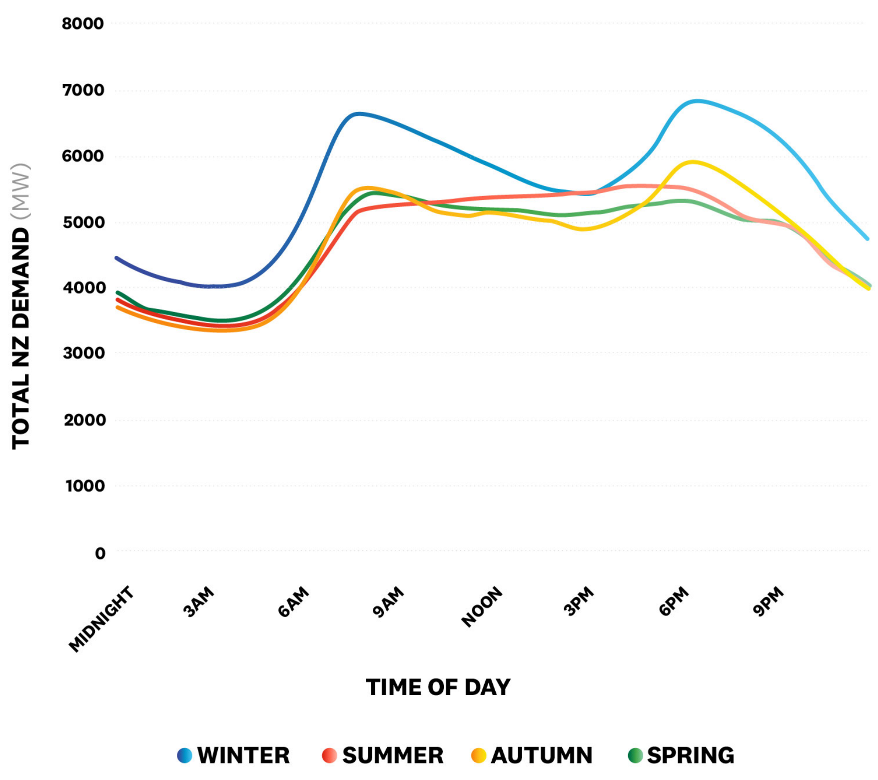


Figure 8: NZ Peak Energy Demand by Gen Less (Gen Less, 2018).

PRO DECENTRALISATION

The approaches to solar PV systems centralised or decentralised both have advantages against each other. However, decentralised solar PV promotes resilience, versatility and community in its integration compared to centralisation in the urban environment. The proposal is not to vanquish solar farms but to reveal the benefits of decentralisation through distributed solar PV and have both approaches co-exist. Solar farms are already proficient and accepted in their design and purpose with potential changes for further improvement. Whereas, distributed solar PV is still yet to be pushed forward to be more than just solar panels on a roof but to be a potential regenerative system in the community. Decentralisation triumphs over centralisation with its mitigating qualities and adaptive use against climate change, which is necessary to be revealed and progress for the demand of its integration.

GLOBAL ACTION

What are actions taken for decentralised solar internationally? Looking at Japan, they were one of the first countries to spearhead solar PV, after surpassing the United States and taking the title of global leader in solar PV production in 1999. Japan's government began their support for residential PV systems by implementing "subsidies, loans, mediation and interest subsidies" (Yoneda, 2008) in 1994 until this day but through different campaigns or local governments. Japan plans to increase its share of renewable energy from 10% to 45% by 2024 (Ho, 2024). In terms of solar energy, Tokyo is on its way by mandating solar PV systems on rooftops of new houses and small buildings starting in 2025. This means home builders who cover projects of more than 20,000m^2 per year are obliged to add solar PV systems into their new projects such as houses and buildings with a floor area of less than 2000m^2 (Hutchins, 2023). This was advanced from Kyoto's current requirements of installing solar PV systems to new or renovated buildings with a floor area of 2000m^2 from 2020.

Germany is also one of the leading countries in solar PV production surpassing Japan in 2005 for the global leader title. In the 1990s around the same time Japan started installing residential rooftop PV systems, Germany executed a 1,000-roof scheme. This developed into the 100,000-roof scheme in 1999 which is a programme that supports the installation through loans and repayments of rooftop solar PV systems greater than 1 KW on residential buildings (Friedrich-Ebert-Foundation, 2006). However, these schemes were terminated in 2003 and continued with compensations and eventually subsidies. Germany's plan is to be supplied with 80% renewable energy by 2030, with solar PV systems as key to achieving their goal. They have set out to revise their current plan Renewable Energies Acts and proposed under solar package one; *a dozen acts to relax the regulave process towards the permits and create frameworks of installing both centralised and decentralised solar PV* (Aúz, 2024).

Australia was the fourth global leader in solar PV production in 2005 and maintains its rank as sixth in 2023 (AGL, 2018). As the country has the highest solar radiation on any continent, it has been recognised as a viable primary source of energy in the early 2000s. This led to growing acknowledgements of locals and the market for solar, opening for services and installations in households (Aztech Solar, 2021). From 2010 to the present day the Australian government has and will continue to heavily invest in solar research, generation, transmission, and storage projects to increase capacity, management, and innovation. Australia also has a target of 82% of renewable energy by 2030 with the government supercharging their incentives, subsidies, and grants. This includes the Large-scale Renewable Energy Target (LRET) for investments in solar farms and the Small-scale Renewable Energy Scheme (SRES) for solar PV systems in households and businesses (Australian Trade and Investment Commission, 2024).

Japan, Germany, and Australia each represent different solar markets in the world and implementations of solar PV. Japan with its urban dense and populated cities such as Tokyo approaches bold solar rooftop regulations whereas Germany, a representative for Europe, incentivises through moderation in subsidies and incentives as its primary approach. Australia follows this same path giving a local market in Oceania but differs from the other countries with its extensive investments and funds. All three countries implement the same business model of PPAs and the policy of Feed in Tariff (FIT) where owners receive a certain rate per watt when selling excess electricity back to the grid which helps with incentives and consumer acquisition. Although, how do these countries compare with New Zealand?

ACTIONS IN AOTEAROA

New Zealand also has PPA business models in the solar market and FITs for excess electricity. However, it stops there as government incentives through subsidies and regulation have not been proposed or implemented, stagnating the market for acquiring mass consumers. Attempts have been made by the Labour Party to amp and support solar PV such as a $4000 rebate to install rooftop PV and battery and $20 million boost for energy projects in local communities under a new policy (Labour, 2023). The National Party became the government and unfortunately has no current plan to incentivise decentralised solar PV systems. This has left banks to step in with green loans for sustainable investments in your household. In addition, New Zealand has a small GDP in comparison, giving less expenditure on funds and subsidies as incentives. New Zealand is already operating at 87% renewable energy in 2022 exceeding other countries' goals hence the lack of government pursuit towards solar PV systems (Ministry of Business, 2024). However, this should not cease the implications of solar as it will lead the transition to a 100% central grid powering all of New Zealand and achieve that goal by 2030 (Ministry of Business, 2024). Solar PV systems validation is not solely through renewable energy in New Zealand, but to primarily increase resilience against climate change.

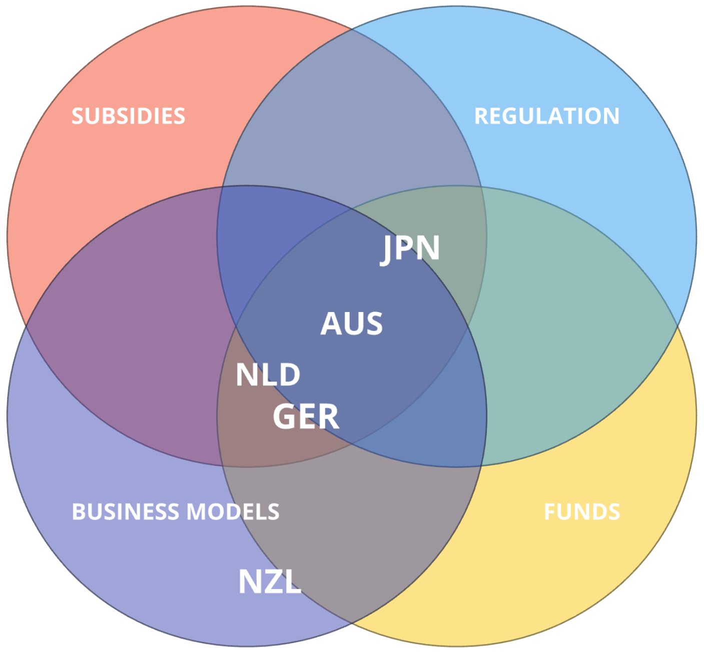


Figure 9: Global Approach to Solar Incentives, NZL stagnant movement.

RESPONSE TO AOTEAROA

As shown by the events of cyclone Gabrielle in 2023, the central grid was disrupted due to distribution infrastructure damaged by flooding, wind and debris resulting in power outages. Cyclone Gabrielle has "left almost 234,000 people without power throughout New Zealand" (Almeida, 2023). The approach of decentralised solar PV systems will add further individual or communal energy resilience, without the sole reliance on the central grid when compromised. The design proposal outcome promotes self-solar energy generation, storage and distribution on and off-site, as a solar station. Due to factors of climate change, extreme weather events will increase in New Zealand shown in its trend towards 2030 shown in Figure 10 (NZESC, 2021) corresponding to the number of outages experienced by customers with local line companies. What is New Zealand's climate response? Auckland has proposed to strengthen the central grid; however, would it promote synergistic benefits of adaptation and mitigation like the Solar Station integration?

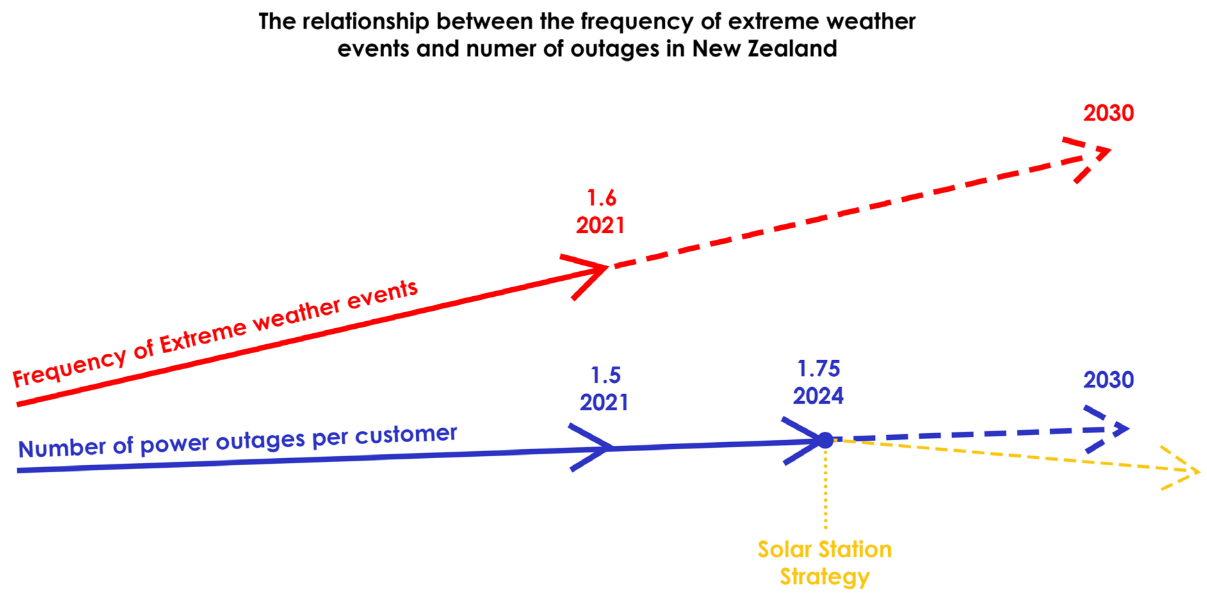


Figure 10: Extreme Weather Events and Power Outages Increasing Trends, Authors own work based on (NZESC, 2021) and (Comcom,2025).

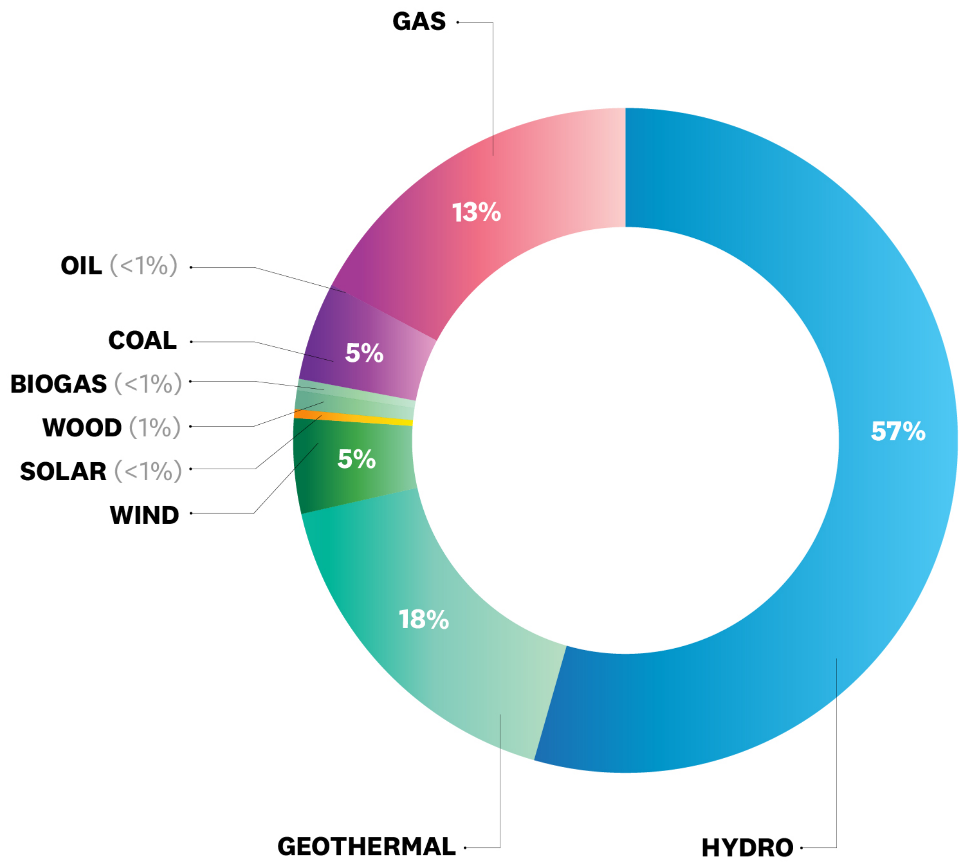


Figure 11: NZ Energy Grid in 2022 by Gen Less (Gen Less, 2024).

This integration of decentralised solar resources for resilience through adaptation also involves the mitigation of fossil fuels. As stated before, the proposal will help towards the transition to a 100% green grid through renewable energy, ridding power plantations of fossil fuels (Gen Less, 2024). This seals a step towards mitigation against climate change by converting New Zealand's power generation to renewables.

It is predicted the incapability to hold New Zealand's increased energy demands in 2030. As stated in the report "Climate Change in New Zealand: Electric is the Future" by BCG, the country will need to invest $30 billion in the transmission and distribution infrastructure by the end of this decade. This corresponds to the additional capacity to hold 4.8 GW to meet demands in the 2020s (BCG, 2022) for the goal of decarbonisation by 2050. In late 2023, Transpower proposed a forecast of $2.25 billion in capital

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The integration of solar stations will address this increase by generating more renewable energy throughout the city contributing to peak demands as connected to the central grid for support. As the solar stations are connected to users homes it reduces the distance needed for the energy source to travel in the community. Therefore, relieving stress within the central grid from reaching capacity during peak demand when the solar station strategy reaches MW output. This also corresponds to the energy peak curve in NZ throughout the year. Distributed Energy Resources (DER) will flatten the curve as the demand for central grid energy will decrease with distributed solar PV. This has been proven within the South Australian energy demand shown in Figure 12 (AEMO, 2018).

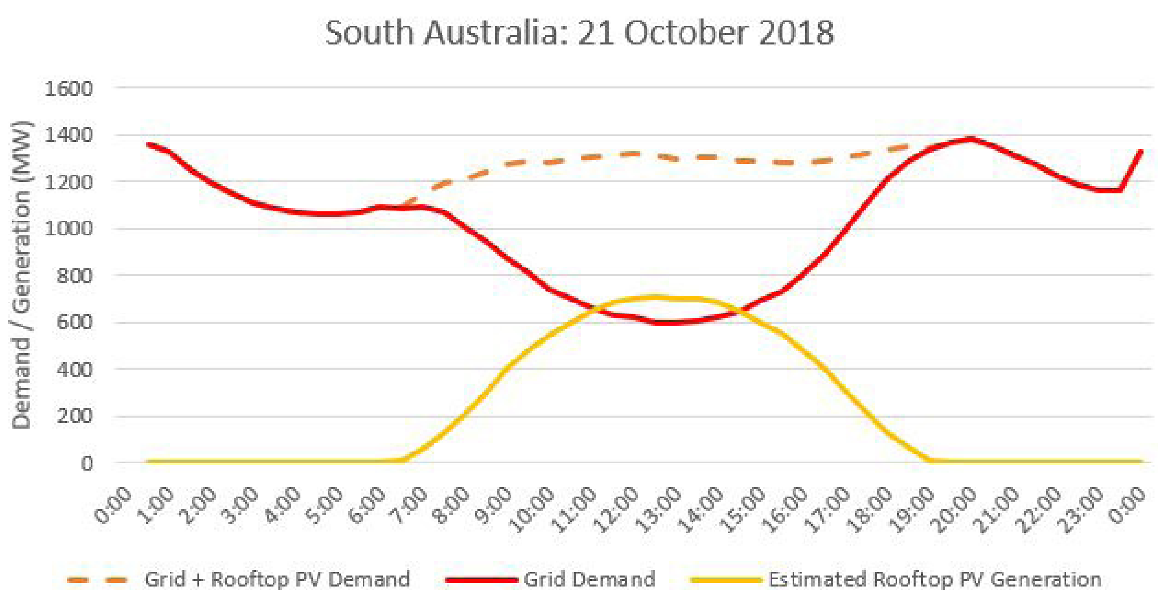


Figure 12: AUS Peak Energy Demand 2018 by Australian Energy Market Operator (AEMO) (AEMO, 2018).

COMMUNITY EQUITY

One large issue of solar PV systems is their upfront costs for consumers. Although the prices of solar PV panels and batteries themselves have decreased, the upfront cost for installation is still a large investment even outside Aotearoa. This can be due to many factors such as low demand, hence supply and labour keeping the installation prices high (RCR, 2023). This results in only a few selected buyers being able to afford the installation creating a gap in the market for low-income homes, revealing the status of a luxury purchase and for the privileged (Best & Chareunsy, 2022).

The cost not only hinders rooftop solar PV but also the type of ownership of the consumer's building, its orientation and the location to host the system. Renters who are interested or need the benefit of solar PV systems have no authorisation over the building's additional installations. This impedes seeking feasibility as most landlords would rather maintain an immediate high-profit margin by capitalising on their housing assets without the inclusion of solar PV systems (Hammerle et al., 2023) or increasing rent for occupants (Ease, 2022). This leaves owner-occupied homes more susceptible to implementing solar.

This correlates to the current state of the house and occupation. Whether it is renting or owning the home, an old building would refrain from any expensive additions compared to a newly built one. Installing solar PV systems may lead to other reforms for current requirements, increasing the costs. The period of home ownership is also a factor. As solar is a large investment, the return on investment (ROI) is between 10-15% in 6 to 9 years (Quotes, 2025). Homeowners may not want to be restrained within the house for 9 years or may not be the occupants to reap the benefits during or after the ROI period.

The orientation of the building is also a factor for integration. A roof tilt facing the north will have higher yields of energy compared to a tilt towards the south. The East, North and West which are along the sun's path in NZ, are prioritised to capitalise on the installation. Roofs outside the sun's path will hinder fruition by lesser yields in parallel or additional costs for railings to be fixed towards the sun (Ministry of Business, 2023).

The location of the host building is also to be considered before installation. Being on a site that has substantial coverage such as trees, depending on how close they are may obstruct direct sunlight for even average yields of energy. Therefore, impeding installation or a smaller solar PV system (RCR, 2023).

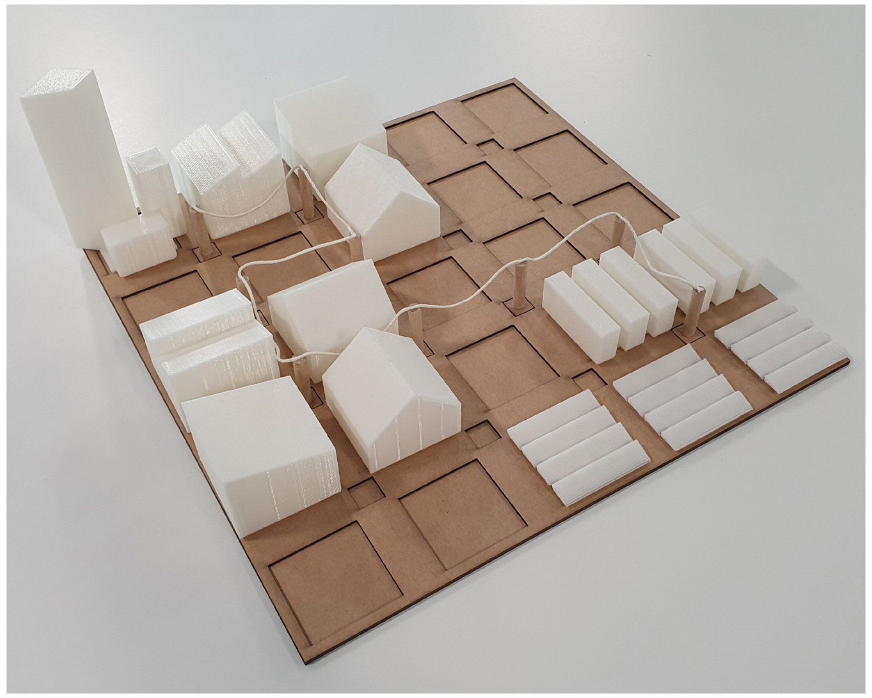
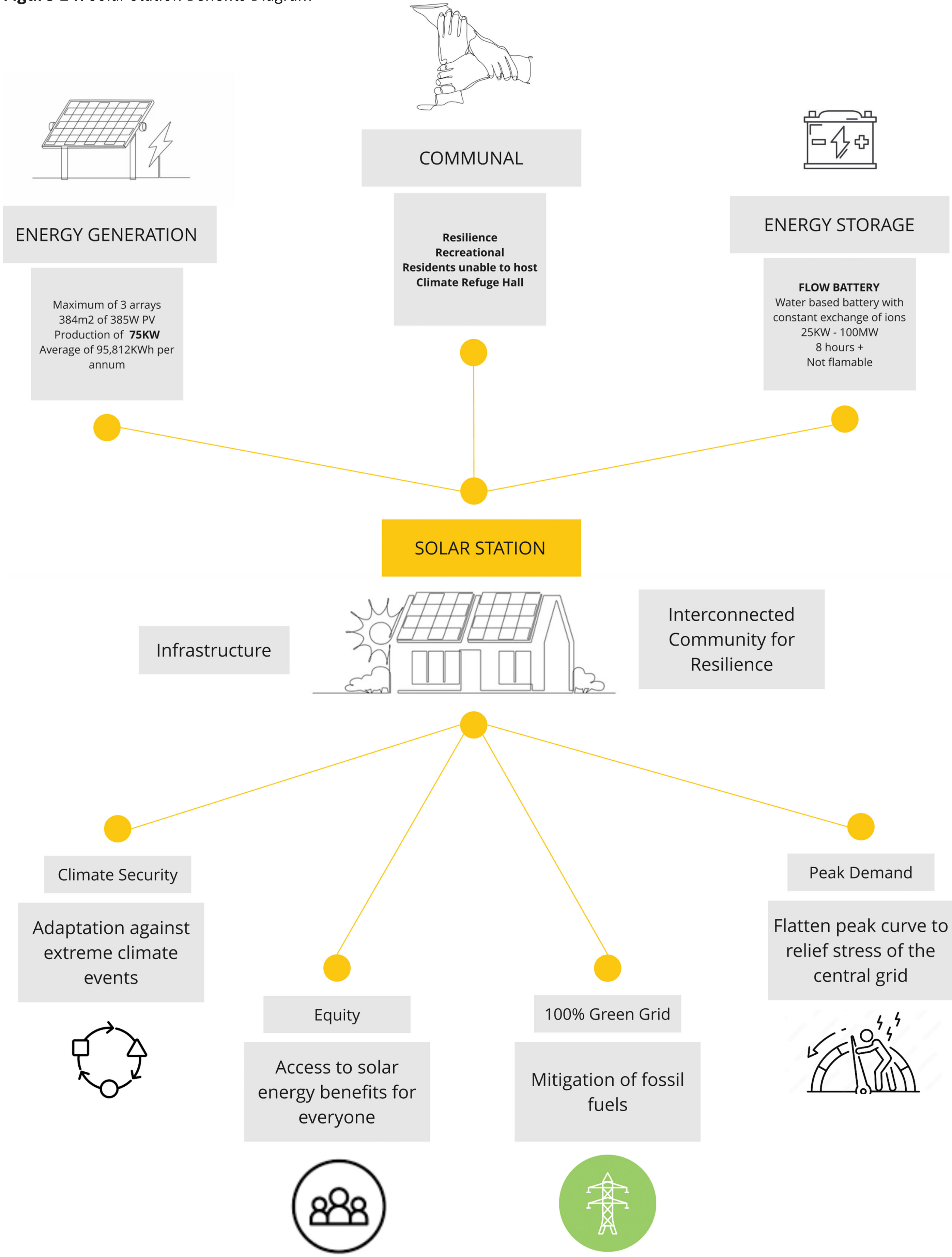


Figure 13: Model Demonstration of different Scenarios regarding Solar PV systems on buildings and Central Grid connection

As the proposed solar stations have renewable energy generation and storage in the vicinity, it avoids upfront installation costs for residents who cannot afford or host rooftop solar PV due to ownership, income and state of the building. This is achieved by connecting homes through the existing infrastructure and gaining renewable energy benefits, closing the gap in the consumer market for rooftop solar PV. With an increase of users connected with solar PV systems through solar stations, it will also increase community resilience through natural disasters, with high-risk central grid disruptions. As its main purpose, this will reduce the number of affected homes and the duration of power cuts by providing emergency electricity. Therefore, consumers connected to the solar station will expand as a communal microgrid creating a cohesive and rigorous system within the community for equal and mutual benefits.

Figure 14: Solar Station Benefits Diagram



CONCLUSION

Neither of the two approaches to solar is perfect, however, decentralised with its versatile and resilient aspects triumphs over-centralisation. Although both solar integrations of rooftop PV and solar farms serve their purposes effectively, the decision was based on its integration against climate change. Countries around the world have already begun and continue to sprint towards integrative solar PV like Japan and Australia. With their government push and consumer acceptance they have succeeded in building and maintaining a market for solar PV systems in all scales. Unfortunately, New Zealand is slow to follow, with small movement from the government as they fail to see the importance and the purpose beyond solar as renewable energy, leaving it in the hands of businesses. However, within the context of Aotearoa, the benefits of decentralised solar will address several of the nation's goals. Integrating the proposed solar station with energy generation, storage and distribution reveals its multiplicity to adapt against climate effects for energy security and energy equity. Its support to the central grid will ease stress during peak energy demands while future-proofing the project's utility to meet energy targets and a 100% green grid. Decentralised solar and the solar station intervention will further catalyse the integration of distributed solar PV systems, to transition towards urban solar resilience throughout communities.

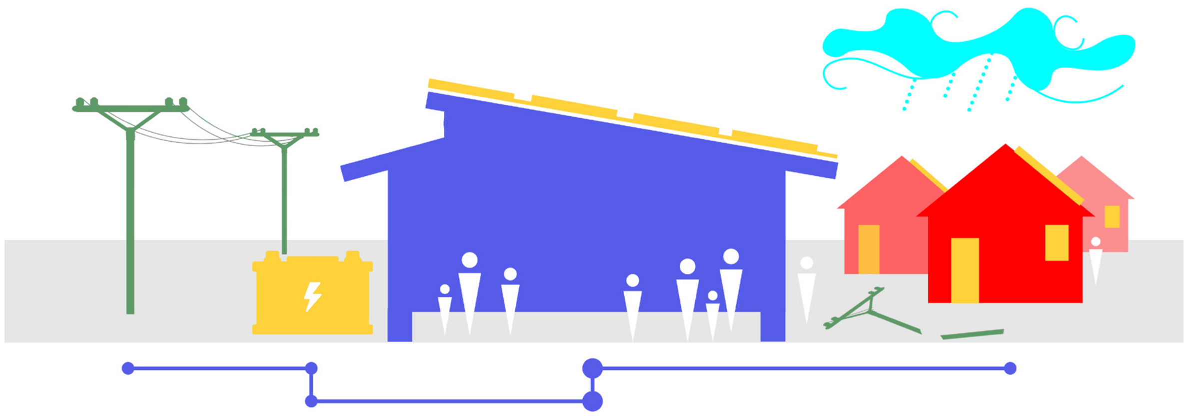


Figure 15: Solar Facility connection to Homes and Central Grid supporting Energy Resilence

SOLAR RESILIENCE TRANSITION

INTRODUCTION

With the benefits of decentralised solar, how can a solar station be integrated into the urban environment to transition towards solar community resilience? This chapter evaluates how the transition of solar PV systems will be associated with New Zealand's current plan of energy and resilience within Auckland. The analysis of community integration and alignment with the Civil Defence Emergency Plan reveals who can begin as a catalyst to support the proposal and its guidelines to merge solar energy and disaster relief programmes to benefit a resourceful integration for the community.

COMMUNITY INTEGRATION

To achieve this, buildings must host solar PV systems across a community to create a network of decentralised systems. This will act as a microgrid to generate, distribute and store energy as one entity for the community. Immediate energy demands will be met through its generation within proximity, resulting in increased security of electricity and resilience. With this approach across Auckland, while maintaining a connection to the central grid, it will support the demands of electricity locally or regionally easing the stress in the built infrastructure.

However, who will host these solar PV systems? As these systems can be implemented in any building it begins with homeowners of stand-alone, duplex or terraced housing. It is clear residential buildings are most of the urban environment, with townhouses and apartments making up 83% of Auckland dwellings consented in 2022 (EBOSS, 2022). Thus, is the perfect market for solar PV systems to be installed, yet only one in every 30 dwellings has them (EMI, 2024).

The problem of integration within the residential sector arises due to its costs for installation, site restrictions and ownership of the building. Therefore, resulting in only a few in the market for purchasing solar PV systems. In addition, the lack of government policy to incentivise rooftop solar PV systems will keep the demand slow, hence supply and labour in the business market. The private household market alone is not enough to drive the push for solar PV systems to create a decentralised community network.

Figure 16: Foodstuffs North Island rooftop solar PV system of 1.16MWp by Revolve Energy (Revolve Energy, 2020).

The same could be said for the private business sector. They can host and generate solar energy, however, there are no regulations and parameters for businesses to abide towards. When businesses do implement solar, such as Foodstuffs and Manawa Bay outlet mall with the largest rooftop solar PV system. It is installed for their electrical demand and sustainable goals, with hopes others will follow. Unfortunately, there is no requirement to do so, besides moral or performance pressures.

Figure 17: Manawa Bay outlet centre with the largest rooftop solar PV system of 1.2MW by Revolve Energy (Revolve Energy, 2024).

Figure 18: Kaitaia College with a 101Kwp rooftop solar PV system by SEANZ (SEANZ, 2019)

However, public facilities provided by the government such as community centres and schools have seen changes through funds like the Solar School Program and the Community Renewable Energy Fund. Shown by Kaitaia College hosting a rooftop solar PV system of 101Kwp and rooftop solar on the Glendowie community centre (SEANZ, 2019). This represents an opportunity for existing facilities for solar integration. Although the approach is a step toward community integration, it remains an on-site energy benefit.

The challenge for existing sites still arises like the residential sector with cost and site restrictions regardless of government or private ownership. These installations have remained to generate energy for their buildings and could only sell their excess energy to support the grid individually or as a VPP. Displayed by the community battery project in Yakabanah, Australia shown in the cast study chapter Figure 30. It has integrated solar energy resources into an existing building to distribute excess energy to its community's local network through a behind-the-meter model. Unfortunately, this type of business model is not in New Zealand yet.

