Node Bawa

[English/noun]: A central point in a network, or the structural junction where a leaf and stem join on a plant.

[Indonesian/verb]: To bring, carry, or transport along.

Repairable, Modular, and Open-source Hybrid Energy Storage System for Weak-Grid Regions of the Global South

Sam Boermans

GADUATION REPORT | 08-2026

Node Bawa

Repairable, Modular, and Open-source Hybrid Energy Storage System for Weak-Grid Regions of the Global South

An integrated design project to encourage sustainable energy autonomy in weak grid regions of the Global South by combining the open repairability of traditional generators with the clean performance of modern energy storage systems and the upcoming sector of LEV battery swap systems.

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Abstract

In weak-grid regions of the Global South, millions of people rely on fossil-fueled **backup generators (BUGS)** to maintain their livelihoods, creating a **shadow grid** that accounts for significant local air pollution and health risks. Despite these environmental costs, BUGS persist as **Dirty & Open** systems: they are mechanically simple and highly repairable through vast informal economies of local mechanics. Conversely, modern clean Energy Storage Systems (ESS) are typically **Clean & Closed**, utilizing proprietary **black-box** architectures that prevent local servicing, leading to a mounting solar e-waste crisis when minor components fail.

This thesis presents **Node Bawa**, a repairable, modular, and open-source hybrid energy storage solution designed to provide a **Clean & Open** alternative. The concept leverages the imminent transition toward **Light Electric Vehicles (LEVs)** by utilizing standardized swappable batteries as the system's primary energy carrier. By bridging the gap between stationary home storage and mobile swapping ecosystems, Node Bawa serves as a central hub that supports both productive needs and personal mobility.

The research utilized a multi-disciplinary approach, including comparative disassembly mapping of industrial archetypes, factory visits in the manufacturing hub of Suzhou, China, and ethnographic field research in Bali, Indonesia. The resulting design features a split-module architecture consisting of an independent **Inverter Module** and a customizable **Docking Module**, connected by an ergonomic, tool-less coupling mechanism. Validation through iterative prototyping and thermal simulations confirmed the system's ability to manage high-power loads safely while maintaining an intuitive experience for users without formal technical training. Ultimately, Node Bawa demonstrates that sustainable energy autonomy can be achieved by aligning modern hardware with the resilient, informal repair rituals of the Global South.

(Abstract provided by NotebookLM)

TU Delft

BIOSPHERE SOLAR

Acknowledgements

This thesis marks the end of my academic journey at the Faculty of Industrial Design Engineering at TU Delft from March to August 2026. When I started looking for a thesis opportunity, I was seeking a product-focused topic that resonated with my interests in design for repair, the circular economy, and sustainable energy that has a meaningful impact on society. I knew that if I ticked all those boxes, I would be able to lose myself in the project and test my skills to the best of my abilities. I never could have expected a project that would bring me all the way to China and Indonesia as part of the research.

Three years ago, I also completed my bachelor's thesis for Biosphere Solar. When I asked Siemen if there were any master's thesis opportunities, he welcomed me with open arms. Eventually we landed on “Something to help more serious energy users who are currently dependent on generators.” After weeks of literature research, I saw the opportunity of a Clean & Open system very clearly. I am very pleased with the result and am confident that it is my best work so far.

First, I want to thank my supervisory team, Bas Flipsen and Sam Franklin, for their guidance. Bas, you were immediately enthusiastic about the subject and have expressed this enthusiasm throughout the project. During the supervisory meetings, we often drifted off into different subjects of common interest before shifting our attention back to the topic. Your technical expertise was very valuable.

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Glossary

SME (Small and Medium-sized Enterprise)
Businesses operating at a small to medium scale, often reliant on stable electricity for productive activities such as manufacturing, retail, or services.

BUGS (Backup Generators)
Small fossil-fueled generators used in weak grid regions. They form a decentralized “shadow grid” that compensates for unreliable infrastructure.

Global South
A term for developing, low- to middle-income regions, including Sub-Saharan & North Africa, South & East Asia, the Pacific, the Middle East, and Latin America, characterized by shared socio-economic and infrastructural challenges.

OGS (Off-Grid Solar)
Low-cost solar systems for households without reliable grid access, typically focused on Tier 1–2 services such as lighting and phone charging.