This leaves the drive for a client to purchase solar PV systems for their own buildings' benefit. It is the thought of the investment for only themselves to benefit from renewable energy. However, what if this perspective was reversed to rationalise the integration of solar PV systems for communal benefit? Therefore, a new building that is publicly owned as a facility, an infrastructure not only for energy but to be part of a community's ecology as an amenity also within its system (interconnections).

The restraints of existing buildings are extensive retrofitting needed to integrate solar PV systems that go beyond conventional rooftop solar PV. Creating a new build presents a resilient design. This allows the location, structure and programme of the building to go beyond the requirements and needs of the community for energy resilience, instead of being confined to an existing building with structural liability. opportunity also allows further interaction with the community and holds dual programs that are formed through resilient design and low electrical demands. This approach reveals the next step of what solar PV systems could be and how they can be integrated not only into a building but the community itself.

CIVIL DEFENCE EMERGENCY PLAN

Public amenities and facilities already exist within the community through stand-alone or retrofitted buildings such as libraries, community centres, and churches, which program should be newly built to integrate with solar PV systems? As solar PV systems can have an important function of powering communities during disasters and disruptions to the electricity grid, this research takes into consideration Civil Defence Emergency Strategies to define the best placement of these systems within the city.

Civil Defence Emergency Management (CDEM) has set out a National Disaster Resilience Strategy in 2019 to communicate its vision for New Zealand as a nation resilient to disasters. The overarching goal:

> "to strengthen the resilience of the nation by managing risks, being ready to respond to and recover from emergencies, and by empowering and supporting individuals, organisations, and communities to act for themselves and others, for the safety and wellbeing of all."(CDEM, 2020).

CDEM will achieve this goal through three main priorities with six objectives in each; Managing risks, Effective response to and recovery from emergencies and Enabling, empowering, and supporting community resilience. Focusing on the third priority; Enabling, empowering, and supporting community resilience has three objectives the proposed solar station addresses.

This strategy aligns with the integration of solar PV systems into the community through solar stations by addressing infrastructure failures of power outages as local distribution and generation of electricity. Therefore, it promotes energy security hence resilience benefiting the well-being of the community during disruptions of the central gird.

Table 1: CDEM Third Priority and Objectives addressed by solar station

Priority:	
Enabling, Empowering, and Supporting Community Resilience	
Objectives:	**Solar Station**
Take a whole of city/district/ region approach to resilience, including embedding strategic objectives for resilience in key plans and strategies	**Decentralised solar** strategy is employable throughout Auckland beginning as a public facility in Manukau City Centre.
Address the capacity and adequacy of critical infrastructure systems, and upgrade them as practicable, according to the risks identified	An **additional layer** for local **electrical distribution** to reduce risks, and meet energy demands and security.
Embed a strategic, resilience approach to recovery planning that takes account of risks identified, recognises long-term priorities and opportunities to build back better, and ensures the needs of the affected are at the centre of recovery processes	The program of the facility as a **disaster relief centre** in an emergency or operations, readiness, response and recovery.

The Tāmaki Makaurau Auckland Civil Defence and Emergency Management Group Plan 2024 – 2029 also sets out goals within the Auckland region. The report addresses Auckland's context in terms of the 4R's Reduction, Readiness, Response and Recovery with their current plans and future improvements in their system of approach. (AEM, 2023)

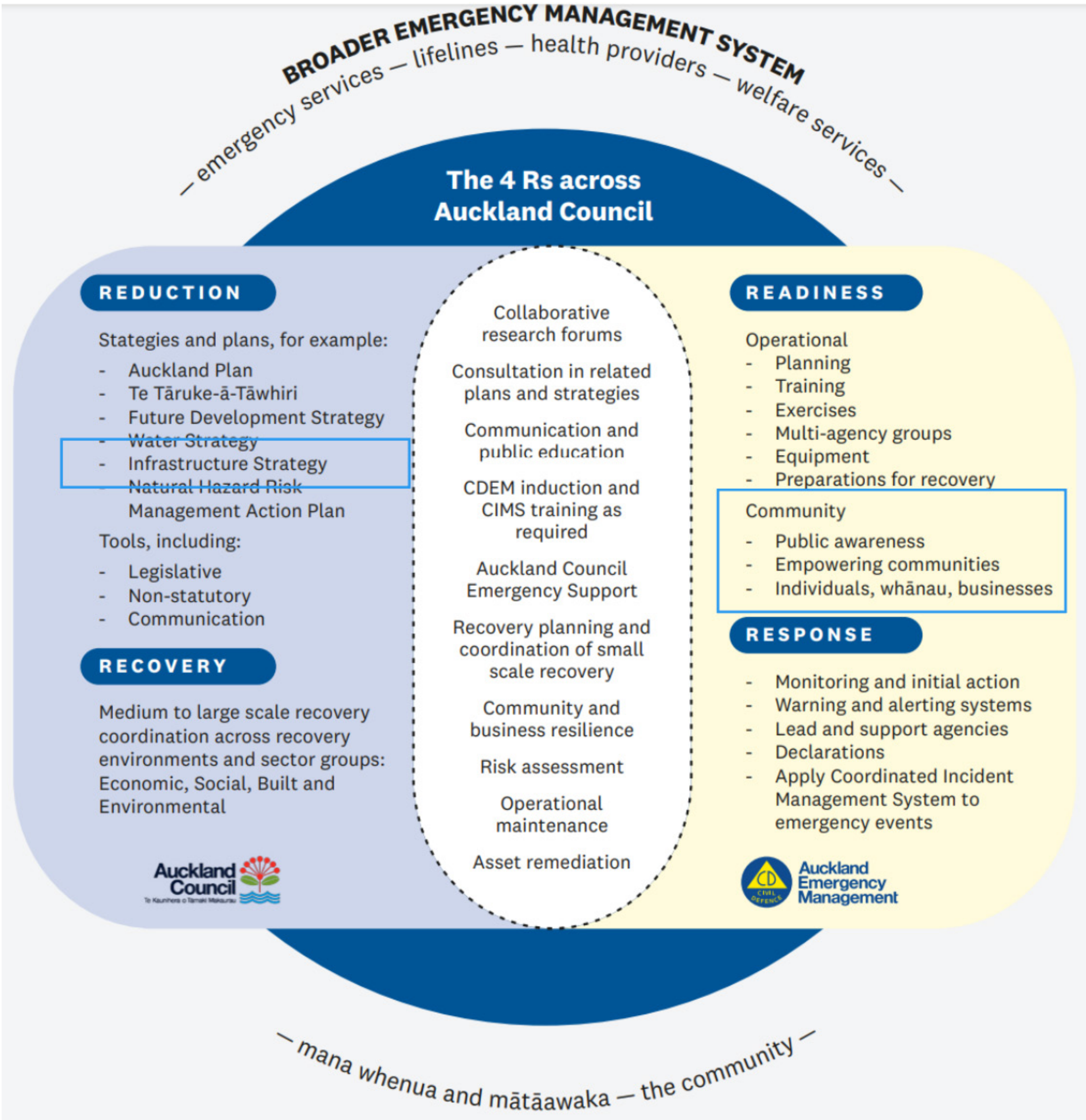
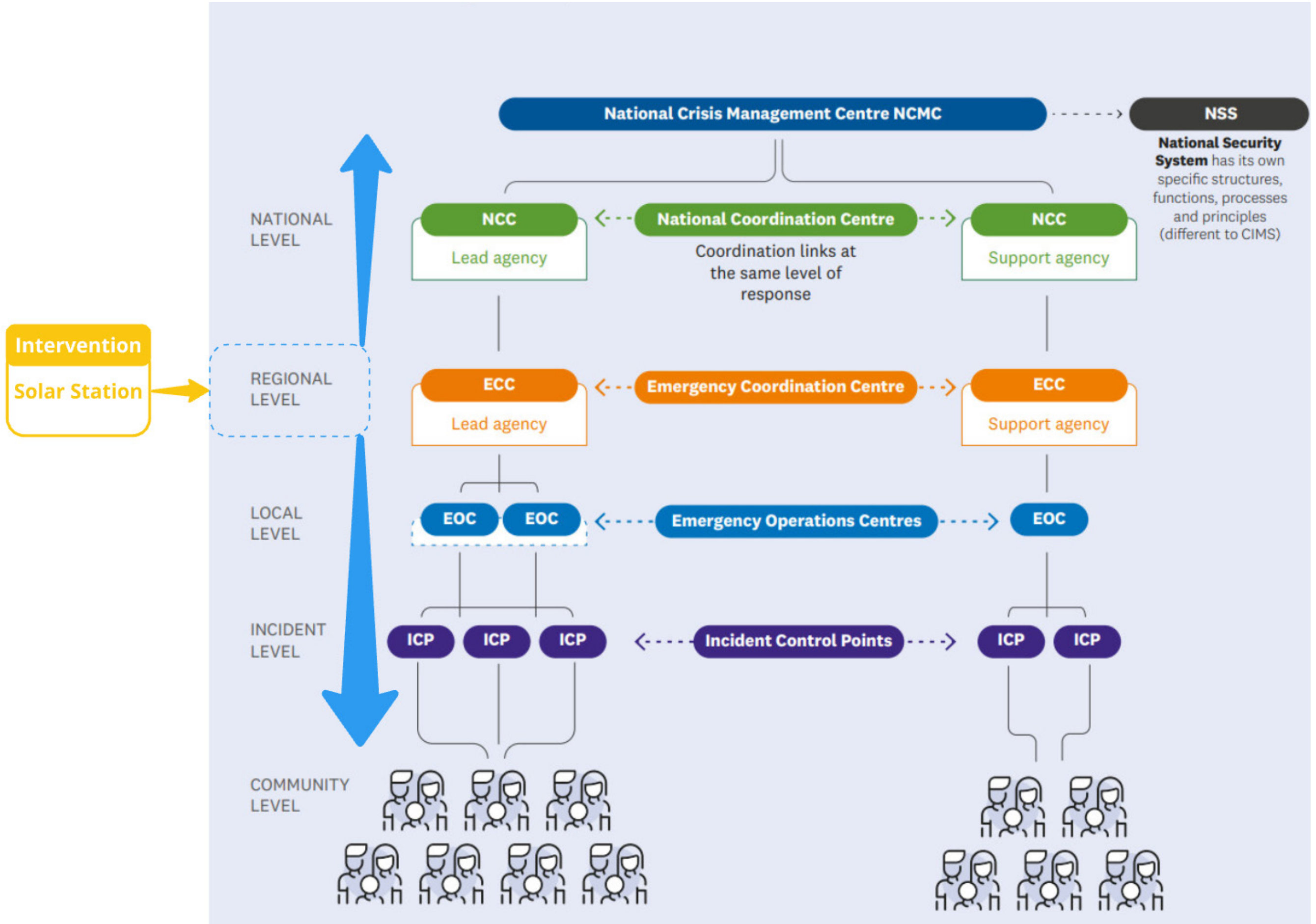
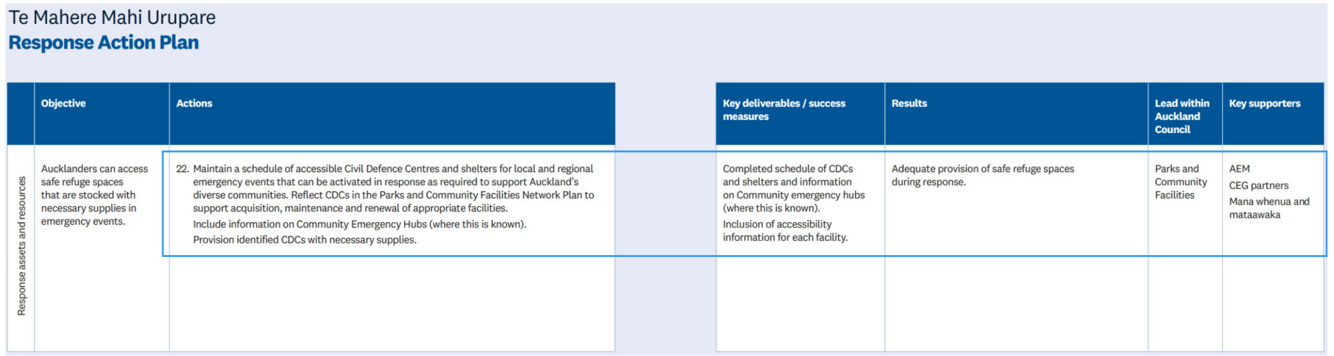


Figure 19: The 4rs, Auckland Council and the emergency management system by CDEM (AEM, 2023).

Figure 20: Response levels and relationships, the scale of the solar station integrated into their system by CDEM (AEM, 2023).





Te Mahere Mahi Urupare
Response Action Plan

	Objective	Actions	Key deliverables / success measures	Results	Lead within Auckland Council	Key supporters
Response assets and resources	Aucklanders can access safe refuge spaces that are stocked with necessary supplies in emergency events.	22. Maintain a schedule of accessible Civil Defence Centres and shelters for local and regional emergency events that can be activated in response as required to support Auckland's diverse communities. Reflect CDCs in the Parks and Community Facilities Network Plan to support acquisition, maintenance and renewal of appropriate facilities. Include information on Community Emergency Hubs (where this is known). Provision identified CDCs with necessary supplies.	Completed schedule of CDCs and shelters and information on Community emergency hubs (where this is known). Inclusion of accessibility information for each facility.	Adequate provision of safe refuge spaces during response.	Parks and Community Facilities	AEM CEG partners Mana whenua and mataawaka

Figure 21: The 4rs, Auckland Council and the emergency management system by CDEM (AEM, 2023).

The intervention of the solar station fits within the response levels and relationships diagram of CDEM. The Solar Station proposal will be introduced as a regional strategy due to its government involvement in Auckland. Once implemented it will positively affect the corresponding levels towards the community and national level for all of New Zealand.

Civil Defence Emergency Management (CDEM) has one central operations centre in Auckland Central Business District (CBD), and another in the north shore and Waitakere **shown in the mapping chapter of Figure 48**. This leaves, South and East Auckland distant from the centre of operations, revealing a gap in fluid communications and movement for emergency response and recovery.

During the events of cyclone Gabrielle in 2023, many were displaced due to their homes being flooded. It was reported there were three official Civil defence centres in Auckland set up, including several community-led hubs. A centre in Mangere did not meet the demand for capacity and was re-located to a larger site of Moana-Nui-a-Kiwa fitness centre with the Manurewa hub experiencing the same issue (Walton, 2023).

The partnership with CDEM to create a new build, disaster relief centre will not only support the community in energy security but also support the demand for the number and capacity of welfare centres to accommodate displaced residents and families. To provide more ample space for staff operations and outreach to tend for everyone in need within a facility will bring Auckland closer to a resilient response to emergencies. Classifying the site as a disaster relief centre further merges the proposal to Auckland's Resilience Strategy. Adding a CDEM outpost/ checkpoint and Solar PV systems integrated with this programme will create a robust emergency response and recovery for the local community.

DISASTER RESILIENT GUIDELINES

The Disaster Relief Shelter Guidelines stem from the research paper "An Overview of the Design of Disaster Relief Shelters" by Abdulrahman Bashawr, Stephen Garrity, and Krisen Moodley. They identify design criteria for disaster relief shelters and provide a more operationally focused guide (Bashawri et al., 2014). The NZ Operational Response Facility Guidelines come from the report "Evaluating Existing Buildings as Emergency Operations Centres" by Civil Defence NZ, which evaluates requirements for Emergency Coordination Centres and Emergency Operations Centres in New Zealand. These centres must meet building importance level 4 (IL4) and align with the National Resilience Strategy's goals for "Effective response to and recovery from Emergencies" (KestrelGroup, 2021). While these guidelines do not specifically target Disaster Relief Centres, they address similar aspects. Given the absence of defined design processes for these centres, these guidelines serve as valuable tools for meeting disaster-resilient building requirements.

Table 2: Disaster Relief Shelter Guidelines.

Factors:	Aspects	Solar Station
1a) **Economic**	- Type of Shelter - Lifetime	A permanent building designed for a lifetime.
2a) **Environmental**	- Climate Variations - Hygienic (water & air)	Designed for site temperatures, provision of living necessities and ventilation. The ability to store and cook food. The washing of clothes and bedding. Maintain sanitation and supply of water and
3a) **Technical**	- Materials and insulation - Hazard Performance - Physical and Psychological Effects	Built of local, quality and sustainable materials with insulated air and water tightness of a spacious floor plan. Thus, occupant protection from natural hazards and alleviates stress.
4a) **Social**	- Cultural Difference - Dignity & Security - Communication	Designed to accommodate and welcome the multi-cultural community. The site is fluid to promote flexible use. Secure for privacy, safety and access to network connection.

Table 3: NZ Operational Response Facility Guidelines.

Considerations:	Example	Solar Station	Level
1b) **Natural Hazards**	- Earthquake - Tsunami - Flooding - Volcanic eruptions	Addressed by site within the safe zones of tsunami and volcanic eruptions. The building is elevated and away from flood zones.	Standard
2b) **Nearby Built Risks**	- Buildings - Structures	Low-rise neighbouring site. Distant high-rise buildings and transmission towers along main routes.	Standard
3b) **Facility Proximity**	- CDEM - Council - Response Agencies - Main Routes	Solar Station is between central Manukau's main routes and the STH 1 motorway. This allows swift access from other facilities.	Advanced towards vulnerable communities, and nearby residential areas.
4b) **Ongoing Services**	- Electricity - Potable Water - Wastewater	Solar PV systems are in place to act as emergency power generation for electricity in conjunction with energy storage. Thus, the building is 100% operatable including water systems	Advanced towards powering other buildings off-site during outages.
5b) **Robust Communications**	- Voice Comms - Data Transmissions	Wires will be underground to eliminate risks of disturbances securing connectivity.	Standard
6b) **Fire Suppression**	- Systems - Structure	Fire sprinklers and extinguishers throughout the site. Fire-resistant CLT and Glulam structure.	Standard
6b) **Ventilation Systems**	- Mechanical - Passive	HVAC systems operated beyond normal capacity from passive systems.	Standard
7b) **IL4 Requirements:**	- Seismic Criteria	Importance Level 4 is required for new and existing ECC or EOC buildings.	Standard
8b) **One in 500 years event**	- Operational	Efficient structure integrity and systems to continue operations.	Standard
9) **One in 2,500 years event**	- Life Safety	Efficient measures to avoid occupant endangerment	Standard

CONCLUSION

Analysing the current energy needs of NZ further advocates the need for an intervention that holds a multiplicity of positive benefits. The solar station addresses these goals not just for energy demands but also for community resilience. Integrating decentralised solar into communities will be a challenge with the current solar market in NZ, but this transition towards solar is crucial to building more resilient communities and the city. Therefore, it will take further action than the private sector to begin the transition, requiring the government to invest in another medium for decentralisation rather than centralisation. CDEM could fill this role as it aligns with their strategy for resilience and emergency preparedness. This will lead to a seamless transition of solar into the community by being part of the urban environment infrastructure and social system becoming more than just a combination of solar PV systems in one site.

METHODOLOGY

INTRODUCTION
Within this research, methodologies were utilised to thoroughly explore and investigate an urban implemented design to help Auckland transition towards individual community solar resilience. After analysing the current state of solar PV systems approach in the urban environment, design-led research has been used to confine this area towards decentralised solar. The methods used were mapping, multi-case study analysis and energy calculations accompanied by sketching and model-making.

DESIGN-LED RESEARCH
Design-led research also referred to as “design in action research”, can reveal new outcomes, reflections and evaluations through an iterative design process (Groat & Wang, 2002). The primary process used was mapping, in addition to sketching and model making were utilised to produce design outcomes through design-led research.

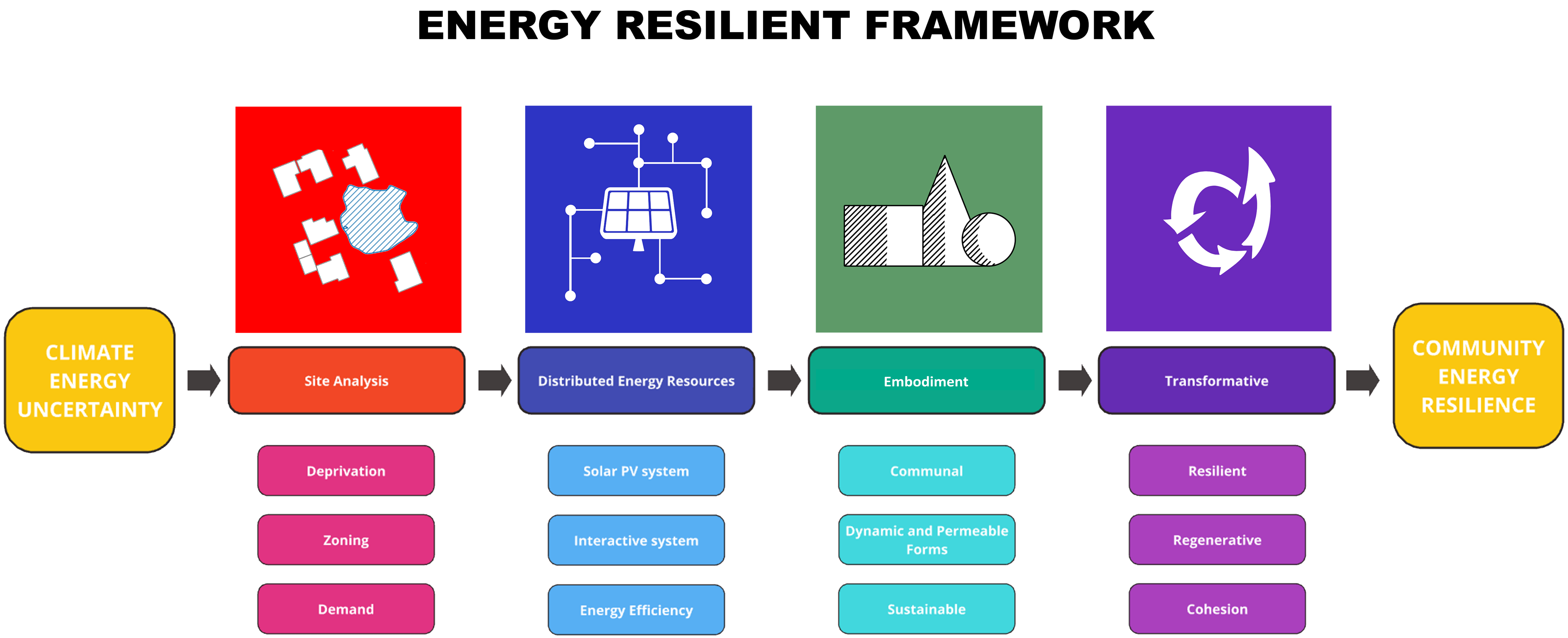
SOLAR RESILIENT FRAMEWORK
The Solar Resilient Framework was a tool used to guide the design process of the thesis intervention Solar Station. The framework is a tool to measure the success of integrated solar PV systems in a project’s urban environment. Derived from three existing frameworks for design and energy resilience, it is a guide to achieving solar resilience.

CASE STUDIES
Solar PV and decentralised systems are singular strategies consisting of multiple components and approaches. To comprehend each concept, individual case studies were analysed resulting in multiple cases for evaluation within a real-life context. “It involves studying a case in relation to the complex dynamics with which it intersects.” (Groat & Wang, 2002). This was addressed through diagramming components of each case study about its approach with solar to expose similar or differential patterns. This helped provide a framework to fuse these components into one site and strategy within an urban environment.

MAPPING
As stated by (Groat & Wang, 2013), mapping is used “In an effort to assess the way the physical characteristics of cities were, experienced and understood” . Within the context of decentralised solar, the mapping of the opposing centralised system was used to reveal how the central grid network travelled throughout New Zealand. This helps to understand its characteristics in the urban environment explored in different scales. Thus, using QGIS, gaps were exposed within the central grid at a national and regional level of Auckland. This presents locations of possible interventions that may lie within the region to support and enhance not only the local community but also the greater Auckland for energy resilience through solar decentralisation.

EXPERIMENTAL SIMULATION
Energy calculations were simulated to evaluate the performance of solar PV systems on specific host buildings and the design intervention itself. It was used to “bring out certain interactions in higher relief for study or data collection.” (Groat & Wang, 2002). Thus, by being a qualitative tool to measure how much energy will be produced or used on a site when integrated into existing buildings filtering facilities for a decentralised system. It allows evaluation to whether extend or constraint design for component performance.

Figure 22: Energy Resilient Framework to bridging research to an architectural proposal.



SOLAR RESILIENT FRAMEWORK

The Architectural Energy Resilient Framework demonstrates the process of a successfully integrated strategy to achieve community energy resilience. This framework was derived from "*14 Patterns of Biophilic Design"* (Green, 2014) for design, "*Resilience Design Tool Kit"* (AIA, 2023) for integration, and "*Resilience Theory and Praxis: a Critical Framework for Architecture"* revealing ecologies of resilience. This framework is used as a tool to analyse against precedents whether it has or will succeed in its integration into the urban environment for more energy-resilient communities using decentralised systems.

It begins with the problem of climate energy uncertainty, with the current central grid infrastructure not always holding against prospective demand from disturbances. These disturbances allude to future climate effects where the distribution and consumer access to energy must be secure and resilient. Furthermore, the capacity of the current central infrastructure to efficiently supply future consumer demands and government goals. This reveals the implementation of decentralised systems specifically solar photovoltaics for their renewable and applicative nature.

Site Analysis - Effective implementation begins with a comprehensive site analysis, considering factors such as deprivation, zoning, and demand. Deprivation analysis addresses energy accessibility, security, and equity, ensuring that the strategy benefits all community members. Zoning considerations focus on situating the strategy in areas vulnerable to climate impacts and close to existing infrastructure for efficient energy distribution. Demand analysis anticipates future energy needs, particularly in areas with planned urban or industrial developments.

DER - The framework emphasises the inclusion of DERs, such as solar PV systems, which are versatile and sustainable. These systems can be integrated into various urban settings, from rooftops to building facades, providing a flexible and scalable approach to energy generation.

An interactive system engages the community by providing both a spatial and electrical connection to the energy strategy. This fosters a deeper understanding of the system's benefits and promotes community involvement in energy resilience efforts.

Energy efficiency is a critical aspect of the framework, ensuring that the integrated strategy conserves energy and maximises the benefits of renewable resources. This includes passive architectural designs that reduce energy consumption and enhance overall system efficiency.

Embodiment - The physical embodiment of the strategy should reflect communal, dynamic, and sustainable principles. Communal designs promote inclusiveness and community cohesion, while dynamic and permeable forms symbolise the flow of energy and adaptability. Sustainable materials and construction practices further reinforce the strategy's regenerative goals.

Transformative - The goal of the framework is to achieve transformative outcomes, enhancing community resilience, regeneration, and cohesion. This involves not only returning to a pre-disruption state but also advancing to a new norm of energy security and sustainability. Cohesion alludes to the transformation of pulling and connecting the community closer together whether it is physically and/or through equity; equal access to benefits. Therefore, this will allude to the strategies, programme, form and goal to perform this outcome.

The energy resilient framework relates to the design-led research on, “how solar photovoltaic systems be implemented to adapt and mitigate against climate change for more resilient communities,” as it aims for energy resilience. This theoretical framework reflects the undergone analysis and methodology throughout the process of the thesis, revealing the crucial pillars and aspects for a successful integration towards community energy resilience. It is the bridge to produce architecture that evokes community transformation through energy forming a new norm (Michelle Laboy, 2016).

Decentralised systems fit in this framework by being a fundamental aspect of success in community energy resilience. Microgrids are the result of interconnected decentralised systems distributed within the urban environment. Distributed Energy Resources (DER) is the wider scope in which the regenerative technology lies. DER is one of the critical pillars for the energy resilient framework as it allows for a community-scale integration. With diverse resources scattered throughout, the urban environment assembles and culminates together to generate something larger than themselves creating a system such as a microgrid. And with this newfound system, hence the new norm, it will benefit the whole community influencing cohesion and securing energy resilience. Microgrids and decentralised systems are the strategies that will be integrated through the theoretical framework.

SOLAR IMPLEMENTATION

INTRODUCTION

How do solar PV systems exist in the urban environment today? There are many ways in which solar PV systems are integrated and used in buildings and communities within a decentralised approach. This includes Distributed Energy Resources (DER) as individual components, decentralised systems as micro-grids or Virtual Power plants (VPP) and Building Integrated Photovoltaics (BIPV) all having a unique set of traits and correlation to each other. This follows with precedents that have successfully implemented these strategies in the urban environment.

DER

Distributed Energy Resources (DER) refer to energy systems or technologies within the consumer or business sector to generate electricity or sell it back to the central grid (ARENA, 2024). These resources are commonly renewable systems to generate, store or distribute electricity for use like rooftop solar PV systems, lithium-ion batteries and EV chargers within the local scale (Transpower, 2022).

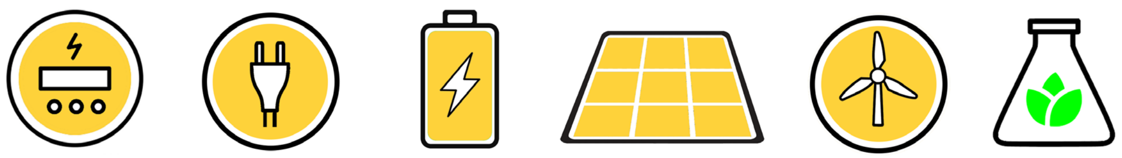


Figure 23: Distributed Energy Resources.

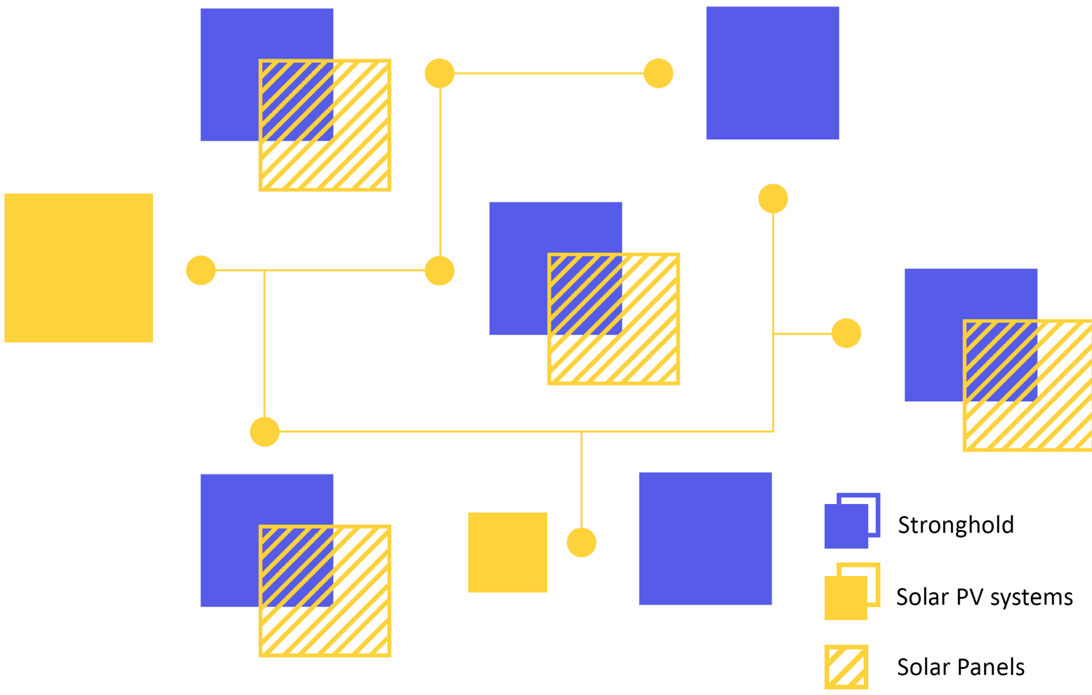


Figure 24: Decentralised Systems of DERs connected Diagram.

DECENTRALISED SYSTEMS

Decentralised systems represent advanced energy strategies designed to bolster the central grid by incorporating renewable energy sources for local generation and distribution (E. Judson a, 2019). These systems are embedded within urban environments and consist of distributed energy resources (DER) that form a cohesive energy network, either on-site or virtually, enhancing community resilience and overall grid stability (Electric, 2024).

The physical network between these DERs creates a system from generation, storage and distribution that can be referred to as a micro-grid. This can be in the form of a community solar, or a local scale solar farm within the community generating electricity for the immediate town off-site. The form of multiple rooftop solar PV systems throughout the community connected through a cloud network is defined as a Virtual Power Plant (VVP), shown in Figure 23 (Kraftwerke, 2024). VVP allows offsite management to control each system selling off excess energy to the central grid.

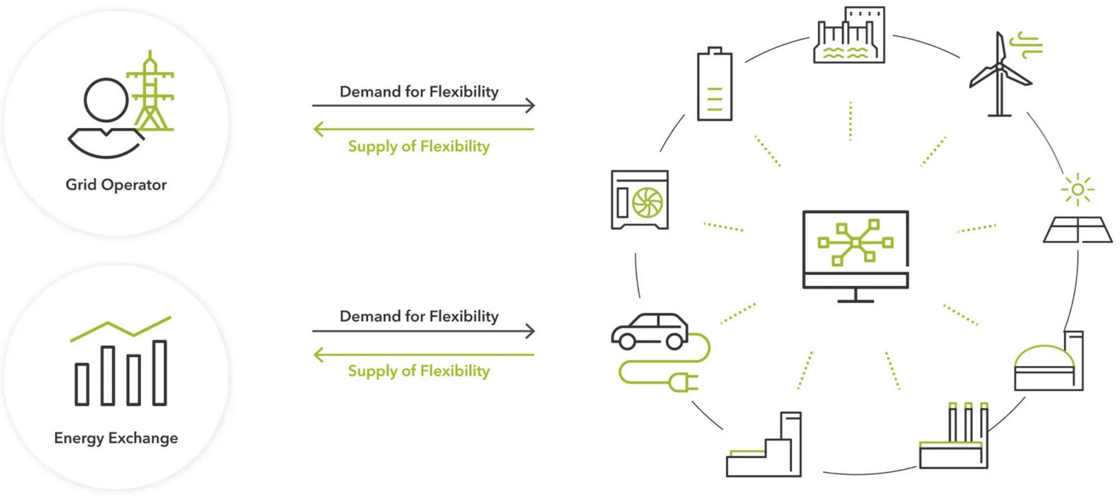


Figure 25: Ecology of Virtual Power Plant by (Kraftwerke 2024)

Micro-grids operate by generating and storing energy on-site, maintaining a connection to the central grid but capable of functioning independently during grid failures (Hoymiles, 2022). They rely on renewable energy sources such as hydroelectricity, solar photovoltaics (solar PV), wind turbines, and biomass to ensure a sustainable and resilient energy supply. Decentralised systems distribute these energy resources across the urban landscape, integrating building-integrated solar PV, communal batteries, and virtual power plants (VPP) to create robust micro-grids shown in Figure 25 (Kraftwerke, 2024).

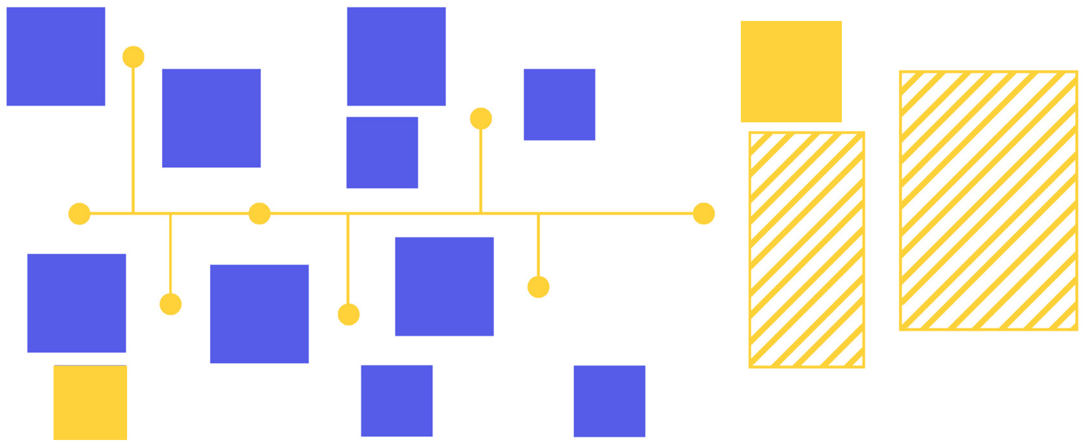


Figure 26: Community Solar Farm distributing to other buildings Diagram.

Stronghold

Solar PV systems

Solar Panels

Implementing micro-grids and decentralised systems in urban areas strengthens the central grid by reducing demand pressures, thereby promoting energy resilience (Electric, 2024). These systems improve energy security and reliability, particularly in the face of climate-related disruptions. By localising energy generation and distribution, they minimise the risks associated with long-distance energy transmission and infrastructure vulnerabilities, ultimately leading to fewer power outages and faster recovery times (E. Judson a, 2019).

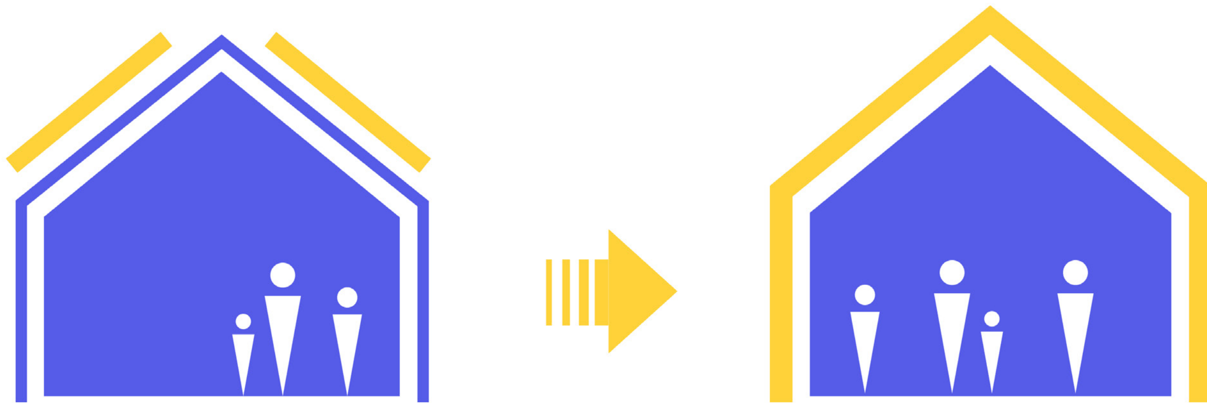


Figure 27: From Rooftop solar PV to Building Integrated PV Diagram.

BIPV

Building Integrated Photovoltaic (BIPV) are solar PV systems integrated into the design of the building envelope. This is achieved through embedding solar cells into its roof or façade within windows or cladding to generate renewable energy. BIPV differentiates from rooftop solar PV systems on buildings as they are installations rather than constructed into the building itself. It also gives the building envelope of the integrated system a functional duplex of exterior protection and power generation, a material and an energy generator (Biyik et al., 2017)

CASE STUDIES

The following precedents represent successful implementations relating to strategies for solar PV systems within the community. Each precedent addresses existing approaches for community resilience and represents key aspects of a system for storage, distribution, host, site, building and program to incorporate into one coherent design. The analysis consists of community batteries, centre, solar and microgrid. Then a BIPV-favoured approach and a disaster relief centre. As these are real-life examples of solar PV systems within a community it display working projects, hence providing a framework for individual qualities that are fundamental to include in the design through diagramming.

As a DER, Lithium-ion batteries are used to store solar energy and exist as “Energy Storage as a Service (ESaaS). It is an energy retail plan that allows multiple eligible customers to access a shared community battery.”(Ausgrid, 2024). The service originated in North America, the Australian government has already committed $224.3 million of funding to help the integration of community batteries in 2022 across the country (DCCEW, 2024).

Figure 28: Energy Storage as a Service in Sydney, AUS by (Ausgrid, 2024).

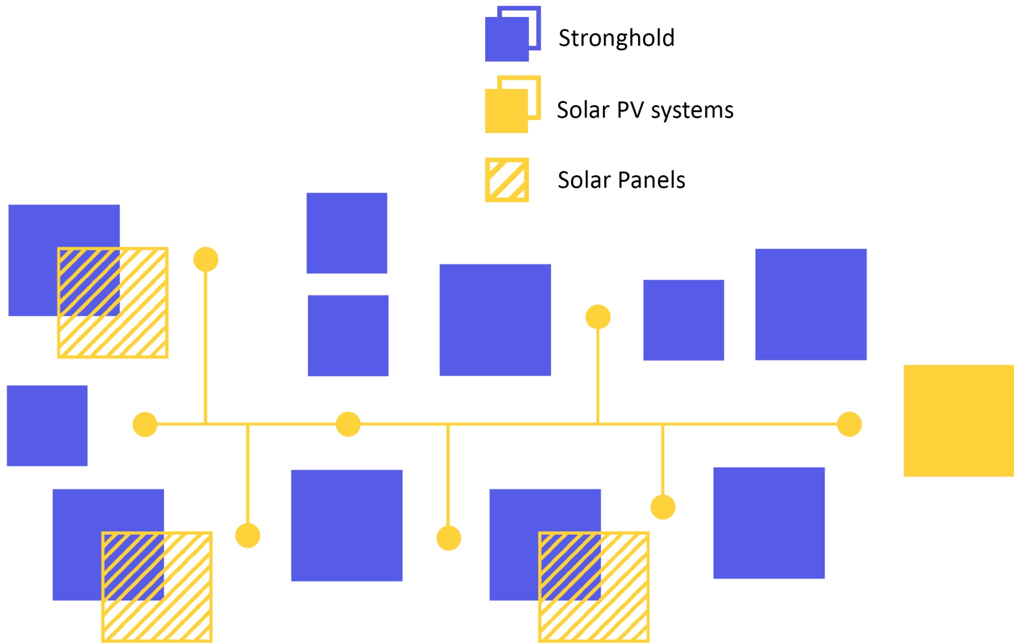


Figure 29: Energy Storage as a Service neighbourhood connection Diagram.

ESaaS is to provide consumers within the neighbourhood access to energy storage to those with or without solar PV systems on their roofs. Whether you are a renter or tenant of any ownership and residential building, you will receive benefits of lower electricity bills through participating energy retailers and eligibility. ESaaS is capable of connecting with businesses, however Australia’s program priorities residents and have completed over a dozen 5 megawatt hours to 10MWh batteries in the state of New South Wales (NSW).

Figure 30: Community Battery site by (Totally Renewable Yackandandah, 2021).

COMMUNITY BATTERY

A successful integration is Yack01 Community Battery in Yackandandah, Victoria, Australia. However, instead of being stored on the meter by an electrical network provider, energy is stored on private land operated by an energy retailer. This behind-the-meter, retail-facing store is the first of its kind in Australia. It works by the retailer selling cheap locally generated solar power distributed to its customers within peak times since 2021. It has a 274KWh battery with a 65KW solar array onsite with energy generated used by the host, a sawmill, first then customers. This pilot project set itself apart through the community lead integration, raising funds with the support of the government, working with local retailers, resources and installers to achieve a transition towards the goal of 100% renewable energy for Yackandandah (Totally Renewable Yackandandah, 2021).

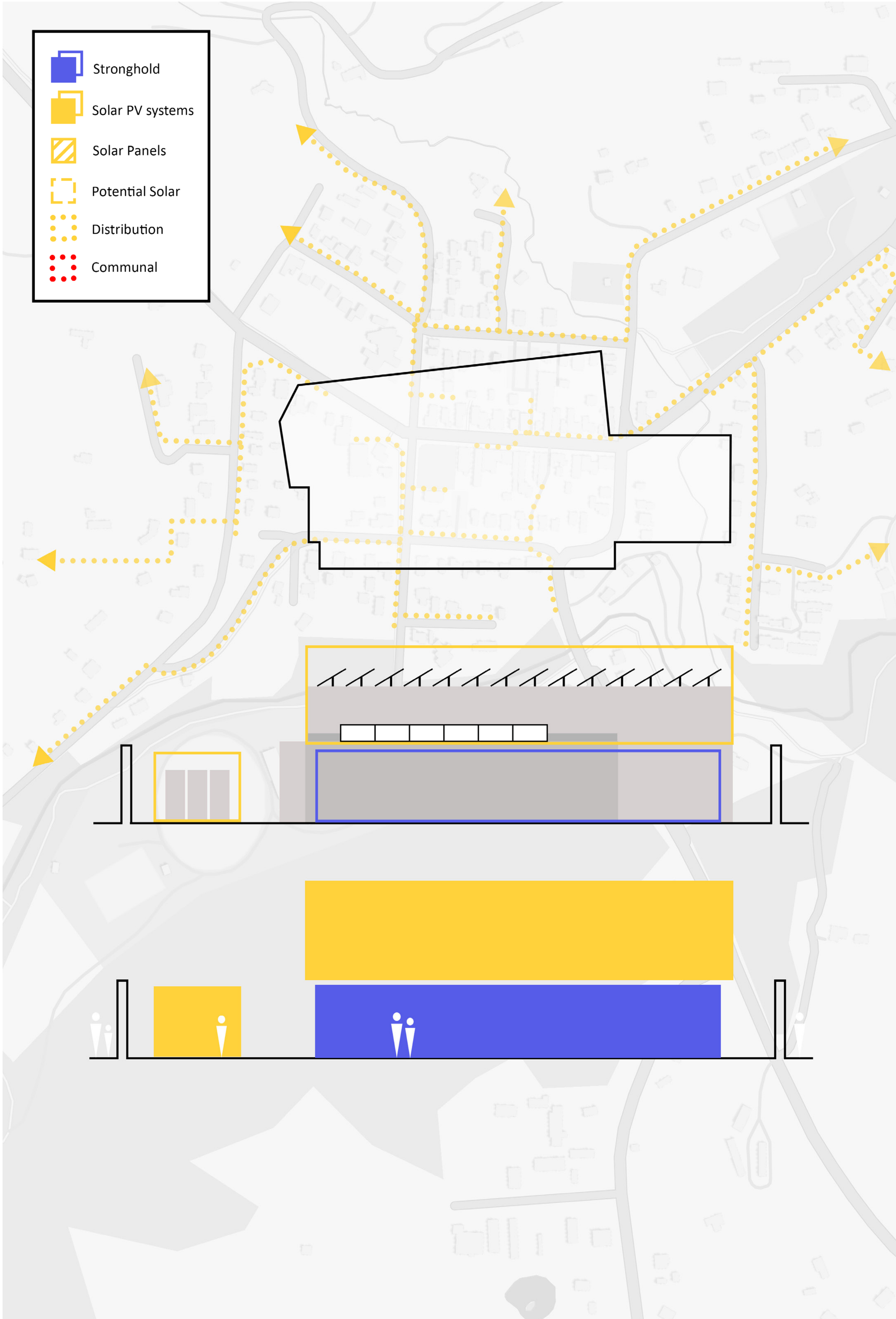


Figure 31: Community Battery Study Diagram.

Figure 32: Community Centre A.B. Ford Park by (INFORM STUDIO, 2023).

COMMUNITY CENTRE

The Community Centre A.B. Ford Park in Detroit, USA, takes it a step further by merging its resilience program against power outages with heat waves and floods for the community of Jefferson Chalmers. Being on a large plot of land as a park, it hosts solar PV arrays and fits in a community centre's program doubling as a climate refuge elevated on a flood-prone site. Its70KW solar PV system with backup storage and generator provides up to 72 hours of power (Lugo-Thomas, 2023).

The centre has been completed in 2023, with the park following in 2024. The project cost $7.9 million made up from the Strategic Neighbourhood Fund (SNF) and City of Detroit bond funds. The cost of its solar PV systems and resources were from the Clean Energy Group Resilient Power Technical Assistance Fund, Urban Sustainability Directors Network (USDN), and the GM Climate Equity Fund (City of Detriot, 2023).

The project reveals a feasible scale of integration within the urban environment of a solar station as part of a community amenity. This is key to transitioning towards the inclusion of solar PV systems through its pairing of other amenities and programs rather than stand-alone structures for a more resilient community.

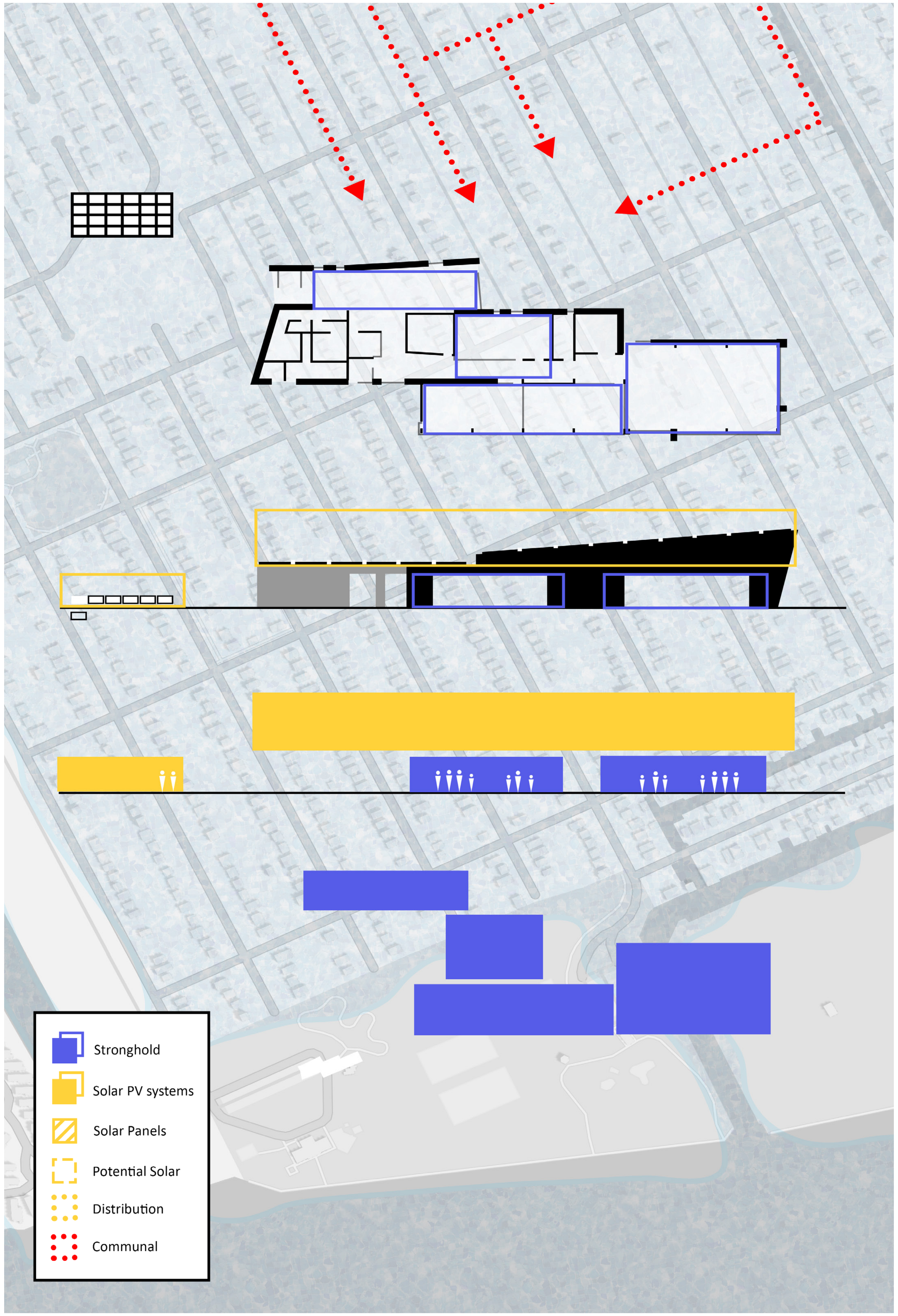


Figure 33: Community Centre Study Diagram.

Figure 34: Paul Horn-Arena BIPV facade by (Allamannwappner, 2009).

BUILDING INTEGRATED SOLAR PV (BIPV)

An example of a BIPV is the Paul Horn-Arena in Tübingen, Germany completed in 2004. This project displays a cohesive program and an integrated design of solar PV into a versatile sports hall. Situated outside the city centre of Tübingen, it provides a centre for indoor activities for the community like sports programs for schools and clubs (Allmannwappner, 2009). The arena is built amongst other facilities for outdoor sports but differs through its versatile use. The southwest façade is the integrated solar PV. The façade holds 970 solar modules giving a total of 520m2 with each a peak output of 45 watts. This will generate 30,000 KWh per year for facility use without the addition of a battery (bba, 2005). The firm Allmann Wappner has designed the solar PV system to be integrated seamlessly and flush against the vertical façade, keeping the cells beautifully exposed. The system embedded into the opaque curtain wall of the two-layer façade differs from other BIPVs by avoiding window or shading and canopy integration.

Furthermore, the Solar façade from floor to ceiling creates an interaction at a user scale allowing a physical connection. This exposes a relationship between the user and solar PV system to induce the realisation of its purpose for renewable energy. Although the Paul Horn Arena is not a disaster relief centre, its robust construction, central open plan and capability of holding 3,000 spectators, could convert to a dual purpose of a refuge.

Figure 35: Close up of Solar PV cells integrated into the facade by (bba, 2005).

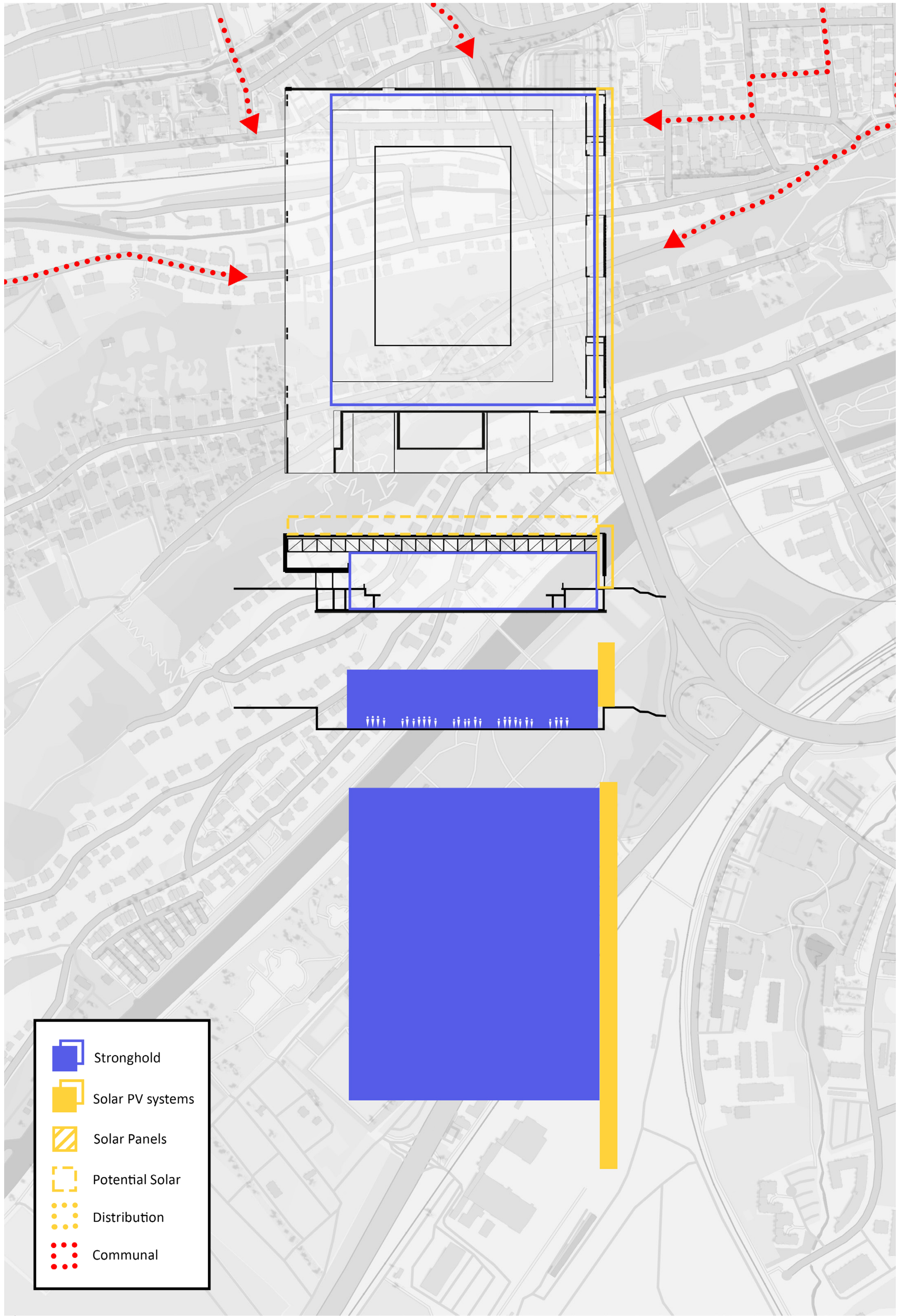


Figure 36: Paul Horn-Arena Study Diagram.

Figure 37: Slowtecture M site and interior by (ArchDaily, 2008)

Slowtecture M, by Endo Shuhei Architects Institute is an example of a city scale program for resilience. Although it does not contain solar PV systems, it represents a successful dual program integrated within the community. Named as the Bourbon Bean Stadium, it is a large new build tennis facility also designed as a disaster relief centre situated in the Miki Disaster Prevention Park. It was built in response of the 6.9 magnitude earthquake of 1995 occurring near Kobe, Japan, only 40 minutes from the park (ATPTour, 2019). This delayed action was necessary to provide disaster affected areas with a refuge and a base for emergency operations after the inability to assist the thousands of people in need during the earthquake.

Completed in 2007, the stadium was built to withstand earthquakes and typhoons, through its robust concrete walls and foundations in conjunction with large steel curved over structure. With an area of 16,000 square meters, it has 9 tennis courts and can comfortably house 4,000 people in tennis event matches (ArchDaily, 2008). With an open floor plan and ceiling height of around 20 metres suits the duality of the stadiums program, to adapt in a different scenario of a disaster. With the merging of programs, it allows continuous operation of the facility as a tennis stadium every day. And through resilient design towards natural events as a disaster relief centre when needed, it justifies its new built integration within Miki City.

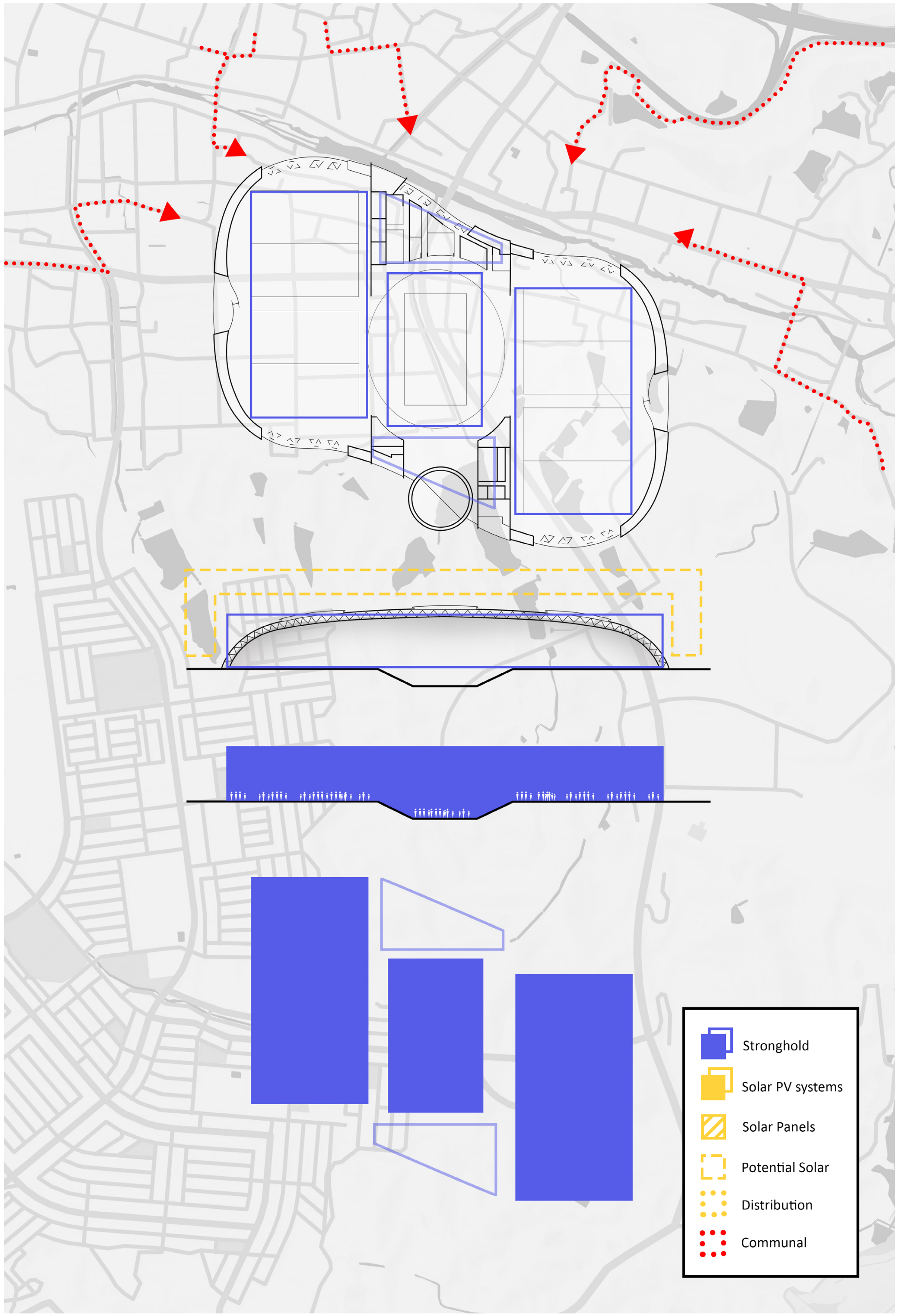


Figure 38: Slowtecture M Study Diagram.

COMMUNITY SOLAR

Community solar is abundant in the United States of America and is ongoing with its integration due to its success. Consumers are connected to this amenity through existing infrastructure and receive the benefits through a subscription. Benefits of lower electricity bills and energy resilience for your home and the community. The fees will contribute to the maintenance and operations of the community solar for all to obtain the same. Thus, increasing equity to those who cannot host rooftop solar PV systems through financial, building ownership or physicality factors (Energy Efficiency & Renewable Energy, 2024).

Figure 39: Marrows Street Solar Farm Section by (ESA, 2024).

An example of a community solar project is the Marrow Street Solar Farm in the town of South Hill, Virginia USA. Being part of the Dominion Energy Virginias Shared Solar Program undergoing resource consent, the project is developed by ESA, a solar energy development and engineering company (ESA, 2024). The parcel is an industrial zone and was traditionally used for timber. The site's primary use is silviculture within the woodland sections of South Hill. The solar farm is close to the town's substation resulting in efficient distribution and using existing infrastructure. It provides accessibility for everyone without rooftop solar PV including business owners.

The project has undergone steps with the community through town officials and existing site analysis for a thorough integration. They have communicated the process and details of the project to the residents of South Hill, to further understand community solar for a collective transition for solar.