SHS (Solar Home System)
A small-scale solar installation consisting of panels, a controller, and sometimes storage, primarily used for basic household energy needs.

ESS (Energy Storage System)
A system that stores electrical energy, typically combining batteries, control electronics, and power conversion components.

Micro Storage
Portable Energy Storage Systems designed to power standard AC loads, bridging the gap between low-Tier solar systems and fossil-fueled generators.

BMS (Battery Management System)
An electronic system that monitors and regulates battery performance, ensuring safe operation by controlling charging, discharging, and thermal conditions.

MTF (Multi-Tier Framework)
A framework developed by ESMAP to classify levels of energy access based on capacity, availability, reliability, and quality, rather than binary grid connection.

Dirty & Open System
An energy system that is polluting but highly repairable, characterized by mechanical simplicity, standardized parts, and strong informal repair networks.

Clean & Closed System
An energy system that is environmentally friendly but difficult to repair due to proprietary components and “black-box” design approaches.

Black-Box Architecture
A design approach in which internal components are inaccessible or intentionally obscured, preventing user repair, modification, or third-party intervention.

Informal Repair Economy
A decentralized network of local technicians who maintain and repair products using tacit knowledge, generic parts, and improvisation.

PAYG (Pay-as-you-Go)
A financing model in which users pay for solar systems in small increments over time, often enforced through GSM-enabled remote locking mechanisms.

Serviceability Gap
The disparity between products that can be repaired locally with simple tools and those that require proprietary parts, specialized knowledge, or full replacement.

Light Electric Vehicle (LEV)
Electric motorised vehicles with two or three wheels that are lighter than cars. These can be mopeds, scooters, motorcycles, 3-wheelers.

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The Energy Context

1.0 Introduction

Achieving Sustainable Development Goal 7 (SDG 7: Affordable and Clean Energy) is no longer just about extending the national grid. For millions in the Global South, the grid is either too expensive, too slow to arrive, or too unreliable (Garroum, 2025; Utoh et al., 2024). As a result of this issue, there has been a marked reliance on decentralised power consumption. The global fleet of fossil-fuelled *Backup Generators* (BUGS) has grown to an estimated 20-30 million units, equivalent to about 700-1000 large coal power plants (International Finance Corporation (IFC), 2019).

Apart from their carbon footprint, these BUGS pose a significant health risk. “Existing evidence suggests that BUGS can be a potentially important source of local and regional air pollution in developing countries” (IFC, 2019). In 2016, exposure to Particulate Matter (PM) was responsible for about 2.5 million deaths (IFC, 2019). Given that air pollution is a leading cause of premature death and disease in many developing countries, the extensive use of BUGS within communities is a global health crisis.

Hirmer & Guthrie (2017) state that electrification and development go hand in hand, and Bhatia & Angelou (2015) mention that access to energy is vital to economic, social, and human development. It is essential for driving industrialisation, boosting productivity, and achieving the SDGs. Expanding infrastructure and upgrading technology to cleaner alternatives are crucial objectives that can foster both economic growth and environmental protection (Utoh et al., 2024). Luckily, this transition is already happening at an enormous pace (Garroum, 2025). Companies like Sun King are growing rapidly with their low-cost *Off-Grid-Solar kits* (OGS) and *Pay-as-you-Go* (PAYG) business model, rapidly expanding access to low-cost solar energy across the Global South.

Access to abundant energy has created a new global problem: the electronics and solar e-waste crisis (Munro et al., 2022). The first issue is the short lifespan of these cheaper off-grid solar systems, which is much shorter than that of the roof-fitted installations typically known. Additionally, much of the Global South still lacks the infrastructure required to manage these waste streams, thereby disproportionately shifting the environmental burden to the communities these systems are meant to empower (Zebra et al., 2021).

This chapter establishes the narrative for this project. The goal is to obtain a clear contextual overview of energy use, generators, the upcoming solar market, and a potential opportunity for product development.