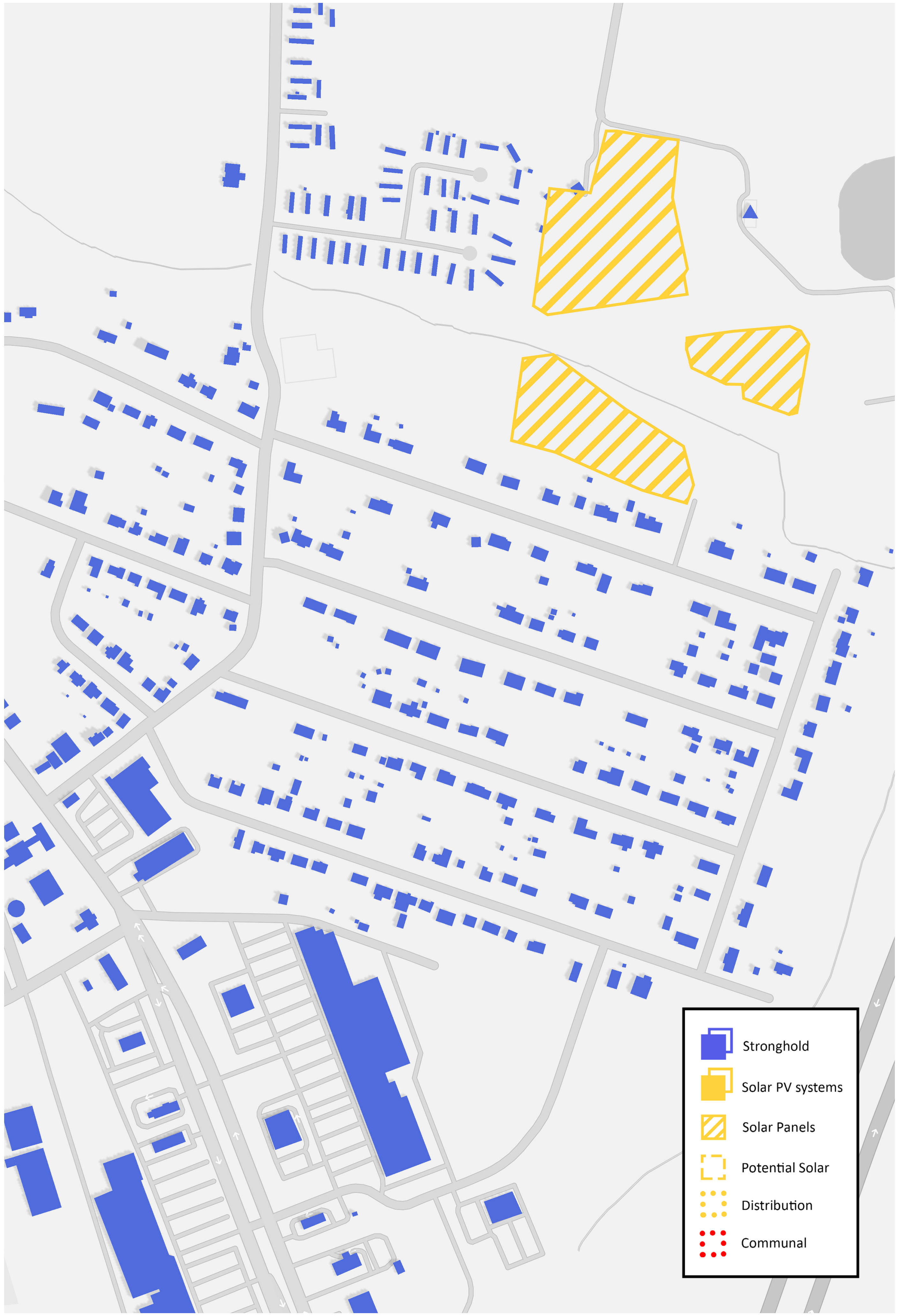


Figure 40: Marrow Street Solar Farm Study Diagram.

Figure 41: Rooftop Solar PV of Community Microgrid by (Garza, 2023).

COMMUNITY MICROGRID

A successful implementation of microgrids and decentralised systems is found in the small mountainous town of Castañer, Puerto Rico. As an island, it has experienced the effects of climate events against its central grid. With a population of 3 million, power outages are frequent, "three to four times a week" (Wyss, 2022) in the town of 6000 in Castañer. During Hurricane Maria in 2017, some parts of the island were left dark for a year, with Castañer without power for eight months expected from their fragile infrastructure.

The system has no upfront installation costs for users, only paying a flat fee of $771 a month compared to $1,000 prior (Wyss, 2022). These payments will then go back to the systems equipment costs, operation, and management. Users also benefit those who are not linked, by lending others to plug in to charge phones, strengthening community connection.

This has also led to a second microgrid in Castañer, with two more in the works through the government's Community Development Block Grant Disaster Recovery fund of $1.3 billion; to develop more microgrids across Puerto Rico (Wyss, 2022). This marks the beginning ripple effect for a sea of micro-grids for community resilience leaving users excited for its future exponential growth.

The micro-grid of Castañer begins with a bakery, having 51 solar rooftop panels feeds energy to industrial batteries and inverters inside a nearby beauty salon. Electricity continues to flow to the "US Post Office, an ice cream parlour, a private residence and an electric vehicle charger" clearly demonstrating the concept of community microgrids with a decentralised solar system.

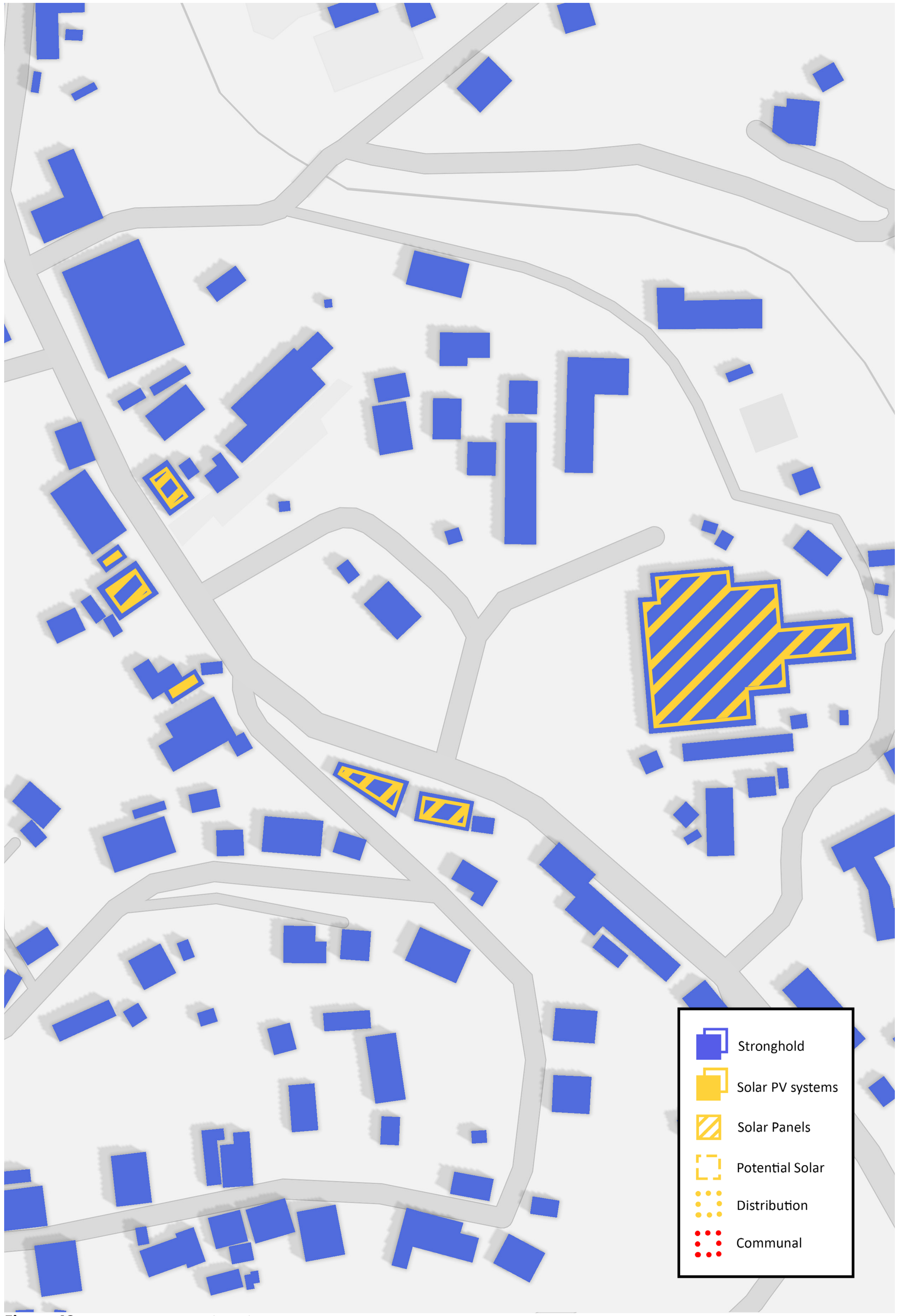


Figure 42: Castañer Microgrid Study Diagram.

Figure 43: Evaluation of each Study Diagram to merge each characteristic and qualtiies reflected into the design of the Solar Station.

CONCLUSION

Each of these solar implementations represents successful integrations of solar PV systems. They are more than just technology or buildings with solar panel connections, it is the way they are integrated and used as a service for community resilience. Whether that is to sell excess generation from private to the public through a community battery or a communal facility for on-site support. Evoking interactive relationships with these systems through BIPV. Including community solar and microgrids providing generative and connective distribution to joined users. It reveals these solar PV community integrations are feasible with the ability to be part of the community's social and built infrastructure. As each case study operates through one strategy, reveals the possibility of merging these systems into one ecosystem on one site. The disaster relief centre provides a program to facilitate this combined strategy in the community with dual purposes.

Furthermore, analysing the design elements of these systems and case studies gave a better understanding of how to configure the ideal integration of solar PV systems in a communal facility. This was done by diagramming each project to highlight locations of solar PV systems or potential implementations and their strongholds defined as communal or just a private service.

DESIGN PROPOSITION

MAPPING

Using the data of Transpower Assets to analyse New Zealands central gird, revealed how the system moves through the country focusing on the North Island. These revealed the relationship of solar farms and arrays in proximity to substations. Thus, a factor when locating sites for solar farm projects to distribute energy. Multiple lines are compacted from Wellingotn to Auckland with strands diverging to various locations from the mainland pathway. This could be seen as a holistic and interconnected network.

However, at a regional scale, it is clearer to understand the national grid vulnerability of its linear nature. This is revealed by some substations with only one connection going through, leaving instances like the region Hawkes Bay with two points of transmission entry from the main national grid pathway. Thus, when severe storms occur these transmission lines are at a higher risk for disruptions resulting in power cuts or even regional isolation experienced by many in Hawkes Bay when two substations were damaged within the region.

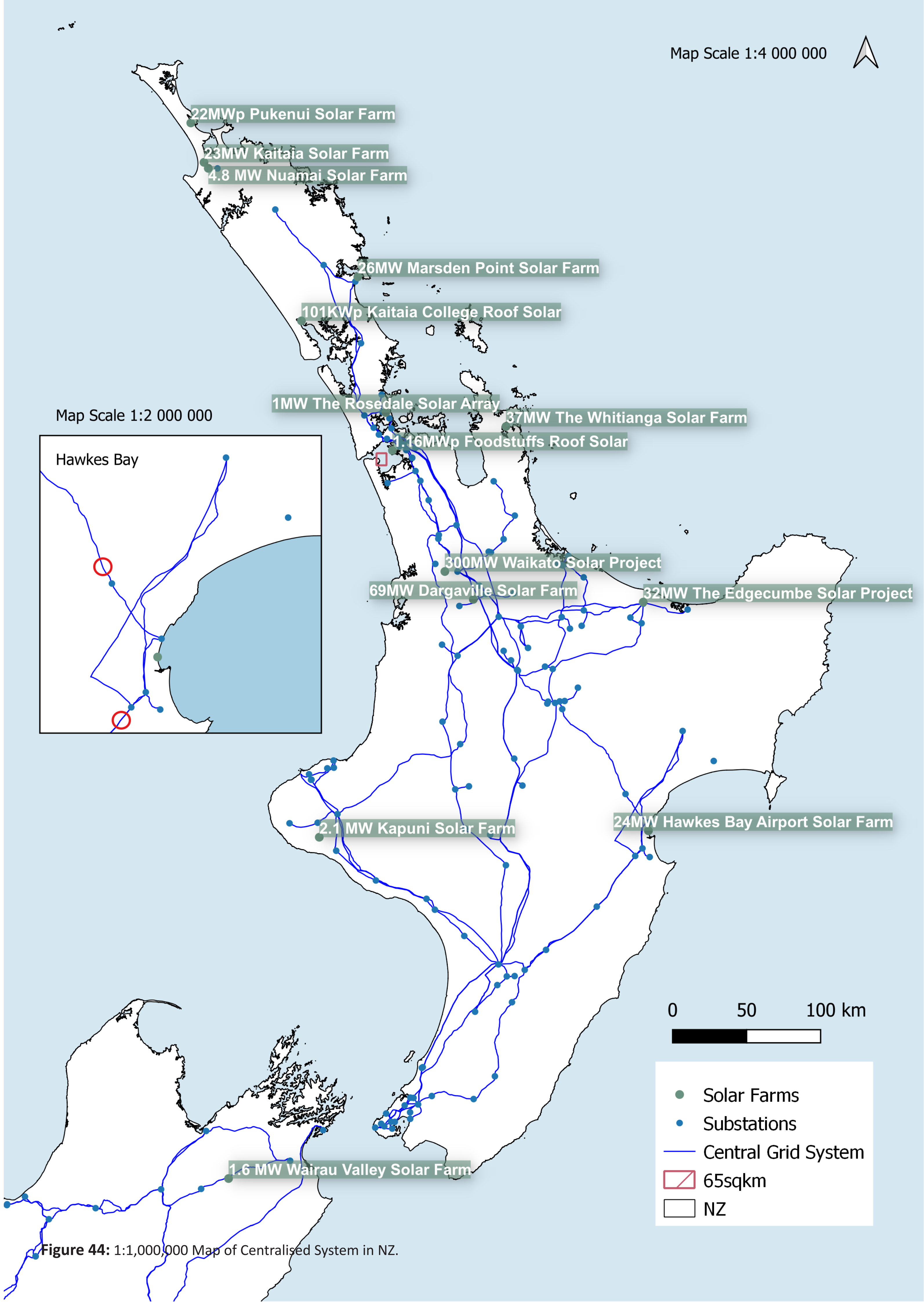


Figure 44: 1:1,000,000 Map of Centralised System in NZ.

Moving towards the Auckland region at 1:600,000, characteristics of singular connections within substations are present. However, substations are scattered in Auckland giving a more interconnected central grid than most regions and prominently travelling through its southern parts. At this scale, we can also see Auckland's 13 wards to analyse the affected areas caused by cyclone Gabrielle. As the damages from flooding were widespread, the North Shore, Albert-Eden-Puketepapa (central), and Waitakere (west) wards were most affected revealed by the number of reported red and yellow stickers given to damaged buildings. This is also associated with damaged infrastructure causing power outages experienced in the North Shore and West Auckland.

What's more eminent in this and the next map is the surface area of 65 square kilometres. This testifies the amount of land needed for solar PV to generate 13% of NZ's current energy demand to reach 100% powered by renewable energy. This is equivalent to 65,000 rugby fields across the country as big as the Manukau Ward.

The location of the intervention within the urban environment is a factor for a connective community, in proximity to residential and commercial areas. Through this requirement parcels within these zones will be scarce, thus analysing unutilised land. The national grid presents this opportunity for empty parcels in neighbourhoods due to transmission towers. These potential suburban sites; from 49m2 to 540m2, could be utilised as solar shelter interventions shown in 1:200,000 map, Figure 48. Isolating the sites of hospitals and schools will support the possible solar shelters throughout Auckland to create an interconnected system for a second medium of energy through decentralised solar.

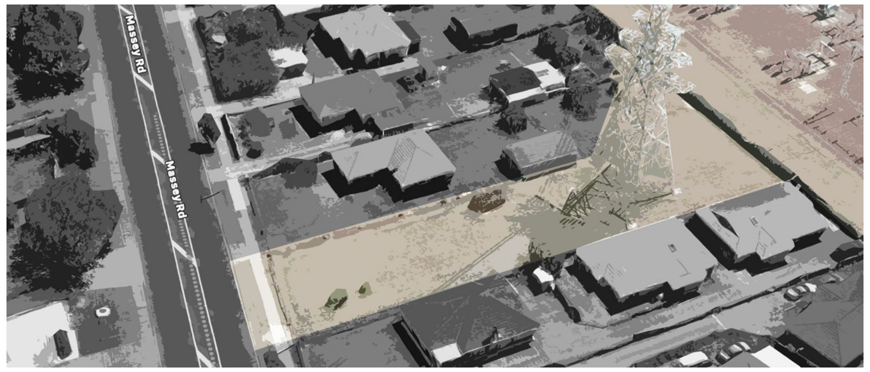


Figure 45: Unutilised Spaces from Centralised assets.

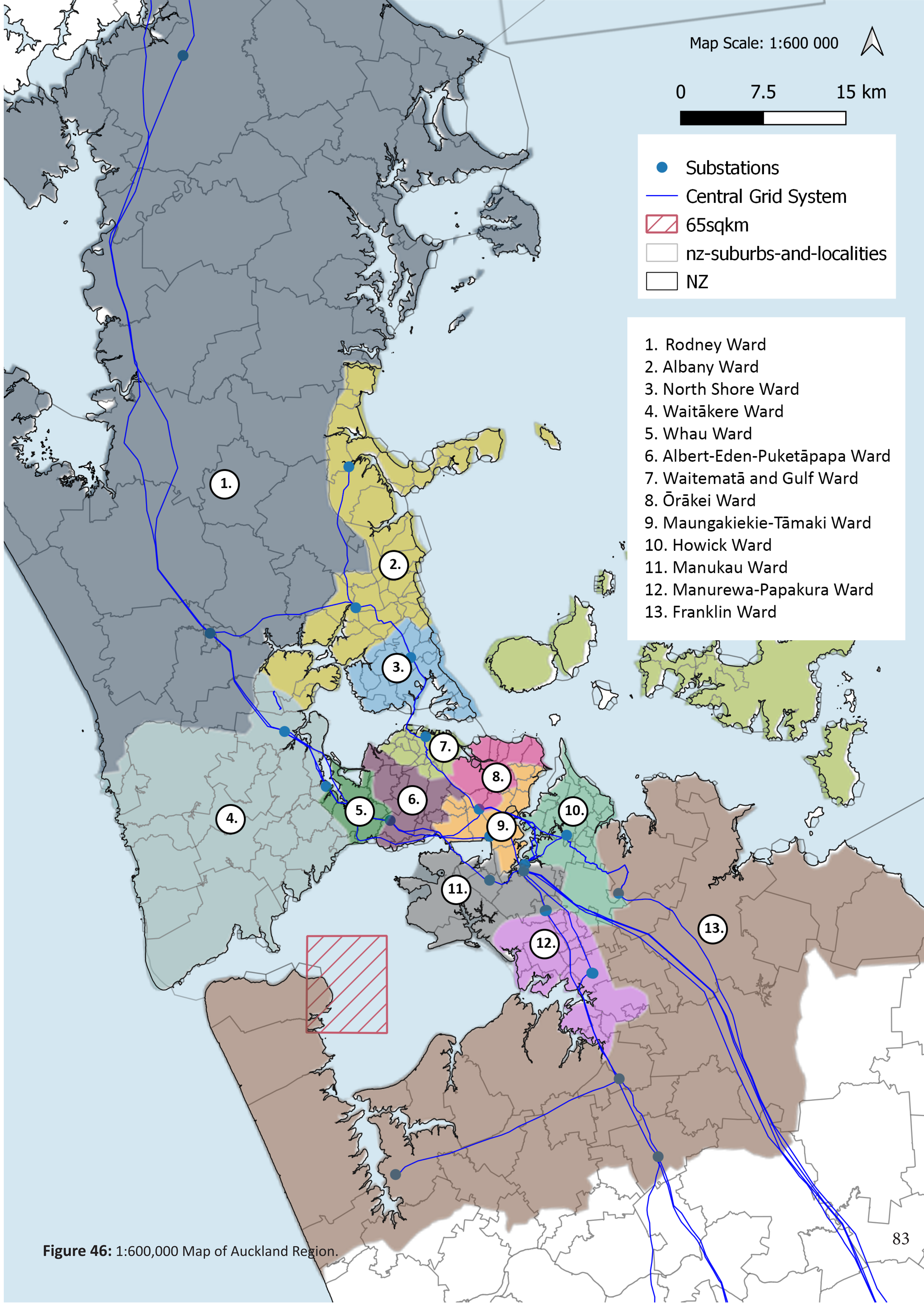


Figure 46: 1:600,000 Map of Auckland Region.

However, where will this system begin? We can also analyse Auckland's deprivation scores in each area. This reveals the Howick ward is one of the least deprived in Auckland, also correlating to being the least reported damages on buildings by the cyclone. Thus, South Auckland is justified for the location of intervention being the most deprived ward for the proposal of a solar station for energy equity a step addressing fuel poverty.

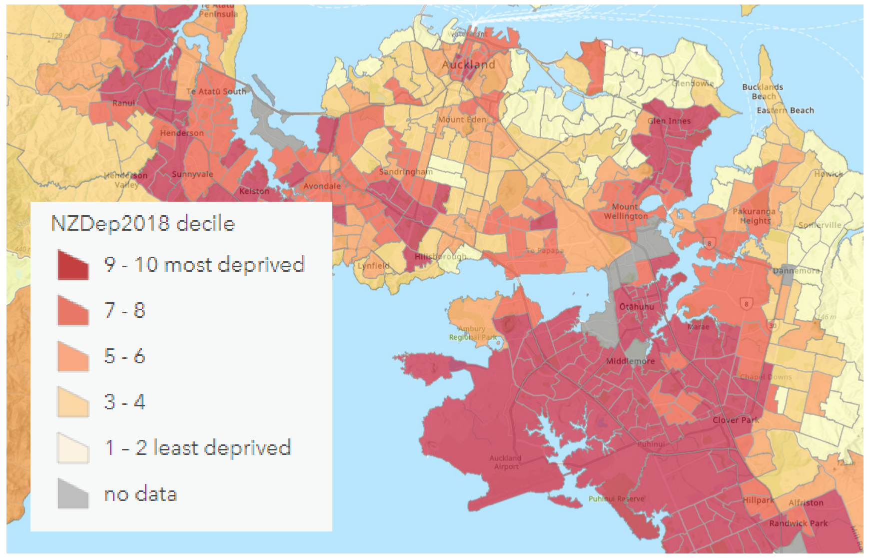


Figure 47: NZ Deprivation 2018 Map of Auckland by (J et al., 2019).

Aligning with Civil Defence Emergency Management (CDEM), they only have three throughout the region. One is located within the CBD as the main headquarters, another in Waitakere and the North Shore. This added layer reveals the absence of control over South or East Auckland allowing the implementation of headquarters for CDEM.

The intervention must be near a substation allowing connective support towards the central grid for energy supply and distribution. This reveals the suburbs of Mangere and Manukau as potential stations to be nearby. Linking with the main CDEM Headquarters in the CBD, a clear route should be followed from central to South Auckland for efficient response times during emergencies. Given the two potential substations in South Auckland, Manukau gives a clear, straight motorway route towards its substation concluding the interventions suburb.

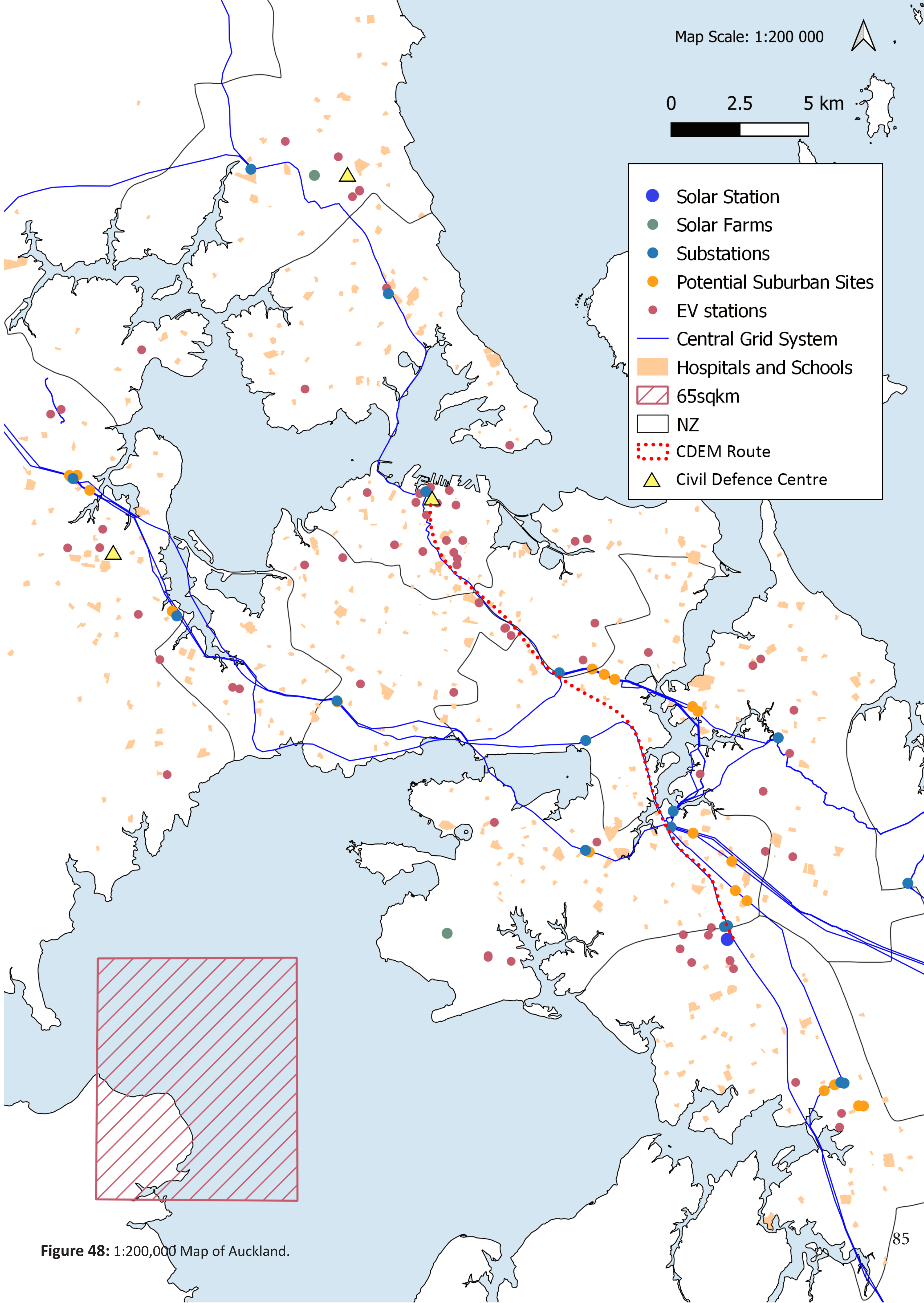


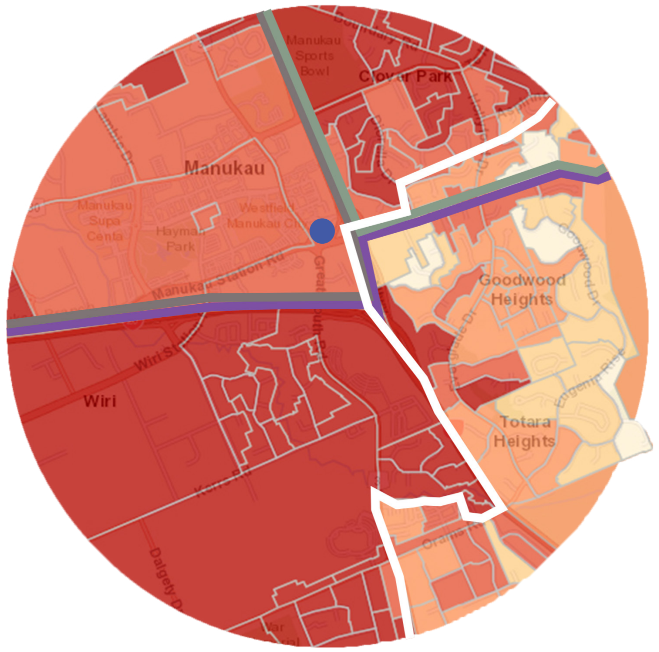
Figure 48: 1:200,000 Map of Auckland.

Locating existing community facilities, schools and Marae's shown at 1:100,000 scale has revealed plentiful areas to act as community hubs or welfare centres to support during emergencies. However, there are no sufficient Civil defence centres or permanent quarters for CDEM to coordinate and operate within South Auckland. accessing one of Auckland's largest hazards of Volcanoes is displayed. The city being situated on a Volcanic field raises potential risks thus procedures for evacuation or shelter. This reveals its parameters and safe zones within South Auckland reinforcing the need for an EOC with the programme of a disaster relief centre. Manukau sits within these boundaries presenting a secure suburb.

With the support of other public facilities during emergencies, the intervention will act as the central communication for South Auckland while increasing the capacity to accommodate those displaced. As the intervention will be a public amenity for the community of Manukau, the everyday programme of the Solar Station is a badminton facility. There are a few badminton facilities skewed in the east and far south, revealing a grey area in Manukau. Thus, a new specialised sports facility will be introduced for badminton with a demographic present within South Auckland.

The deprivation map concludes this site by revealing a boundary between the deprived and least deprived in the Manukau Area. This is a factor to address energy poverty experienced within the south by providing energy security through distribution and connection in support of the least deprived communities.

Figure 49: Boundaries of deprivation, and three Auckland wards.



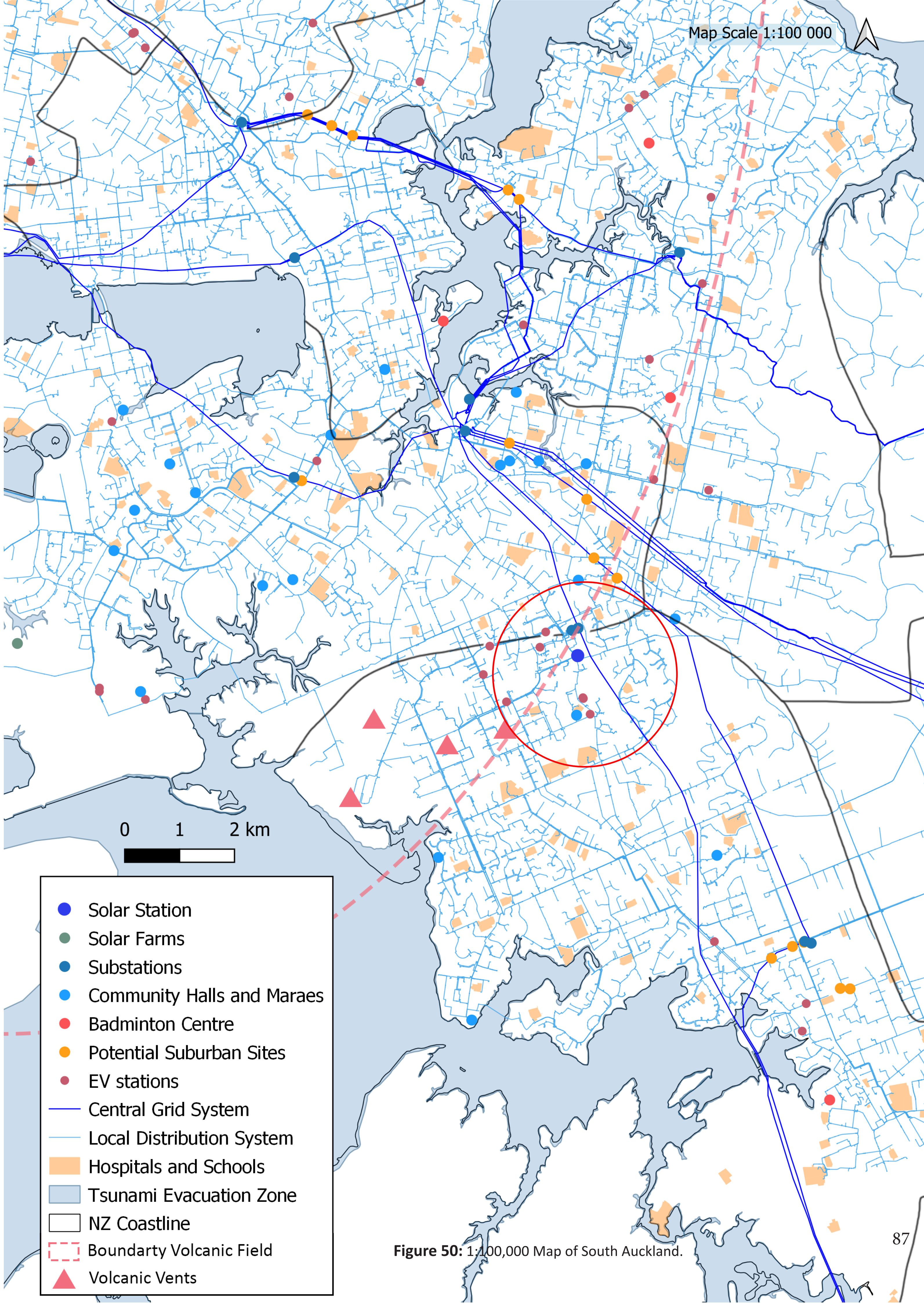


Figure 50: 1:100,000 Map of South Auckland.

Auckland’s wards, Manukau, Howick and Manurewa-Papakura meet at a point within Manukau City Centre. This location provides easy access from all three wards during emergencies for other communities to access through main roads such as Great South Road and SH 1 or 20.

Manukau also has a predominant commercial presence within its city centre, leaving residential buildings surrounding these zones. Analysing the unitary plans to reveal the boundary between business and residential zones presents a radius for where the intervention meets public and private. This is a factor in utilizing large surface areas of commercial rooftops while still being within reach of residential buildings for connection, exposure, and access shown in Figure 55. Being situated close to commercial rooftops allows the opportunity to create a system chain to other buildings, expanding energy production and distribution. This stays true by isolating public facilities like schools, churches and hospitals revealing potential hosts for expansion to create a greater system within wider Manukau. The role of these facilities will be elaborated in expiermental simulation. The boundary becomes clearer at this scale of deprivation, a factor to ground the proposal to be in proximity of these deprived areas for energy security and equity.

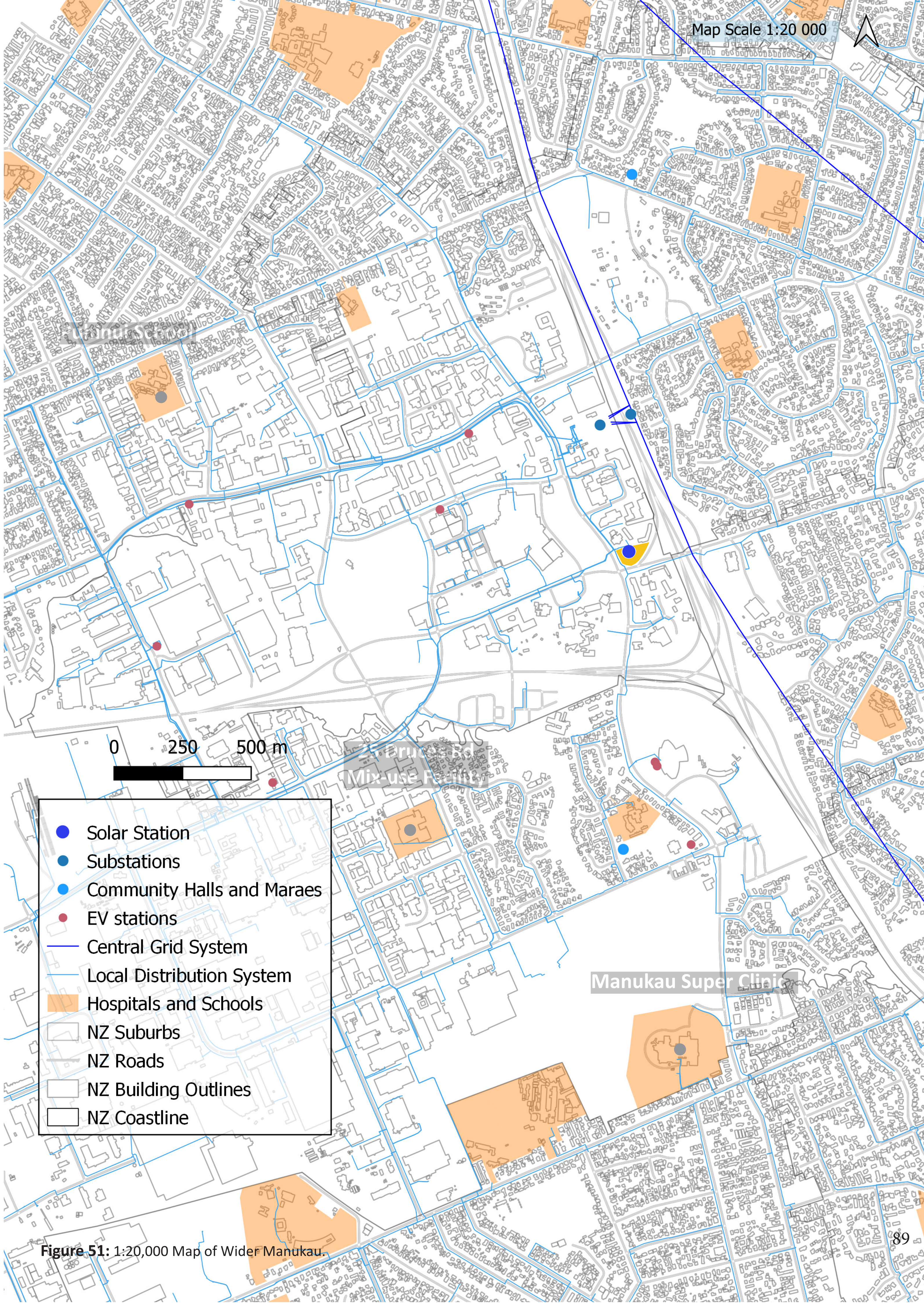


Figure 51: 1:20,000 Map of Wider Manukau.

Manukau City as the chosen suburb still reveals issues of flood-prone areas. Revealing also flood plains exposes sections of Manukau to avoid thus prevent flooding implications. This narrows down the search for the parcel site after considering all the previous layers. Therefore, the intervention will settle in an unutilised corner parcel of Manukau (718 Great South Road, Manukau City Centre, Auckland 2104) in proximity to the substation and in between the boundaries of each ward, deprivation, and commercial to residential zones. The existing local electrical distribution infrastructure becomes clearer at this scale showing an interconnected system from one site to another. This is crucial to the solar station's strategy from building upon a community micro-grid to a more energy-resilient future.

Figure 52: Solar Station Site in Manukau.

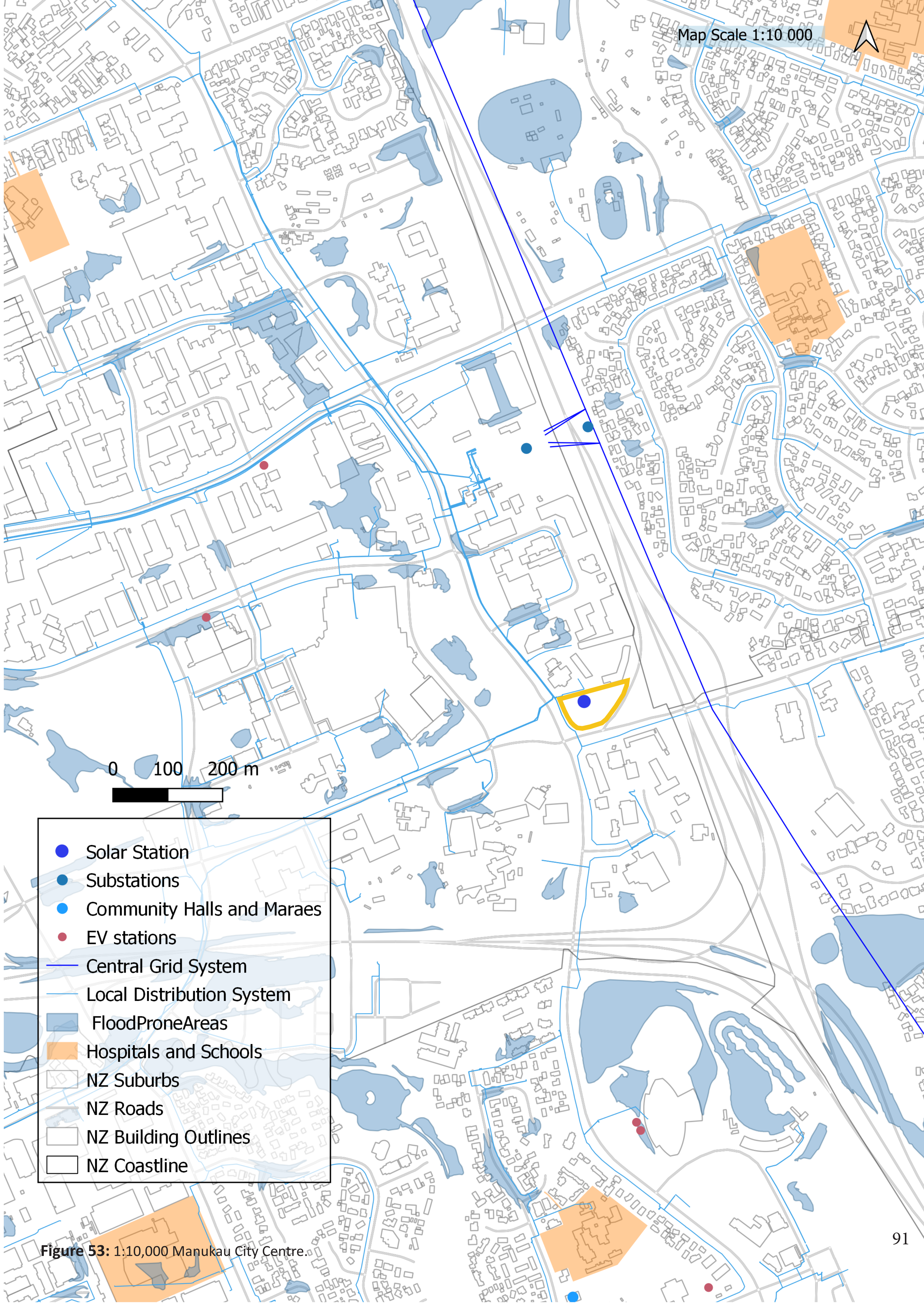


Figure 53: 1:10,000 Manukau City Centre.

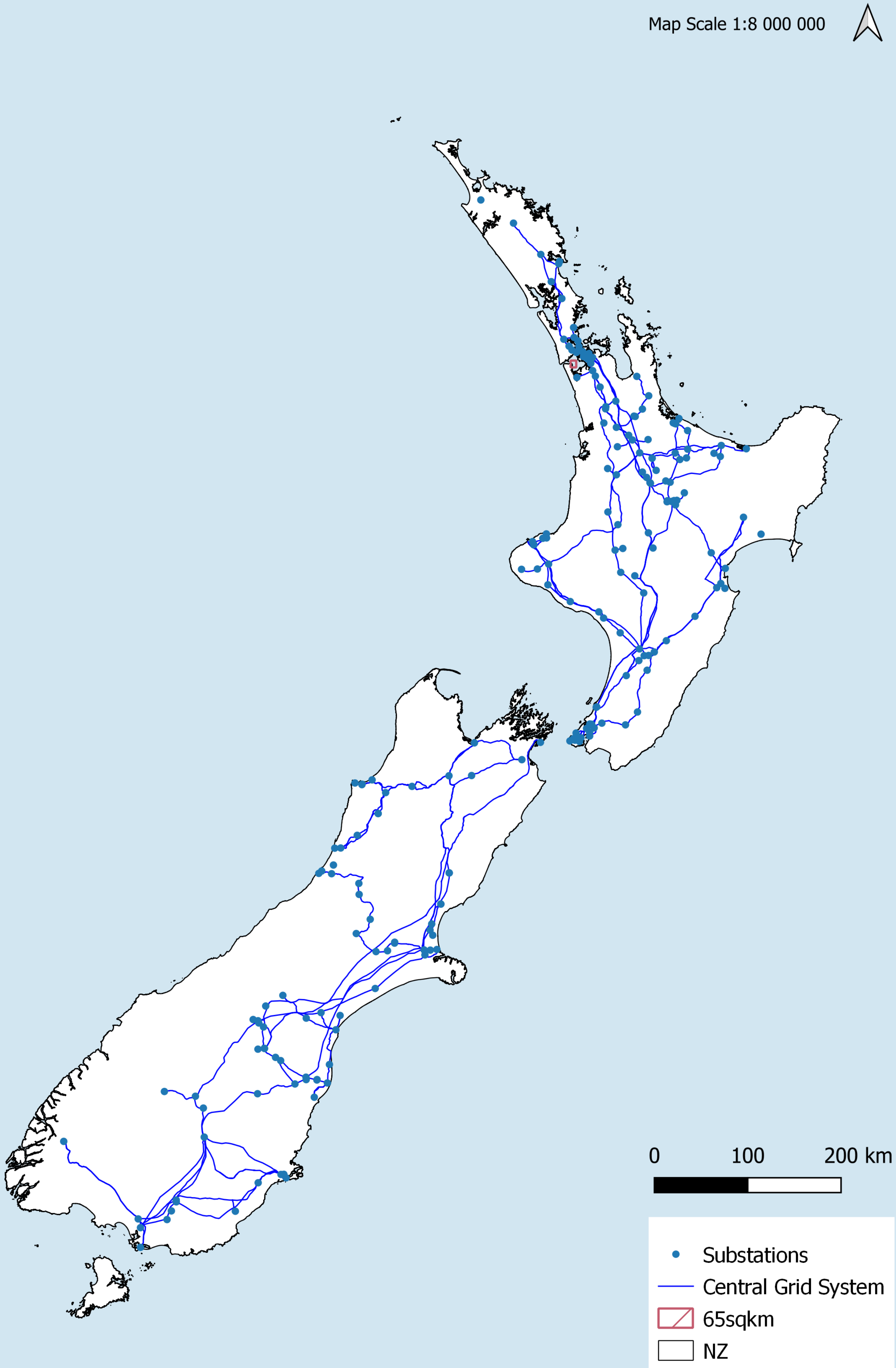


Figure 54: 1:8,000,000 Map of NZ Centralised System.

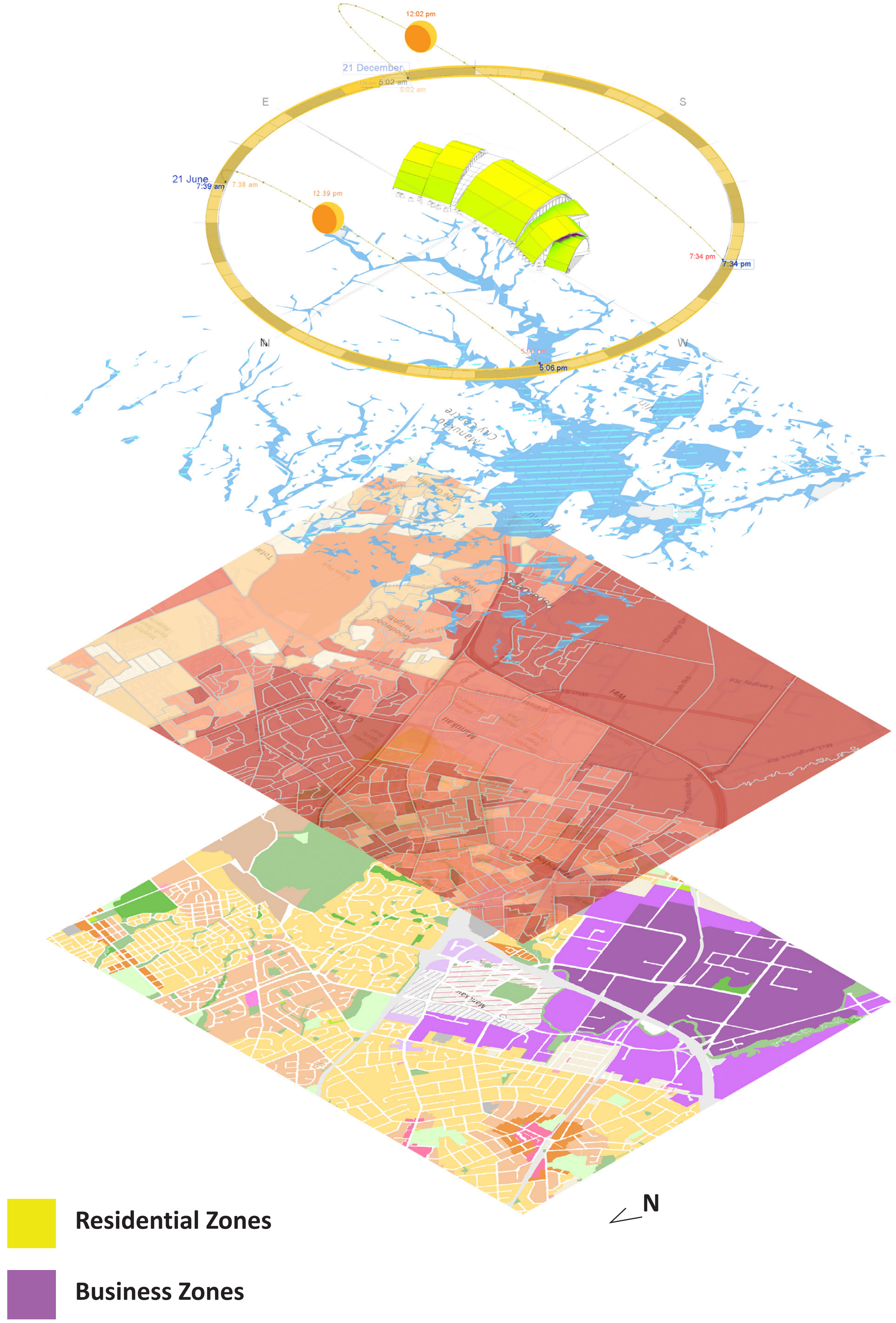


Figure 55: Map Layers of Flood Prone, Deprivation and Unitary Plan Zones placing the Solar Station.

EXPERIMENTAL SIMULATION

An experimental Simulation was conducted to analyse energy usage of three buildings all interlinked within the existing local electrical infrastructure proximity to the proposed site. These results were used to go against data calculated for each building's potential of a rooftop Solar PV installation using the PV Watts Calculator from the National Renewable Energy Laboratory (NREL) (NREL, 2024).

The buildings are Puhinui School, Manukau Super Clinic and 25 Druces Road a mixed-use building. They have been prioritised due its proximity to the proposed site, roof orientation and size. Other than these requirements, it was crucial to diversify the programmes to calculate which facilities are more efficient to sustain and then send electricity back to the solar station.

25 Druces Road energy usage exceeds the energy it generates on-site annually, leaving no excess for distribution. Manukau Super Clinic doubles its demand for energy than what's generated on-site annually, which is also unsuitable for distributing excess energy to other buildings. Puhinui School reveals a favourable ratio of energy generation being triple its demand on-site. This reveals favourable facilities of schools and would also relate to community centres, buildings with low electrical demand to keep the lights or equipment running. Although some buildings don't have excess energy to send back to the solar station it does not sever its connection to be part of the interconnected micro-grid. In these instances, they can join and remain within the system for energy security provided by the solar station like houses without solar PV systems. Furthermore, hospitals are crucial to continue their operations through power cuts, this proposal provides a renewable alternative to diesel generators.

Analysing the potential of Solar PV systems on nearby existing rooftops through experimental calculations reveals how these DERs would come together. This creates a feasible interconnected network for the distribution and storage of energy within existing electrical infrastructure. It shows how each building could and will play a role within this community microgrid by using solar when generating for themselves and then diverting excess to the solar station for wider communal benefit.

PVWatts Calculator

RESULTS 889,712 kWh/Year*

Puhinui School
Consumes: 238,500 kWh

PVWatts Calculator

RESULTS 1,739,831 kWh/Year*

25 Druces Rd Mix-use Facility
Consumes: 1,800,000 kWh

PVWatts Calculator

RESULTS 2,346,420 kWh/Year*

Manukau Super Clinic
Consumes: 2,184,000 kWh
Special Purpose Zone

Figure 56: The analysis for Rooftop Solar PV on facilities for Solar Station connection.

Figure 57: Results from PV Watts calculator assumption of energy generated on Puhinui School, Druces Road, and Manukau Super.

PVWatts Calculator

RESULTS

889,712 kWh/Year*

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	6.82	106,178
February	6.18	88,367
March	5.32	85,081
April	3.99	63,314
May	3.38	56,593
June	2.68	44,209
July	2.86	49,006
August	3.71	62,513
September	4.26	68,913
October	4.97	81,844
November	5.77	89,796
December	5.89	93,899
Annual	4.65	889,713

Location and Station Identification

Requested Location	116 Puhinui Road
Weather Data Source	Lat, Lng: -36.99, 174.86 0.5 mi
Latitude	36.99° S
Longitude	174.86° E

PV System Specifications

DC System Size	671.9 kW
Module Type	Standard
Array Type	Fixed (roof mount)
System Losses	14.08%
Array Tilt	20°
Array Azimuth	0°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	No (0)

Monthly Irradiance Loss

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Performance Metrics

DC Capacity Factor	15.1%

PVWatts Calculator

RESULTS

1,739,831 kWh/Year*

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	6.82	207,631
February	6.18	172,801
March	5.32	166,375
April	3.99	123,811
May	3.38	110,668
June	2.68	86,450
July	2.86	95,831
August	3.71	122,243
September	4.26	134,759
October	4.97	160,046
November	5.77	175,597
December	5.89	183,619
Annual	4.65	1,739,831

Location and Station Identification

Requested Location	25 Druces road
Weather Data Source	Lat, Lng: -36.99, 174.86 1.2 mi
Latitude	36.99° S
Longitude	174.86° E

PV System Specifications

DC System Size	1313.9 kW
Module Type	Standard
Array Type	Fixed (roof mount)
System Losses	14.08%
Array Tilt	20°
Array Azimuth	0°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	No (0)

Monthly Irradiance Loss

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Performance Metrics

DC Capacity Factor	15.1%

PVWatts Calculator

RESULTS

2,346,420 kWh/Year*

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	6.78	280,585
February	6.10	232,087
March	5.34	227,078
April	4.01	169,146
May	3.44	153,577
June	2.67	117,066
July	2.80	127,599
August	3.30	149,264
September	4.43	190,963
October	4.81	210,480
November	5.79	239,462
December	5.88	249,113
Annual	4.61	2,346,420

Location and Station Identification

Requested Location	901 great south road
Weather Data Source	Lat, Lng: -36.99, 174.9 1.3 mi
Latitude	36.99° S
Longitude	174.90° E

PV System Specifications

DC System Size	1786.0 kW
Module Type	Standard
Array Type	Fixed (roof mount)
System Losses	14.08%
Array Tilt	20°
Array Azimuth	0°
DC to AC Size Ratio	1.2
Inverter Efficiency	96%
Ground Coverage Ratio	0.4
Albedo	*From weather file*
Bifacial	No (0)

Monthly Irradiance Loss

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Performance Metrics

DC Capacity Factor	15.0%

Figure 58: Solar Station North Facade and Vegetation

SOLAR STATION

Drawing in the analysis of case study diagramming influenced the configuration of the solar station. The community battery gave the aspect of energy as a service through rooftop solar PV and lithium-ion batteries for storage, addressed through additional strongholds to host the systems for greater yields and holds. The community centre case study gave the aspect of communal invitation for onsite resilience, addressed by site analysis of the solar station to provide energy security in less-privileged areas on and off-site. The Paul Horn-Arena gave the aspect of the interaction with solar PV systems through BIPV, addressed by surrounding the solar station of solar PV to create a relationship between the user and the generating technology. That case study also supports a larger stronghold for scalable programmes and communal activity. The solar station then draws the programs of the Slowtecture M a dual-purpose tennis arena and disaster relief centre.

Furthermore, this program combination with community solar and micro-grids nature in layout, develops a segmented one-mass cloaked with BIPV as the solar station. Therefore, evaluating the energy resilient framework meets the aspects of Site Analysis, Distributed Energy Resources, Embodiment and Transformative qualities to achieve community energy resilience.

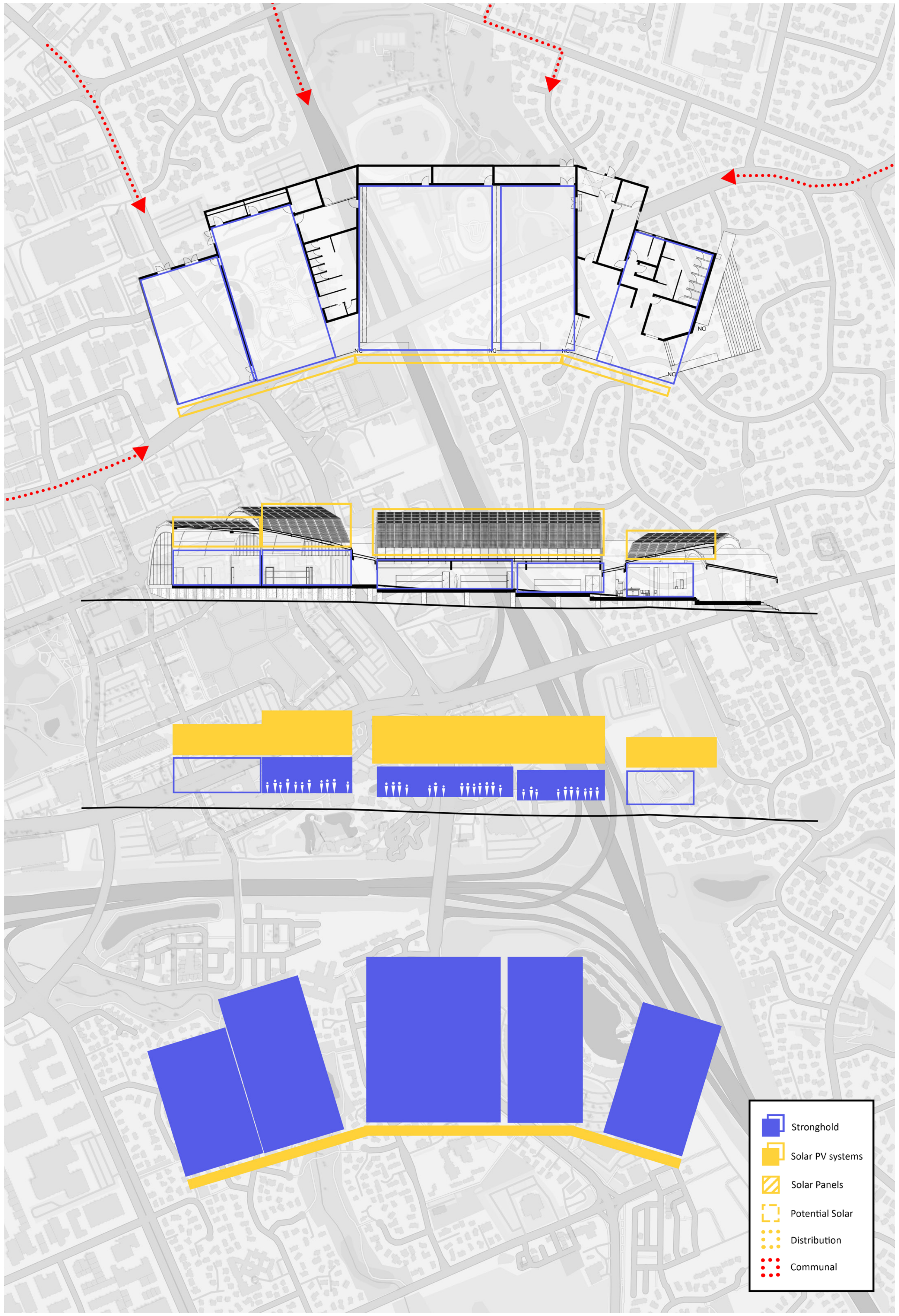


Figure 59: Solar Station Study Diagram Reflection.

ITERATION

To achieve Building Integrated Photovoltaics, the façade of the building must be orientated towards the sun, at the North in NZ. Solar PV panels can also track the sun throughout the day. To reflect this characteristic and avoid extensive costs for a moving roof in South Auckland, it could be permanently shaped as a curve for efficiency. Solar PV films are a flexible material able to bend with a curve. However, these films have lesser yields than normal solar PV cells hence closure to implemented flush curved surfaces and parabolic roof.

Therefore, the first iteration of the solar station did not meet all the qualities of the energy-resilient framework, only meeting Site Analysis, Embodiment and being Transformative. The design did not promote an interactive system shown by the distant solar PV system on the high parabolic roof. This diminishes the relationship with the users on-site with the regenerative technology. Although the quality of Embodiment has been met, the program as a community hub could have been taken further to a more integrated approach aligned with energy resilience. Thus, the response of a disaster relief centre and emergency operations.

The nature of parabolic roofs exposes the risk of being lifted during strong winds. As the solar station will facilitate disaster relief measures, a more climate-neutral building envelope was desired giving a shell form, addressing 1b) guidelines. Hence, the roof will be curving downwards to become resilient against strong winds while giving a more conventional solar PV installation. This also gives a low profile inducing a more stable structure during earthquakes. To maintain the previous parabolic curved roof, the shell form will be divided into 4 sections to follow the sun's path throughout the day, from NE to NW.

Figure 60: First Iteration Programmes and Elevations.

Figure 61: Concept Models of Mass, Structure, and Facade.

Figure 62: Concept Sketches of Design Key Features.

INTERVENTION

The solar station surpasses the purpose of rooftop solar PV systems. The contents of the design are technology that already exists but how it is used is the next step for solar resilience. Solar PV systems are integrated into the building's façade identified as a BIPV to generate renewable energy. A communal battery is sheltered within the building to store excess energy for the community to use during power cuts or peak usage. The system is connected to existing electrical infrastructure, interlinking with other buildings with solar PV systems as a microgrid or through the cloud as a VPP to collect and distribute electricity. The main driver for this proposal was the integration of solar PV systems not just in a building but its role within the community.

Figure 63: Collage of Facility Connections to the Solat Station.

Through the evaluation of maps, the solar station ground itself in Manukau City Centre, northeast of Rainbows End. Being on an intersection with the longest street in New Zealand Great South Road gives access to the facility to the public from the communities of South and East Auckland. Also parallel to State Highway 1 and State Highway 20, straight routes to Central and West Auckland. Situated between these prominent routes, it allows easy transportation to the solar station from Manukau's industrial, commercial, and residential zones. Not only it's easy to get to for the public and emergency response services during disasters, but it also receives exposure within the community addresses 3b) guidelines.

Fundamentally, the location was grounded due to its proximity to the Manukau Substation. It must be connected to a nearby Substation to support the central grid at peak energy demands to avoid distant electrical travel or additional infrastructure. The site was originally a greenfield construction despite being within Manukau City Centre. However, it was underutilised due to its inconvenient corner parcel right next to the motorway used as a car yard and billboard advertisement away from any built risks addresses 2b) guidelines.

Figure 64: Exisiting Site utilised as a Car yard.

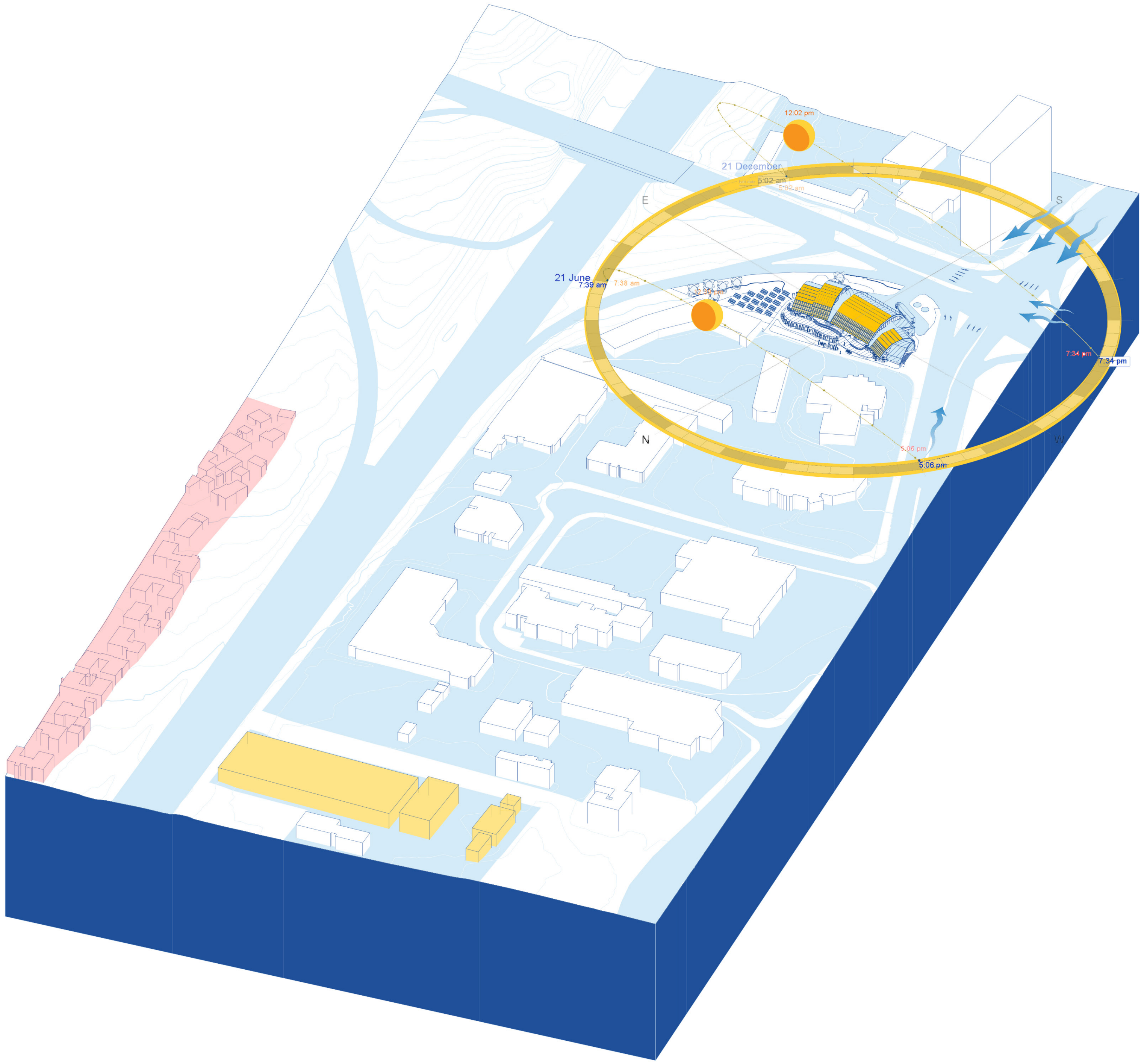


Figure 65: Solar Station Site Analysis.

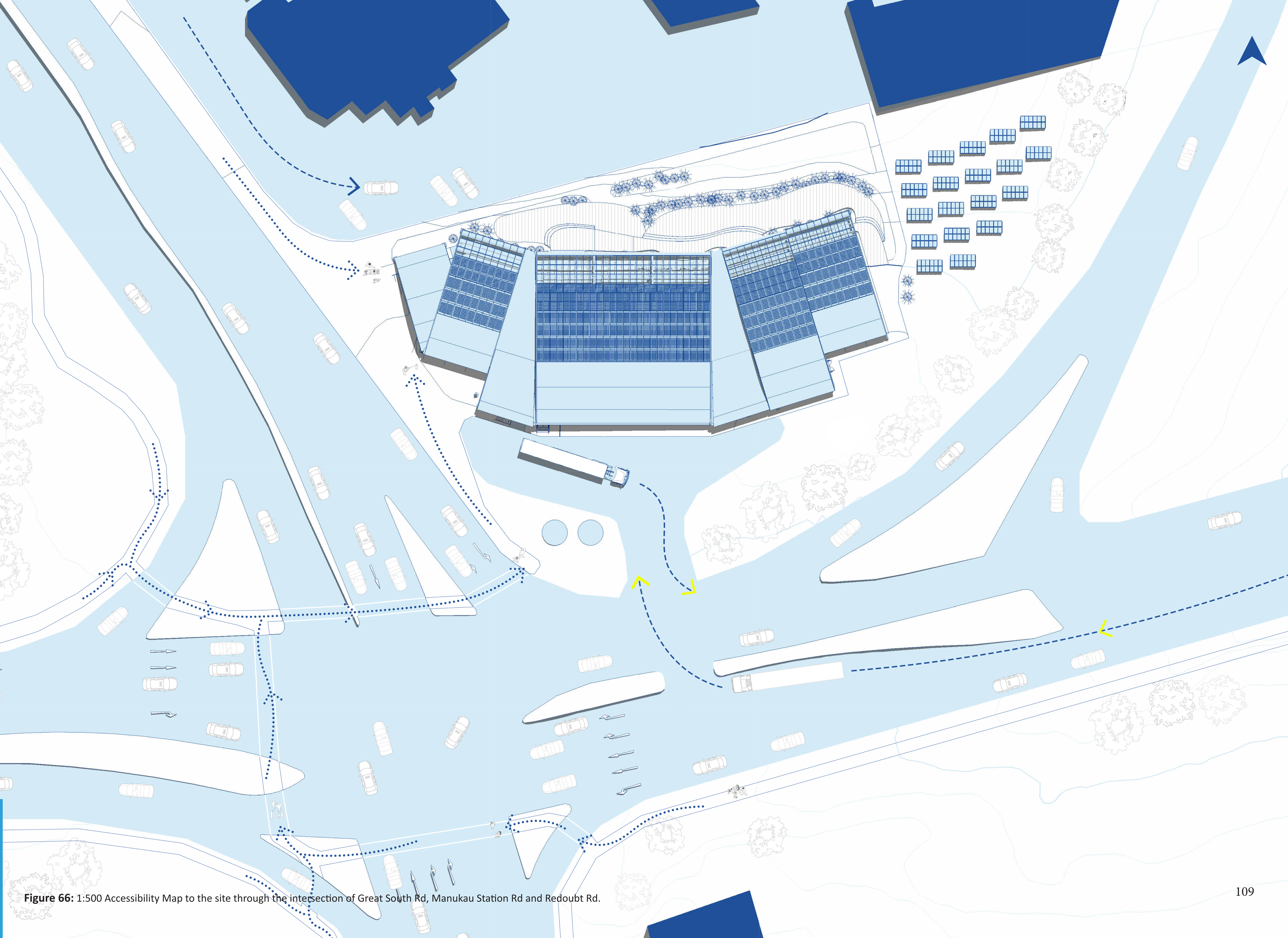
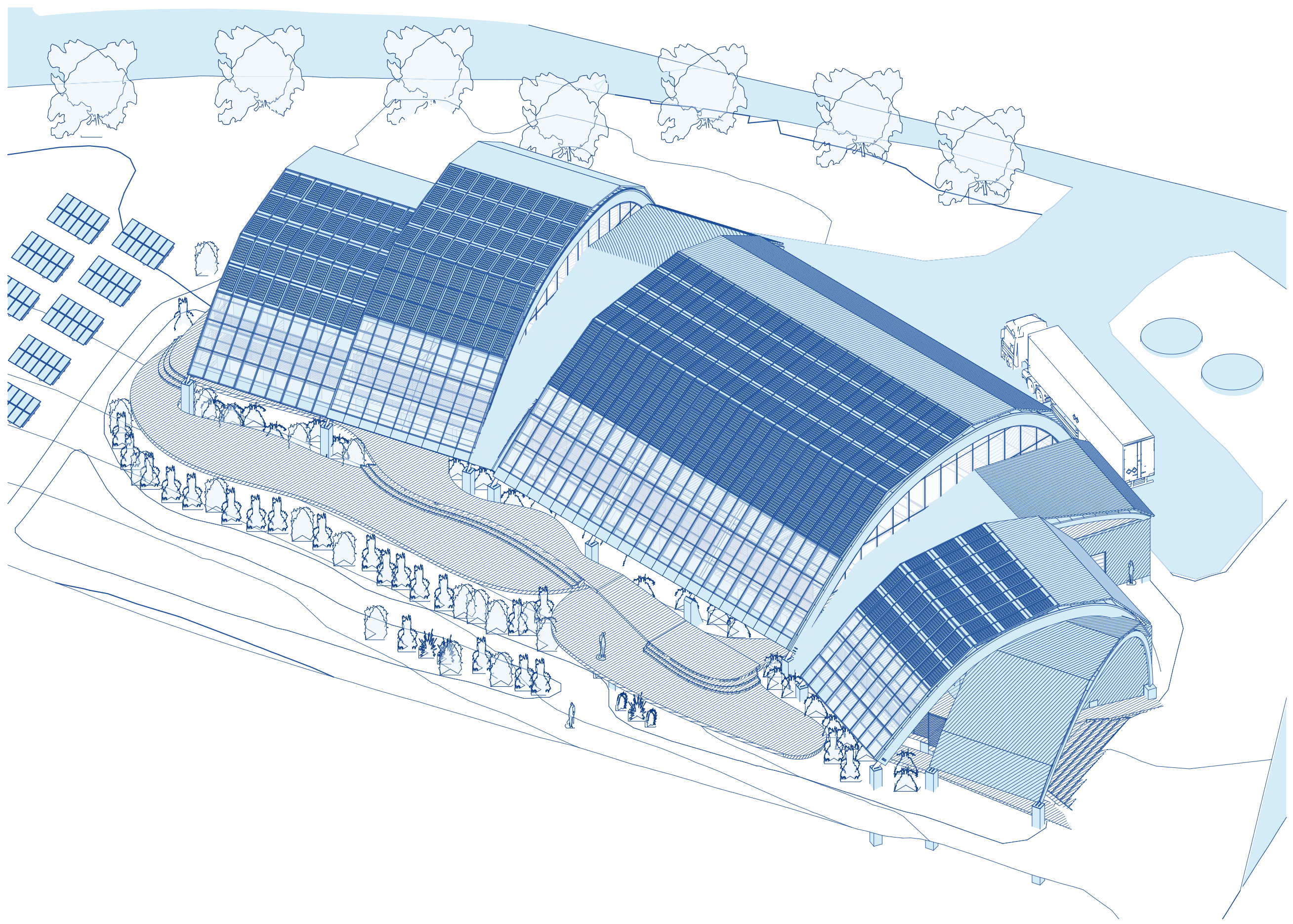


Figure 66: 1:500 Accessibility Map to the site through the intersection of Great South Rd, Manukau Station Rd and Redoubt Rd.

Evaluating the solar analysis of this form and layout reveals plenty of solar radiation on all four elements. There are **494 330W** monocrystalline solar PV panels with dimensions of **1 by 1.7 metres** integrated with the building's façade. The are **57** of the same solar PV panels merged as **19** sun-tracking and ground-mounted. The total number of solar panels on site is **551** giving an area of **937m2**, the size of two netball courts. The site is an **182W** solar PV system producing **212,453kwh** per year. The solar station is estimated to consume **88,560kwh** per year leaving an excess of **123,893kwh** per year to distribute and sell. Data was calculated using the Photovoltaic Generation Calculator from BRANZ (BRANZ, 2025).

The excess generated could provide electricity for **17 households per year**. However, the main purpose of the solar station is to acquire disaster preparedness and community resilience, not an energy plantation. Thus, connected users (subscribers/customers) will not experience any latency during power outages as the solar station can provide **16,833** customers/ households with 8 hours of electricity, which is the average annual power outage duration in Auckland **(Figure 8).** That is more than **13,275** dwellings in Papatoetoe and can extend to 24 hours resulting in providing **5,631** customers which is larger than the **4,341** dwellings of St Heliers.

Figure 67: Relationship of a person on site countour model 1:200.



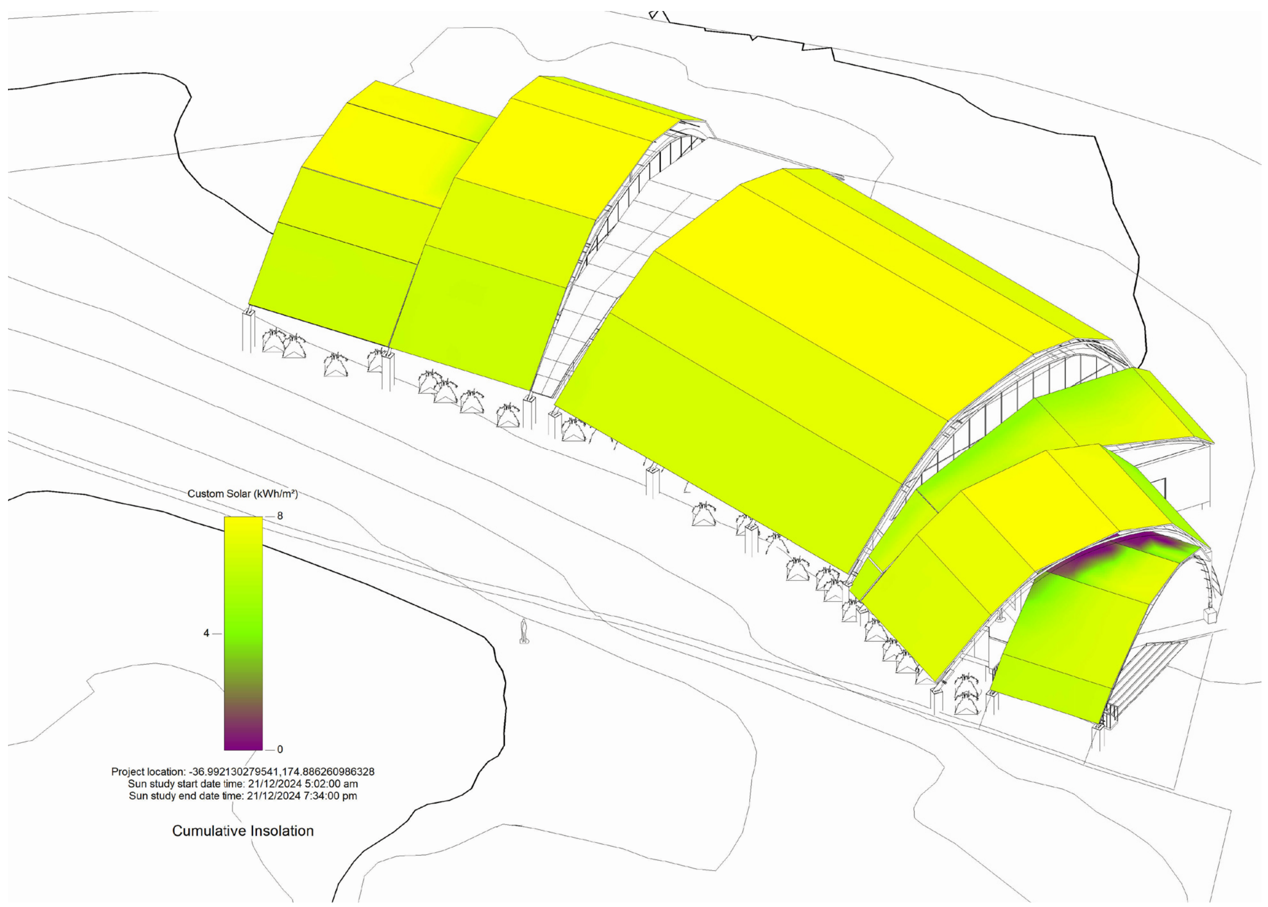


Figure 68: Isometric and Solar Radiation Analysis.

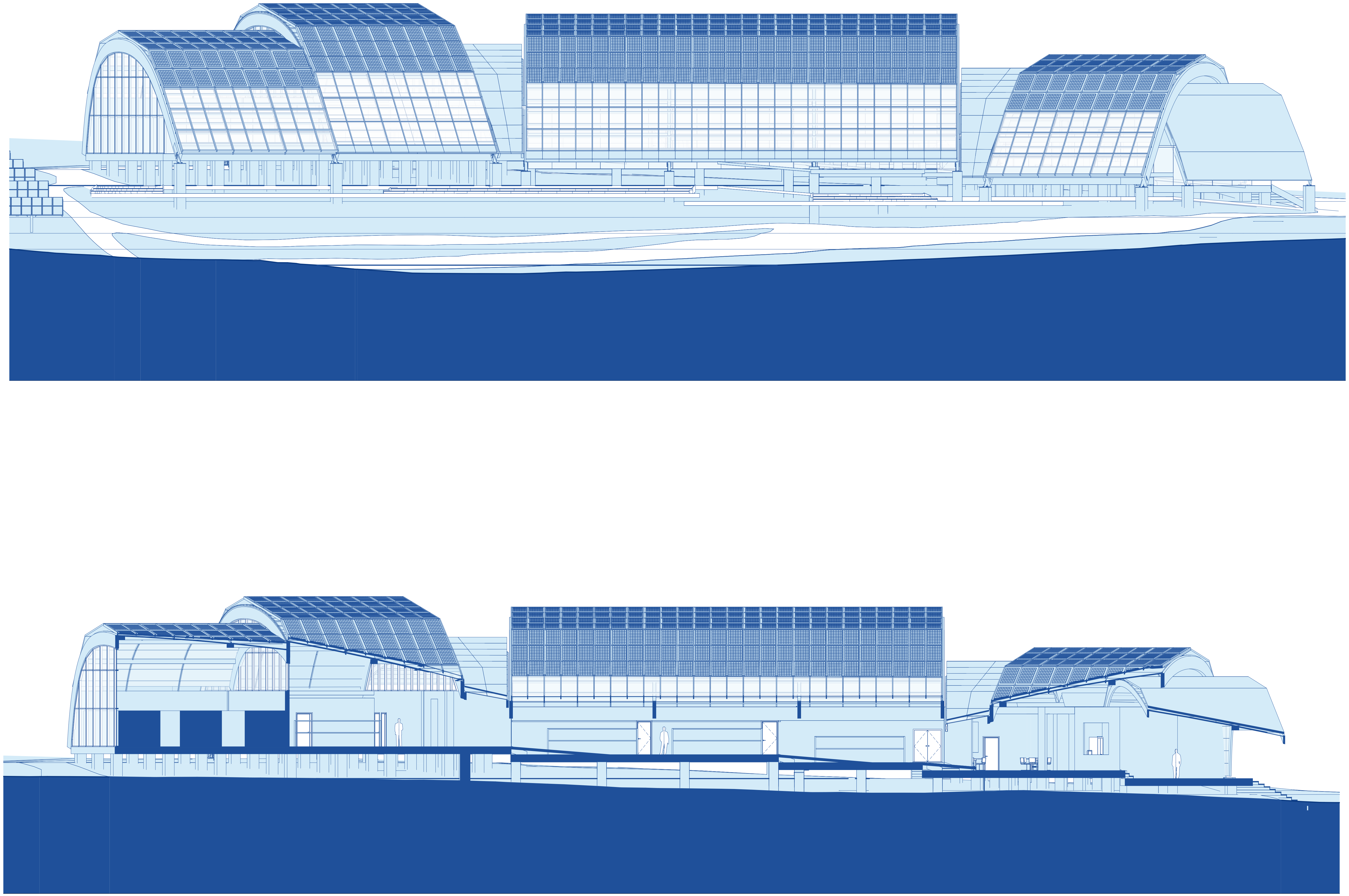


Figure 69: North Elevation and AA Section.

Solar stations have dual programmes, a disaster relief centre and a badminton facility. The addition of hosting solar PV systems creates three aspects of functions in one design. As the shell form was in ratio to maximise surface area for solar PV panels, it induced a large interior floor-to-ceiling height. This produces a convection current where cold and fresh air will only be experienced in the bottom as the hot air escapes towards the high ceiling promoting passive ventilation within the building for energy efficiency. This is ideal for sporting grounds hence the second programme of badminton activities where users produce heat—furthermore, the ability to accommodate masses under the open space during emergencies of the shell structure. This promotes daily communal activity and cohesion bringing people together in times of need during disasters.

The pathway in front of the solar station is accessible to the public as an exterior recreational space to unwind, jog and run. It flows in and out of the site's structure an embodiment of energy's movement, creating an interactive walk highlighting the solar station's integrated solar PV systems, structure integration and site usage. During disaster emergencies, the timber decks serve as a space to set tents for temporary accommodation.

Facing Great South Road, the large open entrance greets with a large glulam beam arch to introduce the embodiment of the strength, support and sustainable qualities the facility holds. The basalt stone wall feature symbolises the facility's permanence and stability while reflecting Manuakus's three mountains used as quarries.

This feature guides you into the first platform. You are welcome at a reception desk for any notices, special events and enquiries for bookings or services. It is also a small office that conducts reports and administration for energy generation and distribution. Behind sits the women's toilets with lockers and showers to cleanse after activities or emergency disasters. Adjacent is the First aid room with medicine storage and freezer. Back on the main pathway is the communal section, opening the threshold to dining and the kitchen to cook meals and have refreshments. It is connected to a pantry and freezer to distribute food supplies within the facility during emergency disasters addressing 2a) guidelines. This room is accessible in the back for lorries to unload into the building easily.

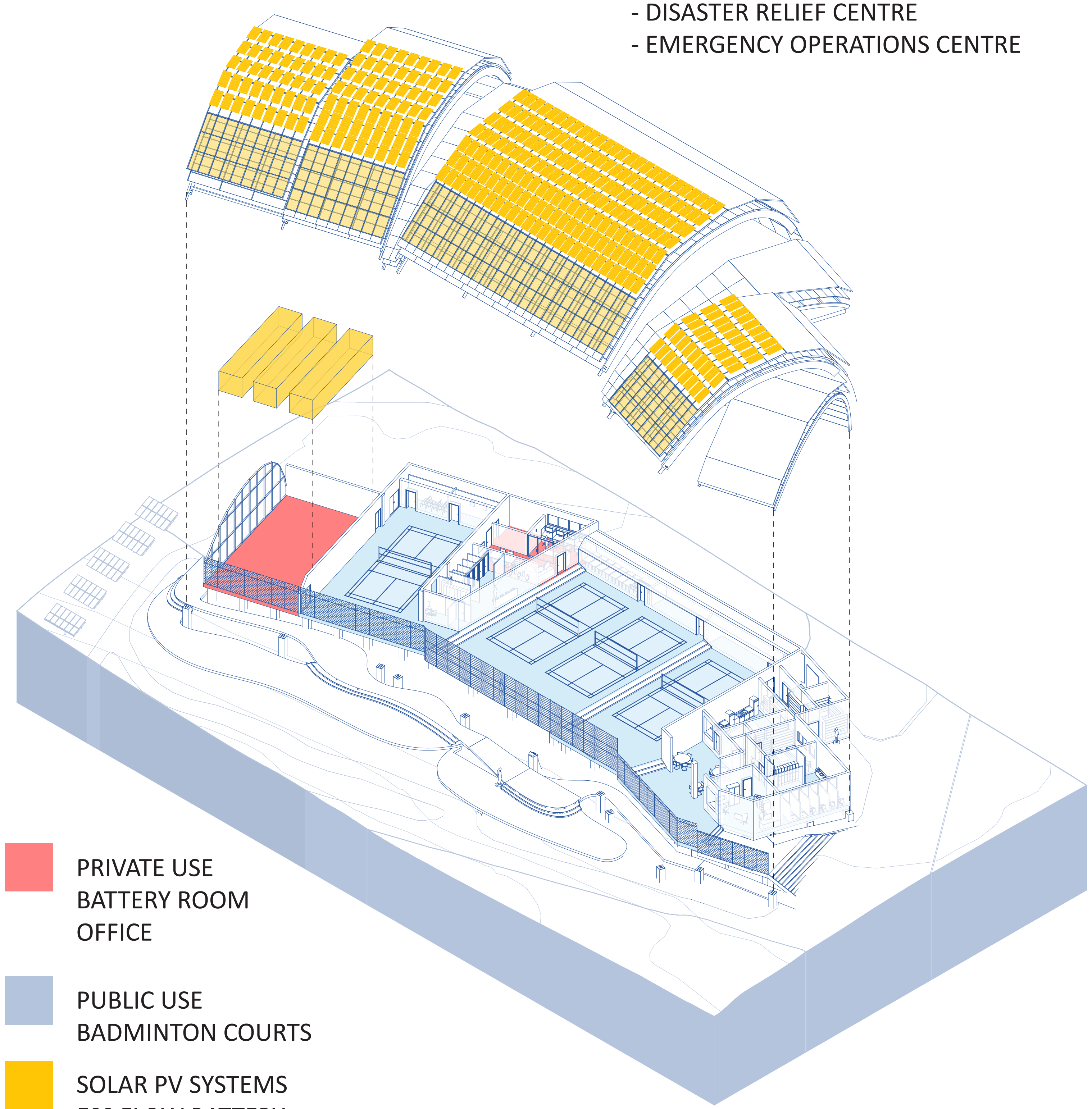
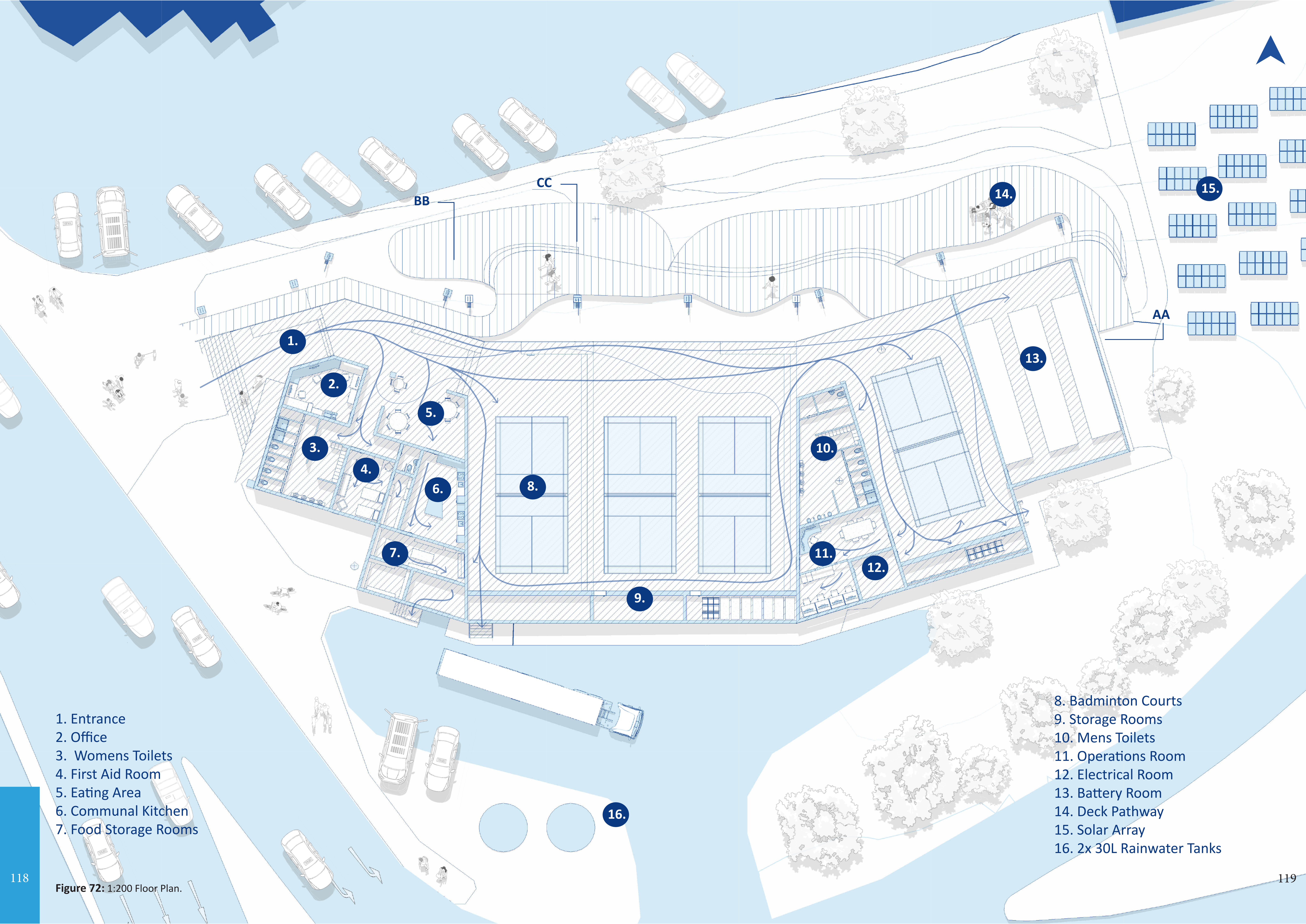


Figure 70: 1:200 Programmes Diagram.

Figure 71: Moment of Entry.



1. Entrance
2. Office
3. Womens Toilets
4. First Aid Room
5. Eating Area
6. Communal Kitchen
7. Food Storage Rooms

8. Badminton Courts
9. Storage Rooms
10. Mens Toilets
11. Operations Room
12. Electrical Room
13. Battery Room
14. Deck Pathway
15. Solar Array
16. 2x 30L Rainwater Tanks

Figure 72: 1:200 Floor Plan.

BB SECTION

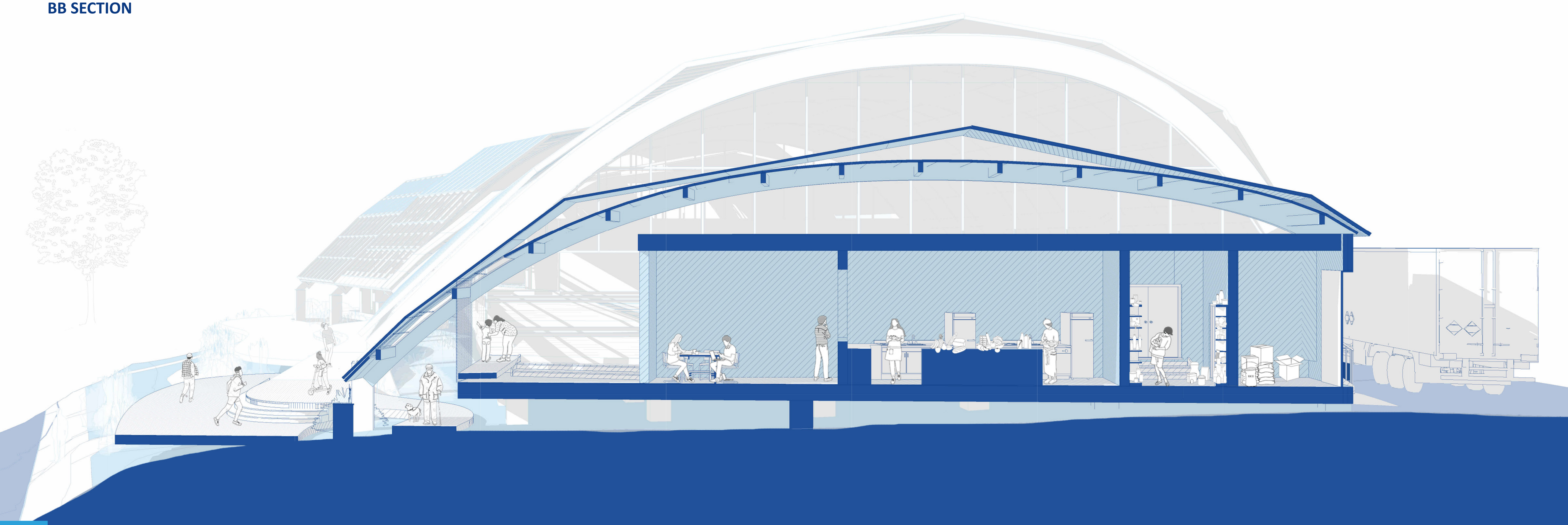


Figure 73: BB Section of the Communal Kitchen.

CC SECTION

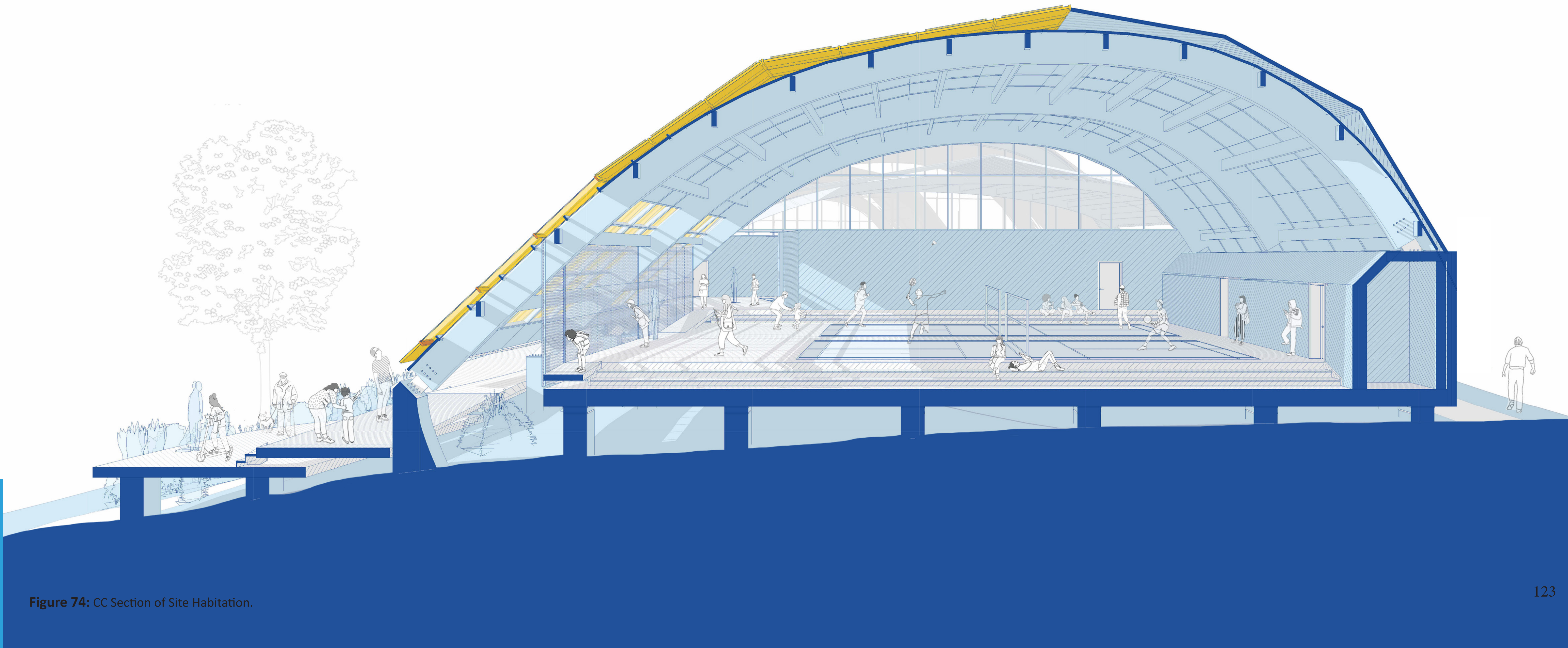


Figure 74: CC Section of Site Habitation.

Entering the second platform unfolds the threshold into a vast interior space of three badminton courts. With a large area for the main traffic flow, there is plenty of space for people to spectate games and lounge around on the stairs. During emergency disasters, the layout has a dual purpose to accommodate many people to seek shelter or stay. At the end of each court is a storage room to hold chairs, tables, mattresses and dividers to reconfigure the floor to whichever scenario addresses 4a) guidelines. This extends to the fourth badminton court on the next platform.

The last platform holds the men's toilets also including lockers and showers. As the solar station is a disaster relief centre, it will also operate as an EOC. Thus, another office space behind the men's toilets is provided to be next to the solar PV system controls and electrical room. An extension to the front reception office space, this room will hold meetings, communications and inspections for CDEM and electrical services addressing 5b) guidelines. Electrician operators will also use this space to control the distribution of electricity to the connected users of the solar station addressing 4b) guidelines. The badminton court on this platform allows for an enclosed space for professional practice.

Pass the fourth badminton court, houses the solar batteries. Instead of using lithium-ion batteries, flow batteries manufactured by ESS inc allow the storage of excess energy for longer, do not pose a fire risk and have the same issues of capacity fade. ESS inc flow batteries are held within 40 feet of shipping containers, with the ability to store between 100kW power for 4 hours to 33kW for 8 hours. There is space for three 40 feet of shipping containers, giving the flexibility to implement one to three containers. This section is restricted to emergency and electrical services.

MASS TIMBER SHELL STRUCTURE
- GLULAM ARCHES
- TIMBER BEAMS

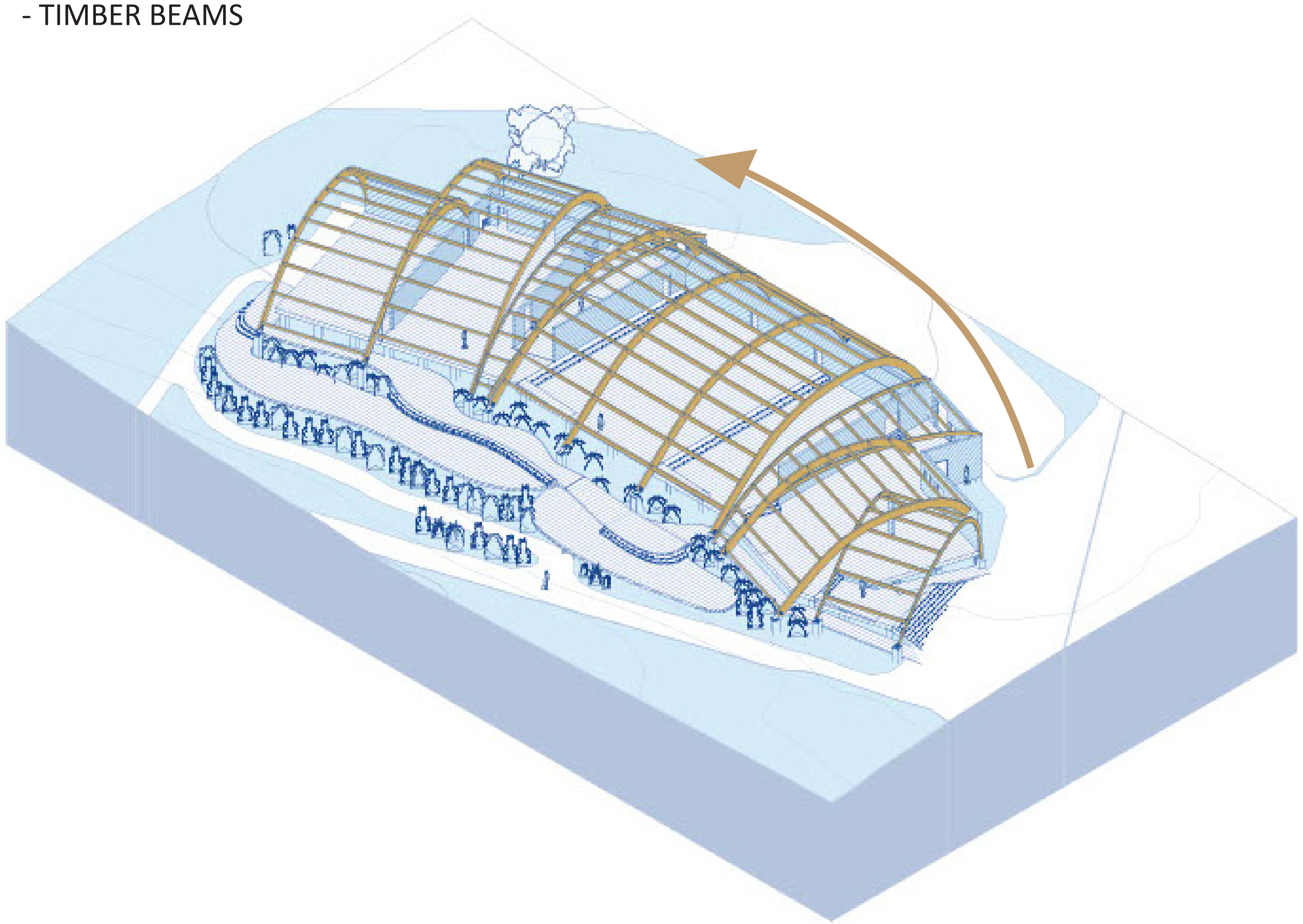


Figure 75: Relation of the Shell Structure and Floor Plan.

Figure 76: Moment of interaction with Solar PV systems.

The shell form will be built from the structure of curved glulam beams, Cross cross-laminated timber (CLT) floors and walls which are seismic resilient. It is comprised of a double skin façade with an outer layer of timber cladding and polycarbonate sheets for windows. The structure is built on stilt concrete foundations maintaining structural and seismic integrity addressing IL4 requirements, 7,8 and 9b) guidelines.

The glulam beams and CLT will be prefabricated locally by Red Stag Timber Lab Limited. Their timber products can be recycled through re-machining and reused in a new building or wood waste as biofuel for kiln drying. Both timber materials are fire resistant, the more layers CLT has, the better it performs addressing 6b) guidelines. Precast concrete piles will also be manufactured locally by Allied Concrete providing a maximum of 70% recycled mix while maintaining structural integrity and longevity. Both practices have an Environmental Product Declaration certifying their sustainable and ethical practices and products addressing 3a) guidelines and embodiment qualities.

In the place of glass, polycarbonate sheets will be used for durable translucent sections of the building. It has more impact and heat resistance than glass providing resilience towards high temperatures, debris and seismic activity. This material is also recyclable by breaking it down and forming more sheets.

"Onyx Solar is the global leader in Building Integrated Photovoltaics BIPV". The company has an endless catalogue of BIPV projects across the world, including a few in Australia. They do various applications specialising in photovoltaic glass holding an EPD. Although their main office is in New York and Spain, they are reliable manufacturers with the right products, extensive research and experience who idolise innovation.

Solar PV panels are recyclable as well through parts reused for new solar PV panels like silicon. The whole structure is recyclable through sustainable sources however, the site is designed for permanent use in its functions and programmes for a lifetime addressing 1a) guidelines.

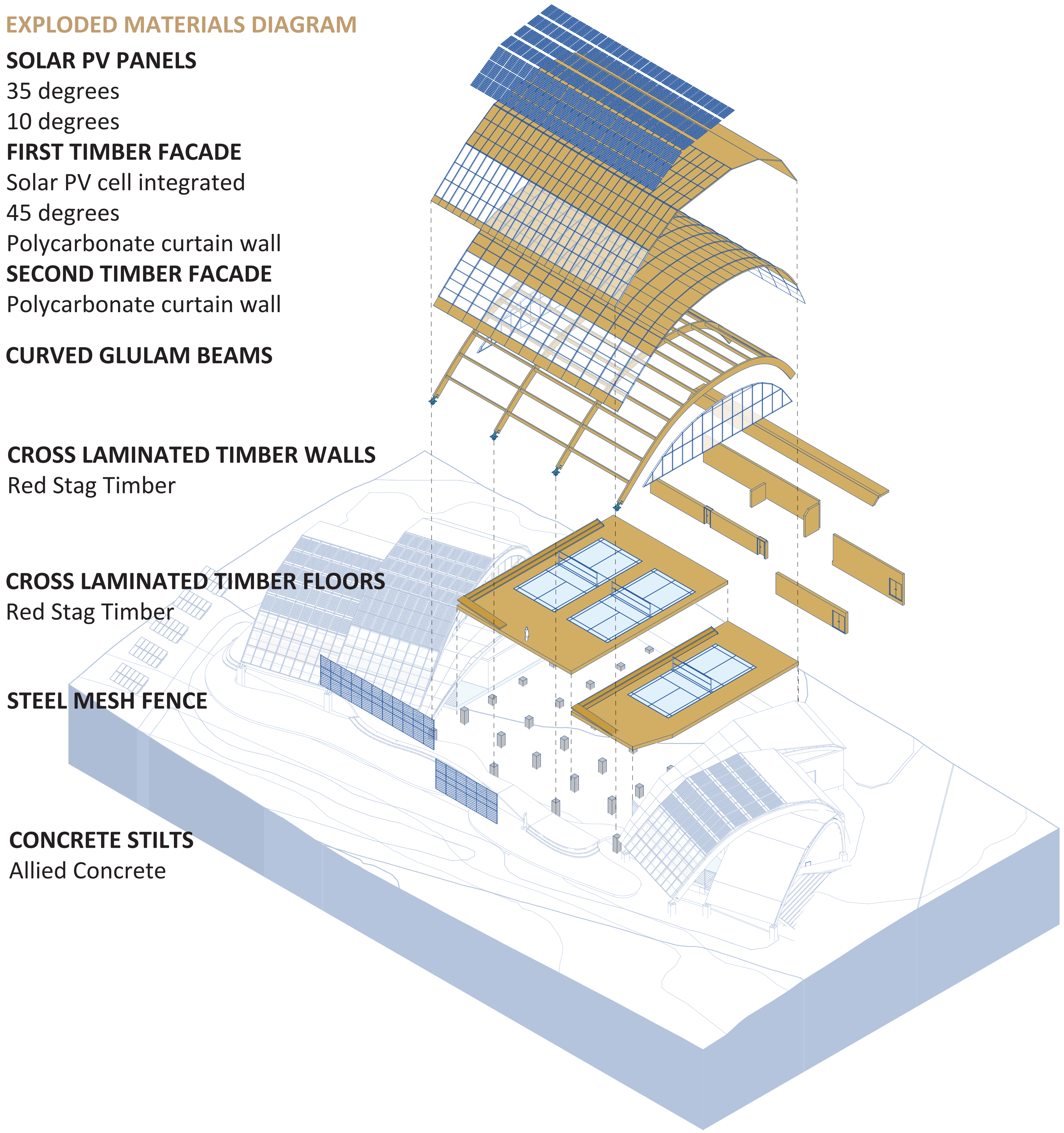


Figure 77: Exploded Materials Diagram.

To avoid using solar films to follow the contours of the shell envelope, the façade hosting the solar PV systems will have three different angles hence sections parallel to the curve of the glulam beams. The first section is at 43 degrees of 7 metres, the second at 35 degrees of 5 metres and the third at 10 degrees of 8 metres. These measurements were used to avoid extreme heights for maximum efficiency, instead are divided into three sections to target average, winter and summer sun angles creating a balanced façade for yields, material and space efficiency. This also correlates to the facade allowing maximum solar gain during winter and minimum during summer.

1. Relationship of exterior and interior spaces.
2. Winter and Summer Solistice Sun to space.
3. Passive ventillation of double facade to cool
4. Secure lighting and sprinklers.
5. Passive stale air outtake through precise gaps.
6. Waterflow to rainwater tanks for non-potable use.
7. Mechanical ventillation for disaster emergencies.
8. Surface runoff travels down permeable site.

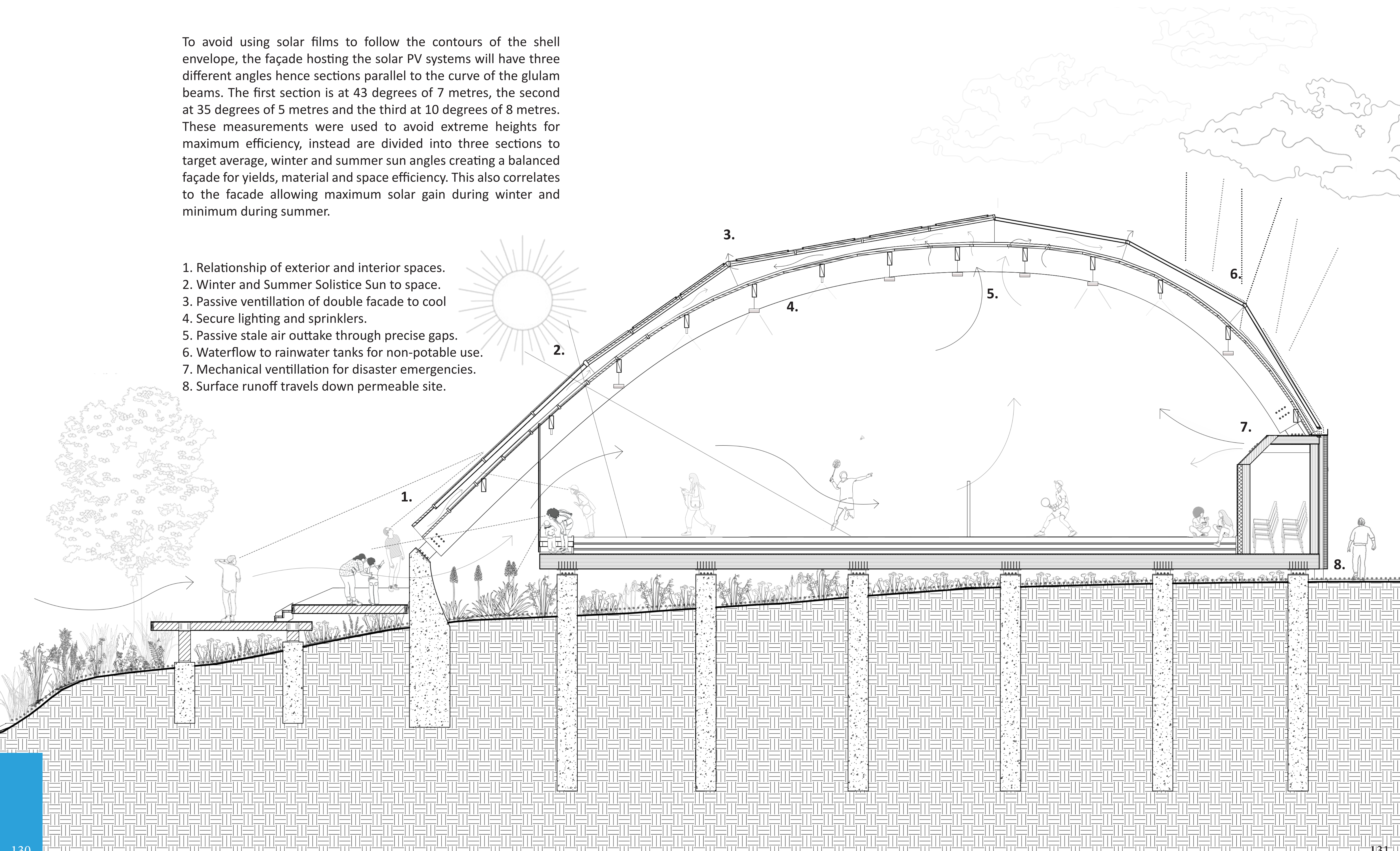


Figure 78: Detailed 1:50 CC Section of main Badminton Courts.

The solar PV cells are integrated within the second outer façade of the building's double skin façade of 150mm in between. This system allows passive ventilation throughout the envelope of the building allowing it to be cooled and lower temperature against direct sunlight. The hot air continues to rise and escapes through designed gaps of the cladding in each façade layer. In addition to UV protection, it allows the embedded solar cells in the outer façade to upgrade to newer technology or replacement.

The front end of the glulam beam/arch disconnects from the CLT floors and is anchored down by a concrete pile. This separation from the floor creates a gap between the exterior and interior space, allowing a connection when you are outside to the inside and inside to the outside. A permeable barrier is in place of short flax and a meshed fence to secure the interior to maintain this relationship but extends it by inviting exterior elements of wind and fresh breeze for passive ventilation. This design allows utility within a low 45-degree space.

The separated floor invites users to interact with this low space appreciating the connection it brings and inducing a relationship between the photovoltaic glass within grasp. This is maintained throughout the exterior walkway of the front façade giving users the realisation of the use of BIPV. This exposes its implementation and uses connecting where energy is generated to where it is used, in the building and their homes.

At the end of both sides of the arch will be gutters to collect rainwater and funnel it towards the two 30,000L water tanks outside the building. This will be used as grey water for the vegetation, toilets and washing clothes or potable water for drinking addressing 4b) guidelines.

The concrete stilts of the building provide a gap for rainwater to flow down the hill and filtrate through the flax spread across the slope before entering the gutters. As it was a green site before and increasing non-permeable surfaces it must travel offsite to avoid any stagnant water.

1. 330W Solar PV panels flush to timber cladding
2. Solar PV cells integrated into clear polycarbonate sheet.
3. 50x150mm aluminium framing for sheets and wiring.
4. 30mm Timber boards.
5. 30mm Translucent polycarbonate sheet.
6. 20x200mm Timber purlins.
7. 200x800mm Glulam Beams.

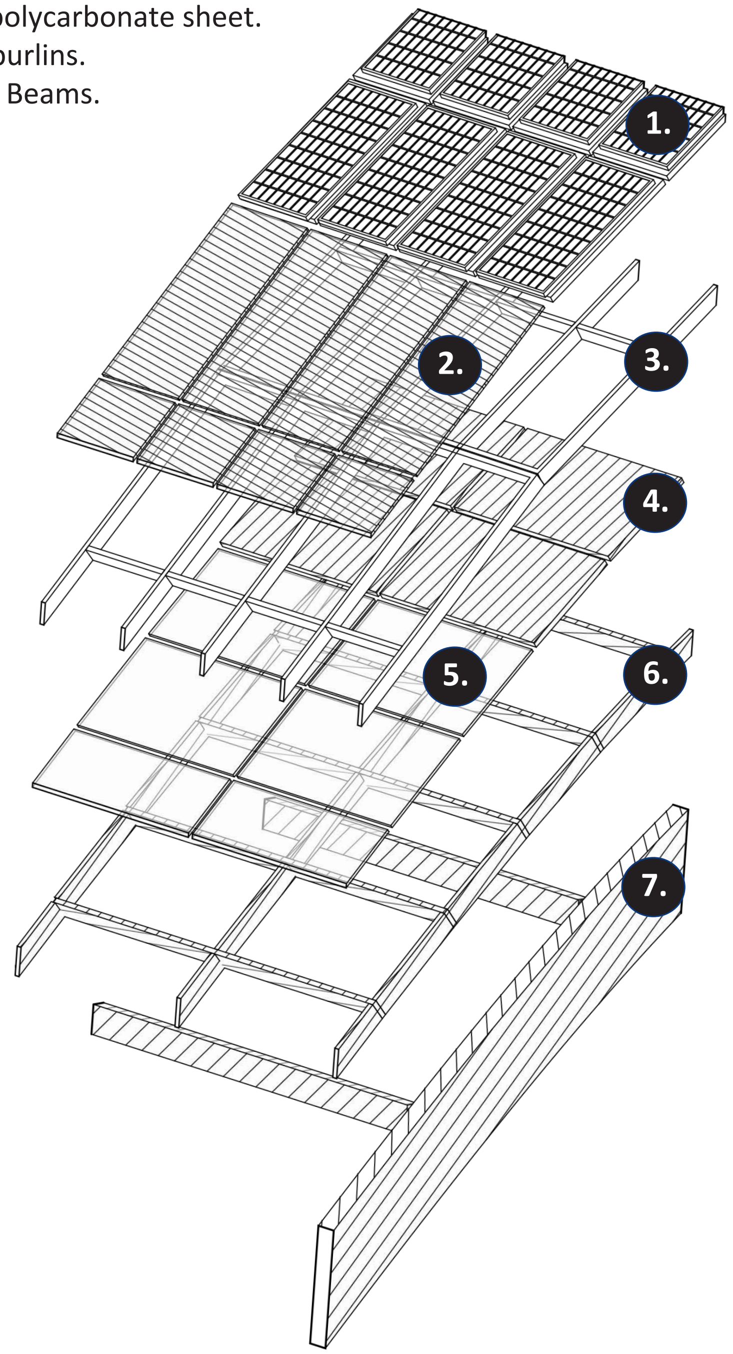


Figure 79: **Facade layers.**

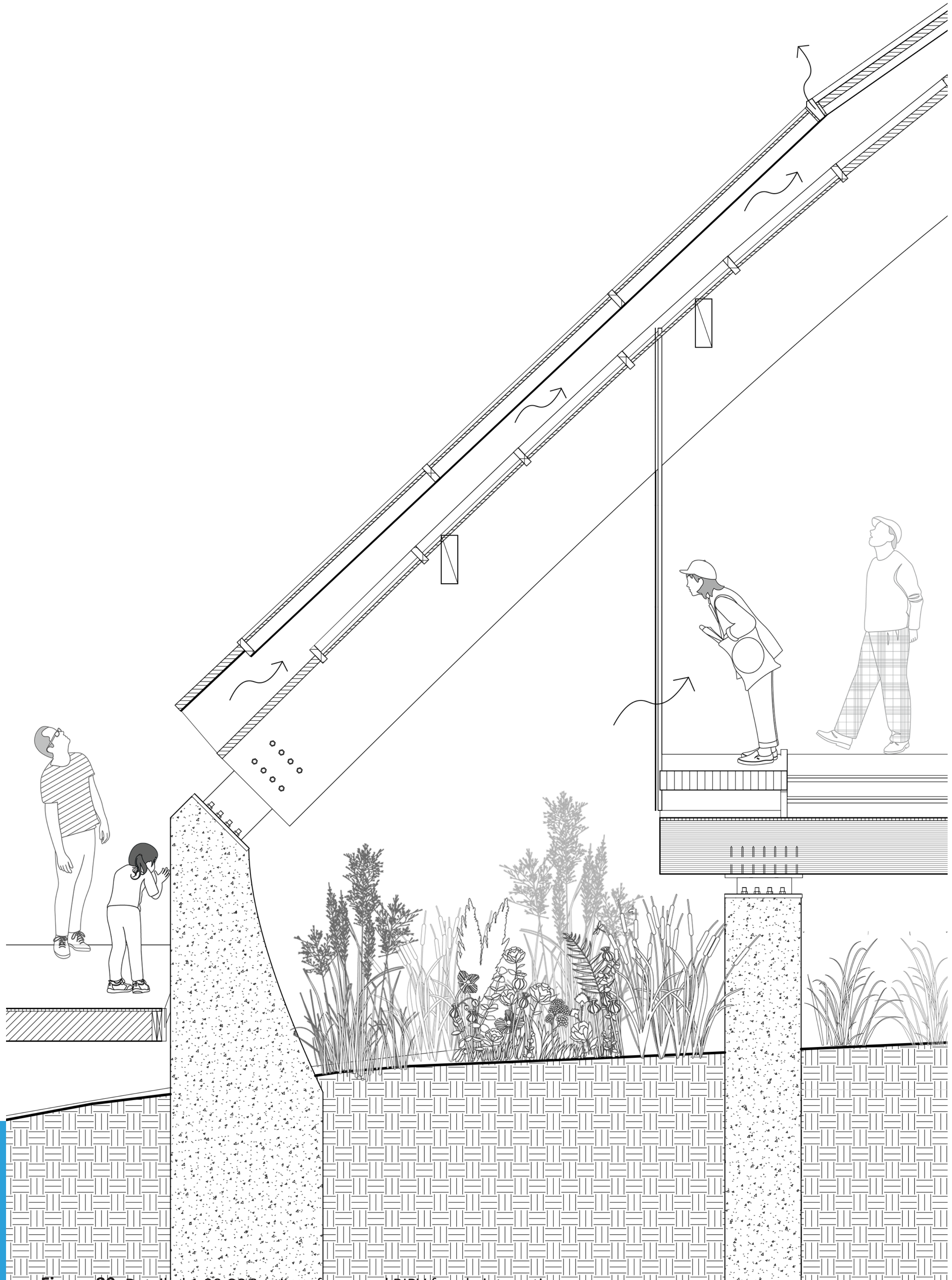
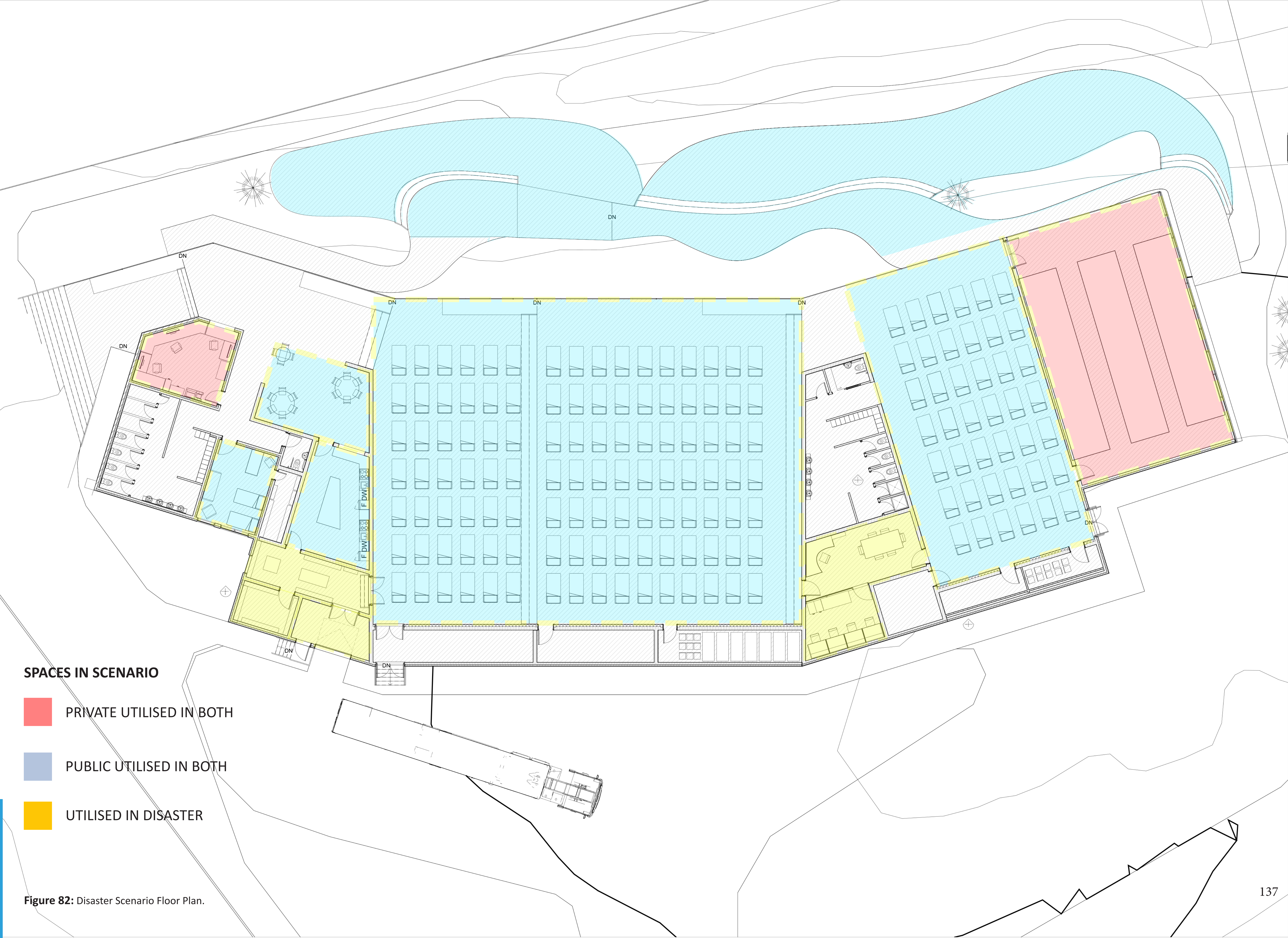


Figure 80: Detailed 1:20 CC Section of user and BIPV facade interaction.

Figure 81: Moment of connection of exterior, exterior and facade.



SPACES IN SCENARIO

PRIVATE UTILISED IN BOTH

PUBLIC UTILISED IN BOTH

UTILISED IN DISASTER

Figure 82: Disaster Scenario Floor Plan.

DISASTER RELIEF SCENARIO

During emergency disasters, solar stations can hold around 200 people. This is to accommodate displaced people inside with mattresses and out within tents who lose their homes and provide living amenities and sanitation. The communal kitchen will supply and distribute food in the facility, where volunteers can cook meals and hand them out to those in need. Food boxes are also available to take away. The first aid room will be managed by a first aider (one of the staff) under normal hours. During an emergency disaster, it will be a station for a nurse or doctor to tend to immediate wounds, injuries or sickness with medication before being taken to the hospital for serious actions. It has a storage room for medicine and a medical fridge tangent to the refrigerator room and pantry as a food bank, accessible through the communal kitchen. This section has direct access to the loading dock, to allow quick off-load of lorries during emergency disasters.

The number of single-bed mattresses that can be laid out over the badminton courts is 147 with ample space to navigate around. Whereas the solar battery section will be for extra storage. Within this scenario, the offices at both ends of the building will be filled with CDEM operators and other emergency services even electrical, to conduct responsive actions and coordination within Manukau during disaster events. This includes data transmissions and communications with ECC. The room will also remain for electricians to operate emergency electricity and distribute it according to connected users. Two 30,000-litre rainwater tanks will be able to provide potable water for 3 days for 200 occupants on site.

Figure 83: Moment of Scenarios between Everyday and Emergency by Front deck.

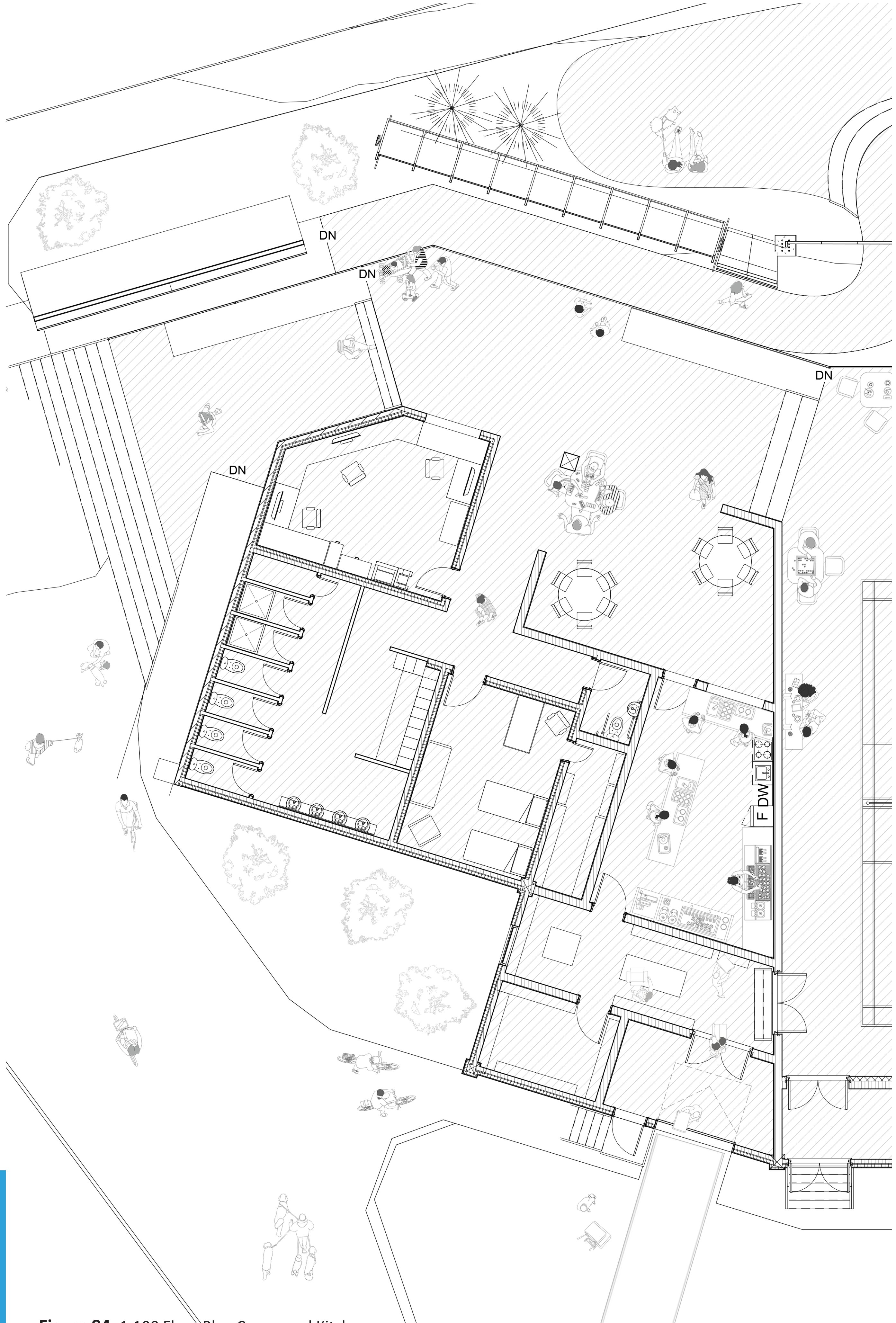


Figure 84: 1:100 Floor Plan Communal Kitchen.

Figure 85: Moment of Scenarios between Everyday and Emergency by Communal Kitchen.

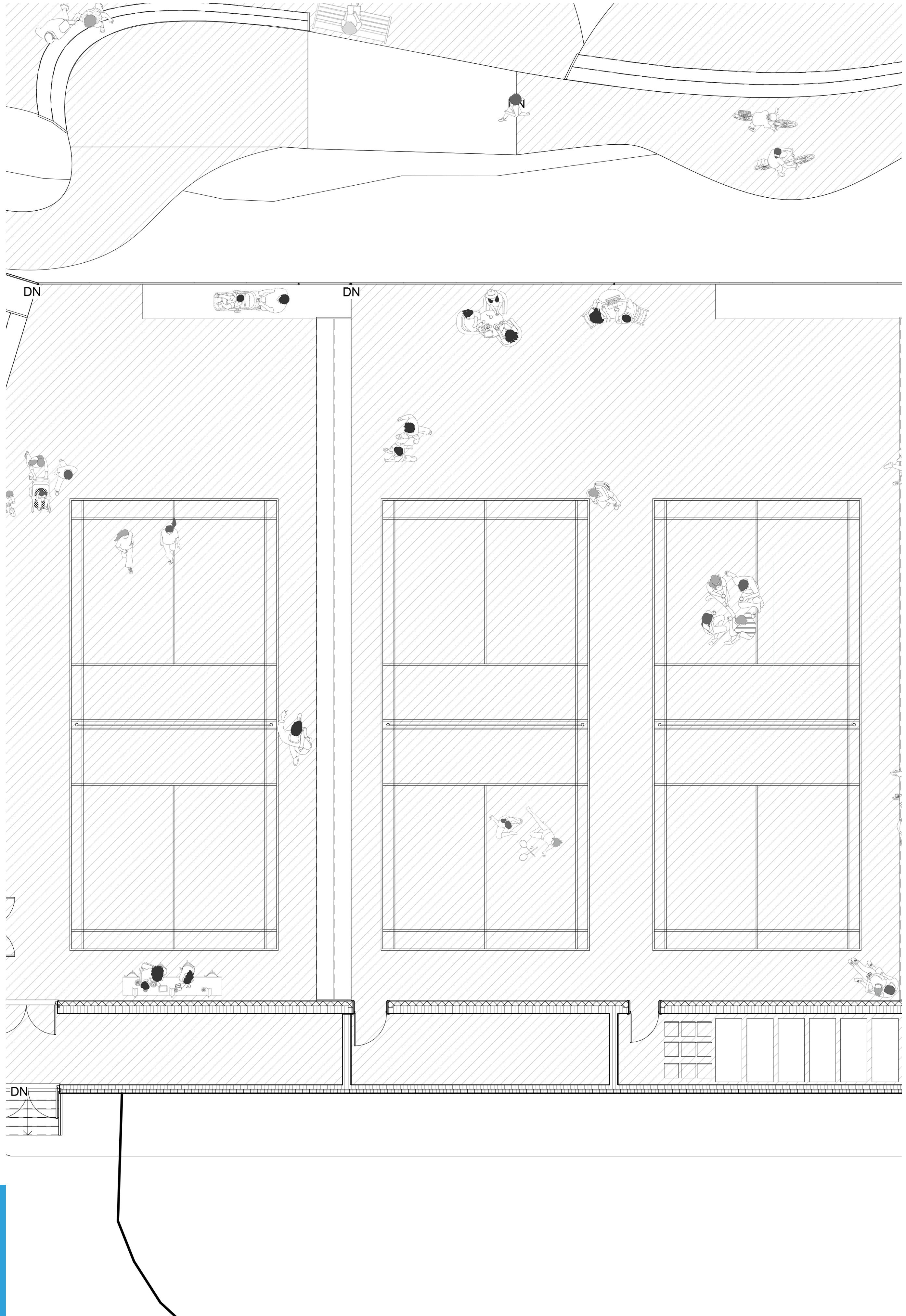


Figure 86: 1:100 Floor Plan of Badminton Courts.

Figure 87: Moment of Scenarios between Everyday and Emergency by Badminton Courts.

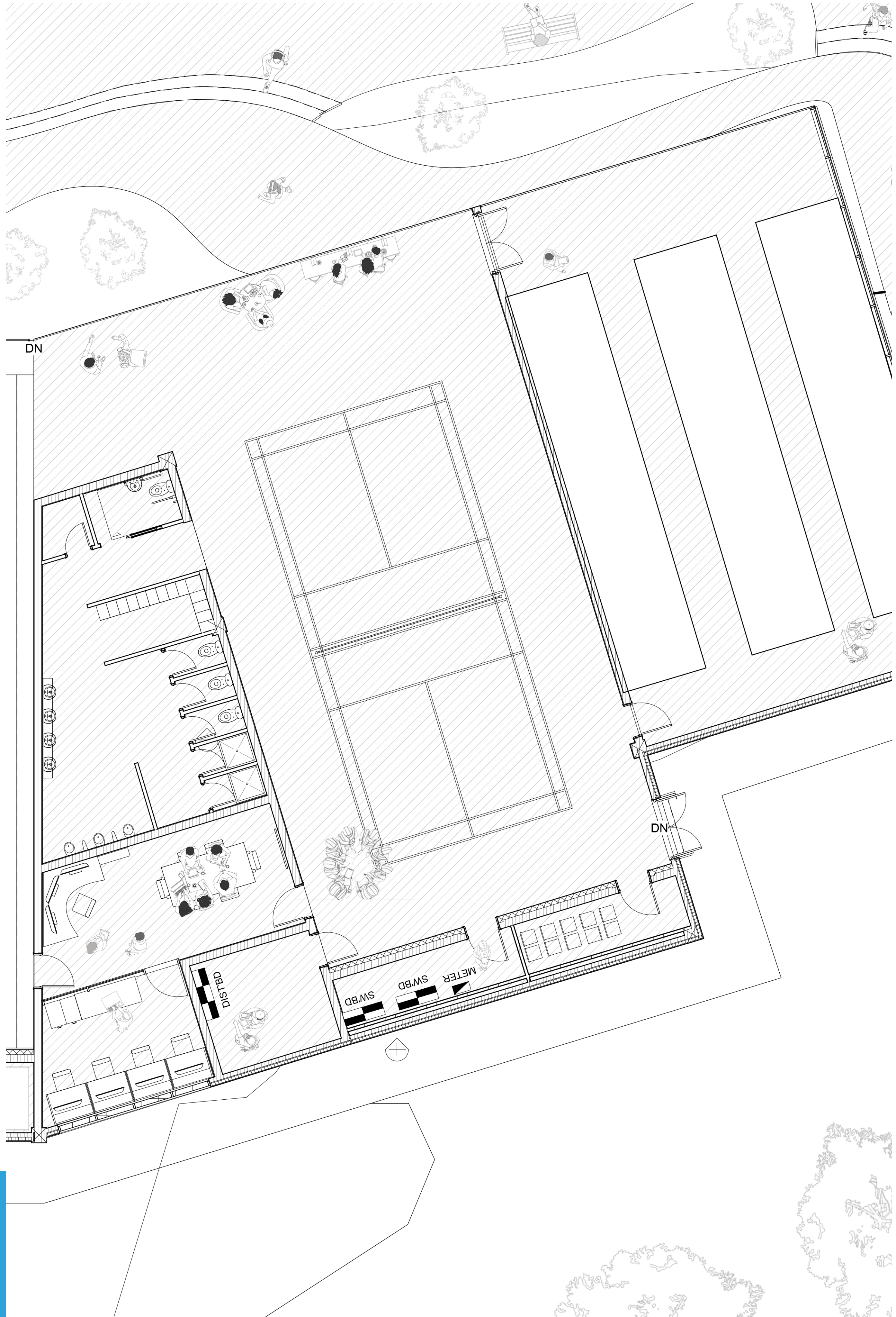


Figure 88: 1:100 Floor Plan of EOC section.

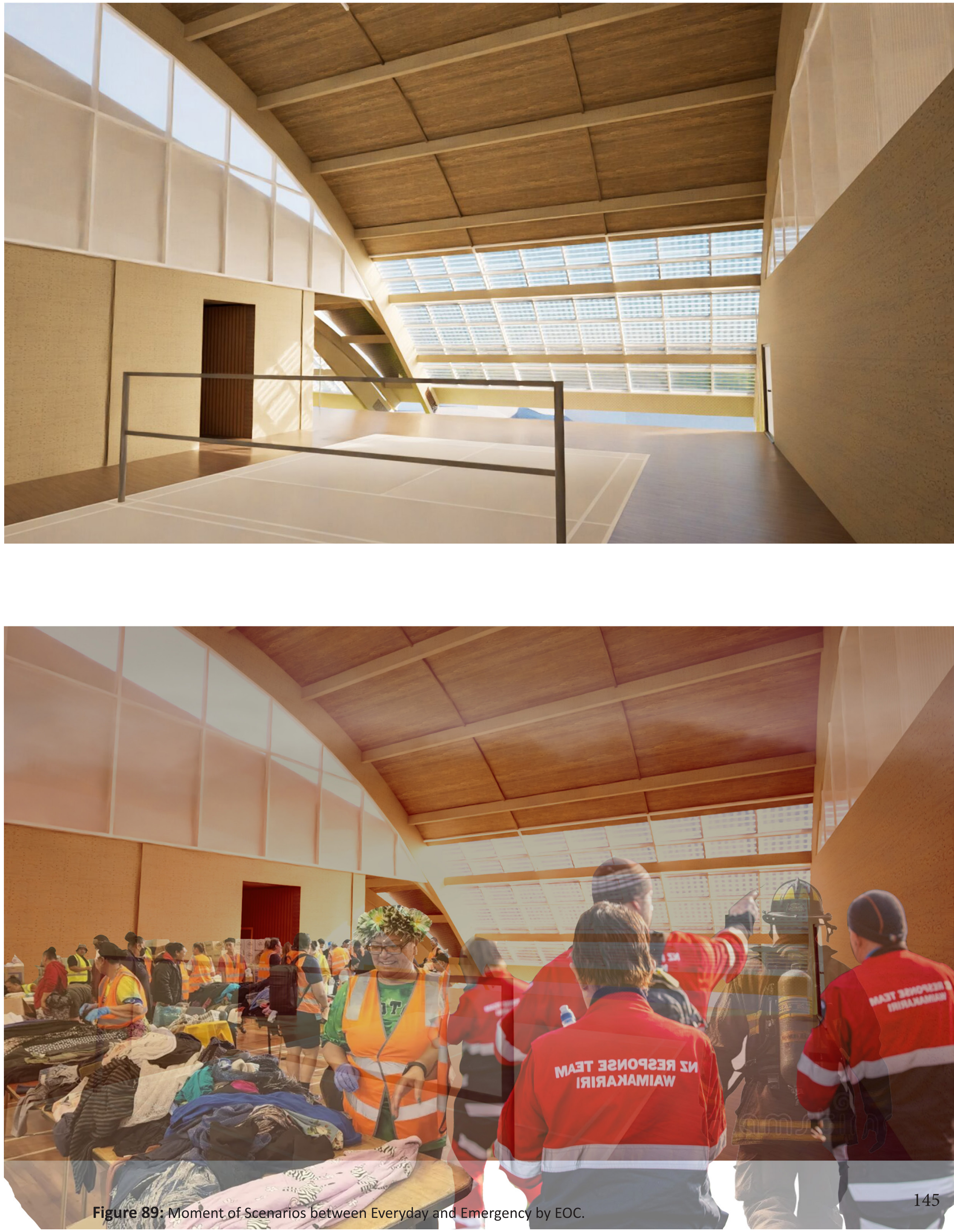


Figure 89: Moment of Scenarios between Everyday and Emergency by EOC.

DISASTER **DAY TO DAY**

Figure 90: Facility Habitation during a disaster and day to day programme.

CONCLUSIONS

RESPONDING TO RESEARCH AIMS

The outcome of this thesis, Decentralised Solar Resilience: The Transition towards Resilient Communities through the Integration of Distributed Solar PV Systems in the Urban Environment has proposed an architecture that achieved the aims of the question *"How can solar photovoltaic systems be implemented to adapt and mitigate against climate change for more resilient communities?"*. The ideal approach of decentralised solar posed the main design driver. These distributed energy resources presented multiple implementations, merging and creating an architecture that conducts on and off-site resilience. Through the alignment with Civil defence providing disaster relief spaces with the energy hub the integration of these primary programs results in a more resourceful new building for the community. Measured by the energy resilient framework, the solar station shows the qualities towards regeneration for community energy resilience. Developing the design through mapping and case studies, placed architecture that challenges the current use of solar PV systems even surpassing climate adaptation and mitigation.

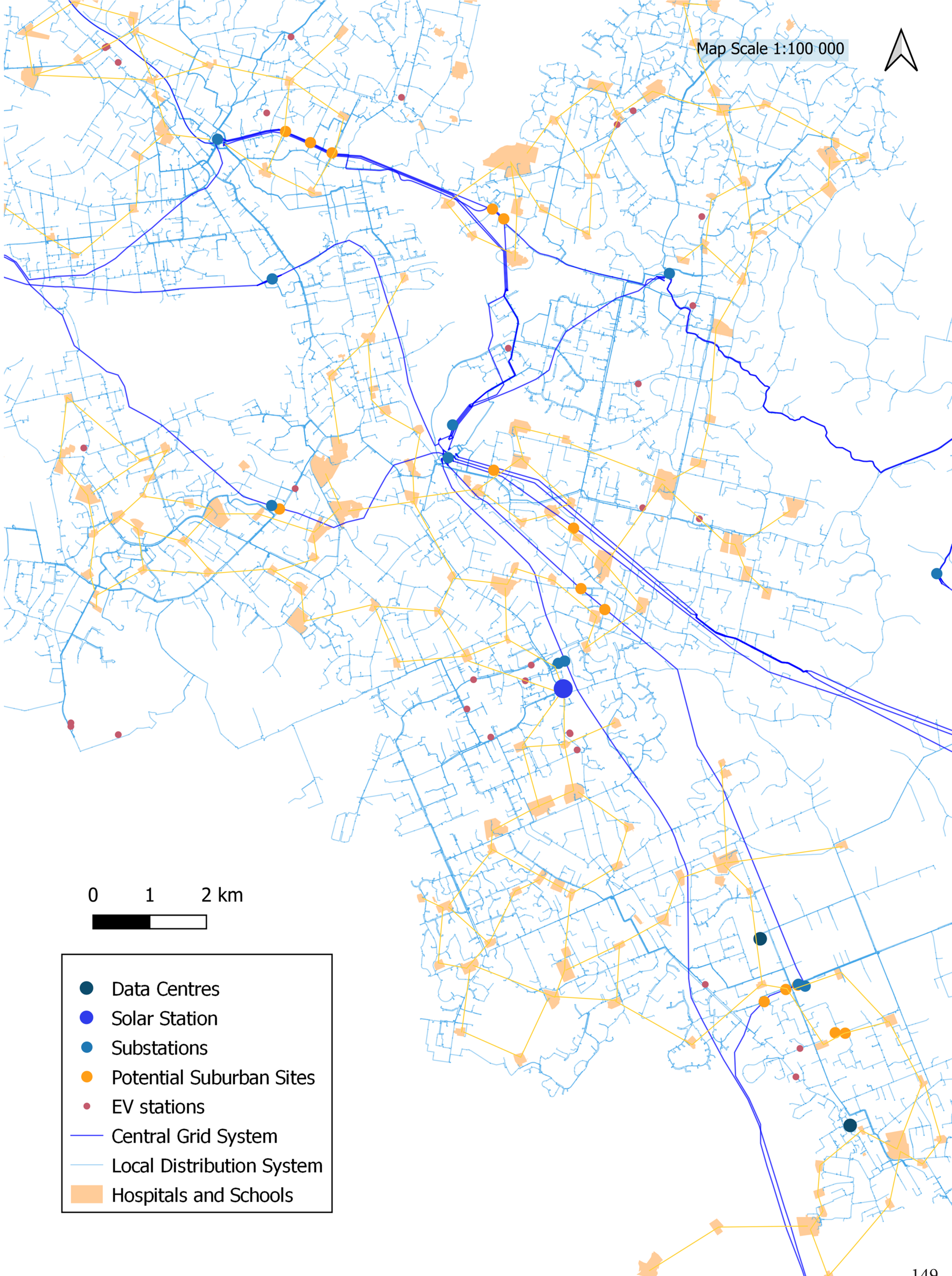


Figure 91: Interconnected sites of DER, creating an Ecosystem and a new norm for Energy Resilience through Solar.

REFLECTIONS

Reflecting on the scope of the research. As climate adaptation was addressed and mitigated as a byproduct, the discovery of benefits reached beyond renewable energy and onto the demand and capacity of the sector. This resulted in further valuable research to help reveal a more compelling integration for solar resilience.

The findings of existing strategies through decentralised solar of DERs, and the discovery of ESaaS reflected the feasibility of distributing and collecting. Practised in Australia, it gave the realisation to adopt Aotearoa to incentivise against high battery costs. With a list of DER strategies, the merging of these systems will address all aspects for maximum efficiency instead of specialising in one.

Exploring the programmes for a solar transition led to the discovery of solar PV disaster relief centres in relation to solar PV. Within the context of Aotearoa, the proposal aligned with the CDEM strategy of regional and national resilience, allowing government involvement.

The discoveries within design were the relations between energy generation and orientation. As rooftop solar PV favour North orientation and a pitch of 30-40 degrees, integrating the systems to address different seasons and the sun's orientation throughout the day gave higher yields. However, finding that facing towards NW (340) over N (0) gave higher yields with a difference of 200kwh annually of 8.9kWp system at a tilt of 30 degrees. This is a difference of powering 10 houses for 24 hours annually hence, the NW section was extended to host more solar PV.

LIMITATIONS AND FUTURE STUDIES

The operation of solar PV panels is 100% sustainable without the emission of greenhouse gases. However, the embodied carbon of these systems and lithium-ion batteries are extensive upfront in their materials and manufacturing. Acknowledging these limitations, the benefits of integrating these systems bring positive change in the community. Producing renewable energy will offset these emissions while providing energy resilience.

The limitation of the proposed strategy is its size will reflect the degree of impact on the community. A single site has limits to producing energy, hence reliance on others to generate and distribute more. Thus, the more interconnected sites the larger the system helps the community.

The sharing and division of energy also require further research. The primary purpose is to distribute energy to those in power cuts, on days without disruptions how much and who will receive priority. There is no clear management of energy during normal days for customers, as factors like saving power for outages, premium and low-income members need to be planned out.

Limitations of this strategy are the funds needed for construction and operations. Although the proposal involves the government, the upfront costs will be high due to the design and import of its solar PV systems. Furthermore, the hidden costs of maintaining and operating this new type of facility, including possible upgrades to existing infrastructure require further research.

Limitations of this research are within its architectural perspective. For a more holistic integration, it will require a multi-disciplinary perspective such as engineering to address costs and system connections of this strategy.

With the proposal exploring integration as a new build, further research would benefit from a retrofitted approach. This will build upon solar PV integration in the community in a different aspect, allowing a comprehensive comparison or merging of two strategies.

Figure 92: Exhibition Board

1:200
PHYSICAL MODEL

BALSA WOOD
CNC PLYWOOD
CONTOUR

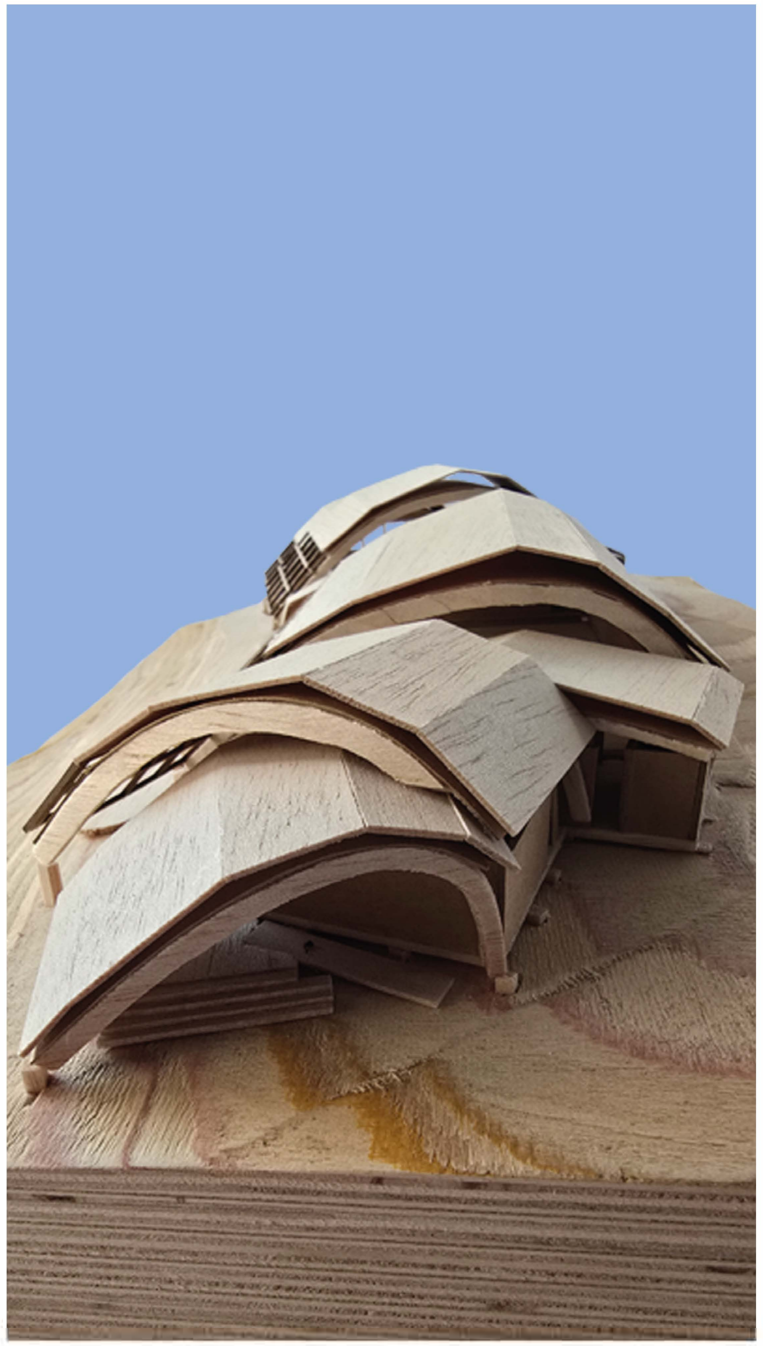


Figure 93: Solar Station 1:200 Physical Model

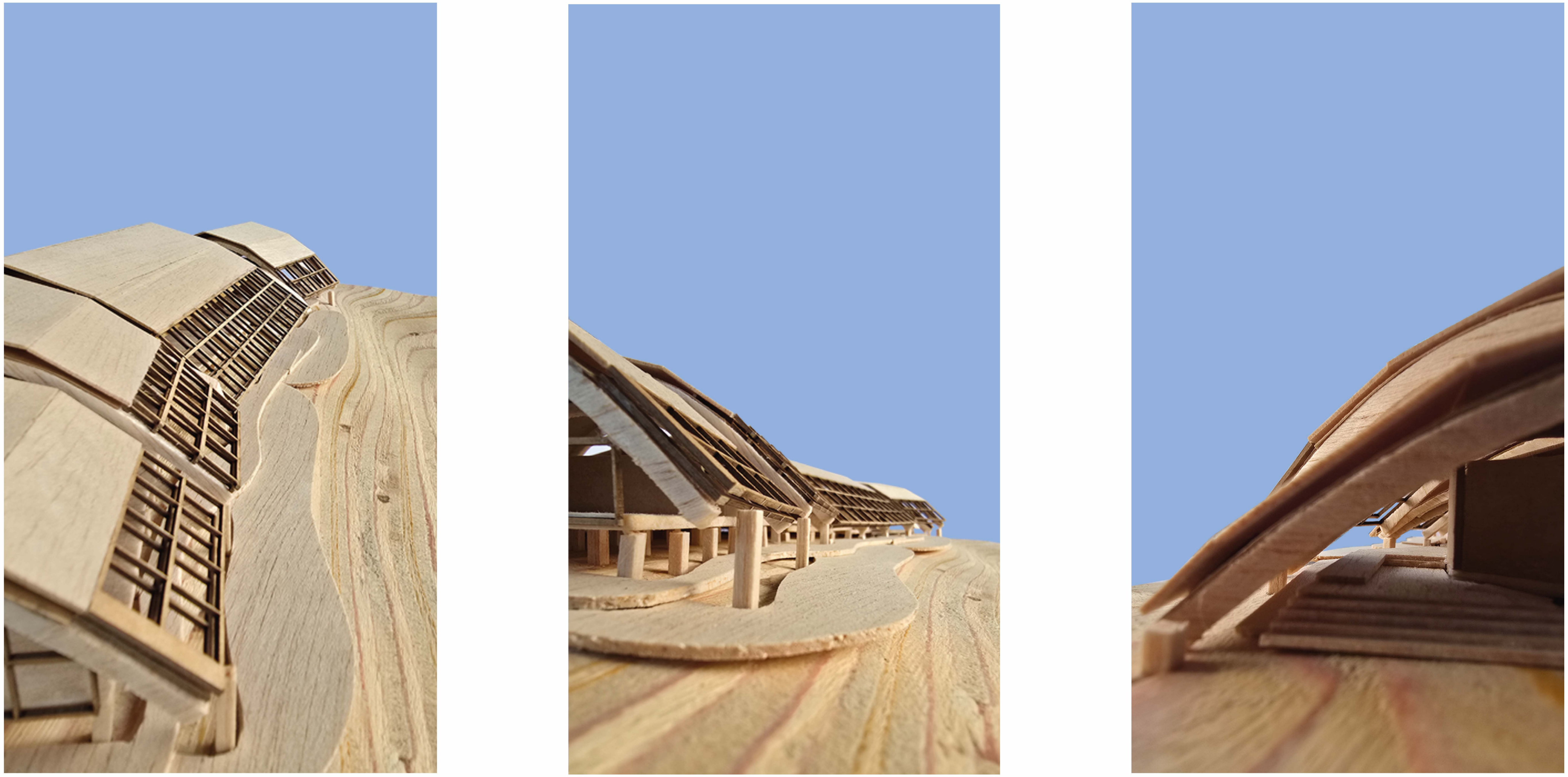
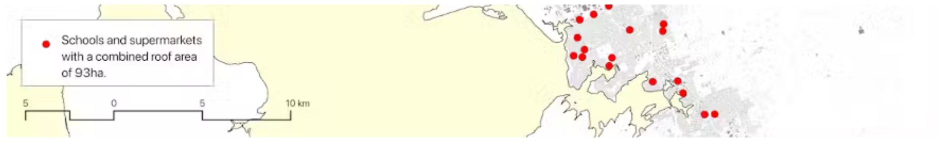


Figure 94: 1:200 Model Moments

APPENDIX

Article published on 16 of September 2024 based on this research by The Conversation.
https://theconversation.com/more-rooftop-solar-in-cities-would-help-solve-nzs-energy-crisis-and-build-disaster-resilience-238193



The rooftops of 167 schools and supermarkets would be equivalent to New Zealand's largest solar farm. Andrew Burgess, CC BY-SA

Both scenarios show how we could better utilise the space available on rooftops in our cities. The second scenario presents a higher potential of creating resilient communities due to its geographical distribution; these places could help locals during power outages.

Locally generated solar power is key to resilient, sustainable cities and New Zealand's transition to a zero-carbon future. Decentralised renewable energy, especially building-integrated solar power, brings power generation closer to consumption.

In a country subject to multiple natural hazards, investment in solar for public buildings and homes could bring several benefits for disaster resilience and climate change mitigation.

We would like to acknowledge the contribution by Kyle Paala, who worked on this research project as part of his Masters in Architecture.

Renewable energy · New Zealand · Distributed energy · Rooftop solar · Solar farms · Disaster resilience · Science + Environment

THE CONVERSATION
Academic rigour, journalistic flair

Arts + Culture · Environment + Science · Business + Economy · Health · Education · Politics + Society

More rooftop solar in cities would help solve NZ's energy crisis – and build disaster resilience

Published: September 16, 2024 8.32am NZST

Getty Images

Copy link · Email · X (Twitter) · Bluesky · Facebook 154 · LinkedIn · WhatsApp · Print

New Zealad's current electricity supply crisis requires immediate solutions.

But we argue the government's emphasis on importing natural gas and construction of centralised solar farms is a missed opportunity.

The case against gas has been highly publicised because of its greenhouse gas emissions and substantial costs.

But the government's focus on large solar infrastructure in rural areas, away from our main centres, misses a chance to address two urgent issues at once – the need to cut emissions and to adapt to climate impacts.

Instead, we should plan local renewable energy generation, integrated into communities, to improve New Zealand's energy security and disaster preparedness.

Centralised versus decentralised energy systems

Centralised renewable electricity generation using large-scale hydro, wind and solar infrastructure helps to cut emissions and move New Zealand closer towards

Article published on 11 September 2024 based on this research by Architecture Now
https://cdn.architecturenow.co.nz/articles/new-zealands-energy-crisis-how-distributed-solar-energy-in-buildings-and-cities-can-contribute-to-a-resilient-future/

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New Zealand's energy crisis: How distributed solar energy in buildings and cities can contribute to a resilient future

People | Words Priscila Besen and Andrew Burgess and 2 others

Priscila Besen, Andrew Burgess and Kyle Paal from Auckland University of Technology advocate for switching the focus from centralised solar farms to decentralised solar power. Image: Ryan Searle and Vivint via Unsplash

1 of 3

New Zealand is currently facing an energy crisis and quick solutions are needed; however, the current focus on investing in solar farms is a missed opportunity in resilience and climate change adaptation. Three Auckland University of Technology academics put forward a case for a less centralised approach.

The energy crisis Aotearoa is currently experiencing demands swift solutions. Driven by a combination of environmental factors and lack of investment in electricity generation capacity for years, low supply meant New Zealanders faced power cut warnings on the coldest morning of May. In addition to the risk of power cuts, this combination of low supply and high demand can lead to price increases at a time of year when people need electricity to keep their homes warm,

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