1.1 The Energy Scales

1.1.1 The Bad Grid Reality

"You know that feeling when you're waiting for the cable guy, and they say 'between 8 am and 6 pm, and you waste your entire day, and they never show up? Now imagine that, except the cable guy is 'electricity,' the day is '50 years,' and you're one of 600 million people. At some point, you stop waiting and figure it out yourself." (Garroum, 2025)

Approximately 1.5 billion people live with broken electricity grids, resulting in frequent power outages: 2 billion experience blackouts for at least 100 hours annually, and 1 billion for at least 1000 hours annually (International Finance Corporation (IFC), 2019). In some contexts, such as Nepal, losses due to electrical outages are estimated to reach 17% of annual sales for firms that experience them. SMEs that invest in electrification often overestimate the profitability of a connection and become trapped by high connection costs, which in Nigeria can exceed 10 times per capita income, resulting in inconsistent supply that is too unreliable to drive sustainable growth (Scott et al., 2014). The inability to bypass energy constraints by investing in generation squeezes smaller firms out of the market, widening the gap between larger companies and the general population.

Scott et al. (2014) also argue that the predictability of grid failure is often more important than the grid failure itself. In countries such as Nepal, where the *bad grid* follows a reliable load-shedding schedule, SMEs can adapt by implementing night shifts or providing on-site housing for staff to work during periods of power availability. Conversely, in countries like Nigeria, where outages are highly erratic, firms cannot plan their manufacturing processes, making it virtually impossible to operate without relying on a generator.

Grid extension is often not viable due to high maintenance costs, and in low-population-density areas, these costs will only increase.

The cost to connect a rural household ranges from $266 to $2000, with a payback period of 1-17 years (Garroum, 2025). In Sub-Saharan Africa, only 15.3% of the rural population has access to electricity as of 2012 (Baurzhan & Jenkins, 2016). Bhatia & Angelou (2015) report that even connected households experience low-voltage electricity problems at random times during the day and night, rendering the supply essentially unusable for many uses.

Poor installations, sketchy wiring, and a lack of proper insulation come with a major risk of electrocution. Aside from generators, there is also the case of illegal usage, such as *hook-ups* to the national grid. This electricity piracy poses a significant safety hazard due to the widespread use of substandard materials and the absence of safety devices such as circuit breakers (Bhatia & Angelou, 2015).

In urban areas, the dangerous and unreliable grid is often characterised by a *bird's nest* of chaotic, informal wires (Figure 1.1). The grid is so unreliable that fossil fuel backup is the dominant power source in urban areas. In Nigeria, small-scale BUGS generate more electricity than the central grid (IFC, 2019).

Figure 1.1
Representation of the Grid in the Global South

1.1.2 The Myth of the Ladder

There is a societal bias or myth that assumes a simple, unidirectional progression in which people completely abandon inferior fuels as their income increases (Masera et al., 2000). However, evidence shows that this Energy Ladder is more of a transition than a total switch over. As always, reality is more nuanced, and the process is complex, with traditional energy forms coexisting with new ones.

Masera et al. (2000) introduced the *Energy Stacking* model. The report argues that energy or fuel stacking allows users to maximise energy Security. Gas cook stoves may coexist with kerosene lamps, OGS, grid connections, and BUGS simultaneously.

Masera et al. (2000) conducted a longitudinal study in Jarácuaro, Mexico, using household surveys and emissions measurements over four years to understand the socio-cultural dynamics of fuel choices. Their work is more descriptive and focuses on why specific cultural practices (such as cooking tortillas) prevent a complete transition to LPG.

Waleed & Mirza (2022). Using the "6Es" framework (Ease of Access, Ease of Collection, Ease of Use, Ease of Economy, Efficiency, and Environmental Friendliness) and notional data, they analysed over 24,000 households in Pakistan to create a continuous Household Energy Transition Index (ETI).

The important takeaway from these sources is that households do not switch fuels. Whatever solution is proposed to address the adverse grid reality and the downsides of using fossil-fuelled electricity, a generator will not be replaced immediately with a new technology. It will remain in rotation as long as it functions.

1.1.3 The Multi-Tier Framework

Access to energy is vital for functioning in the modern world. It contributes to higher levels of education, better health care, and a more fruitful economy (see Appendix C). It is important to establish a baseline for global energy use. The question is not whether there is a connection, but rather whether electricity use can be distributed along a spectrum. Bhatia & Angelou (2015) say that "Binary metrics for tracking access to household electricity fail to capture the multifaceted nature of access to electricity."

The Energy Sector Management Assistance Program (ESMAP; Bhatia & Angelou, 2015), primarily funded by European countries including the Netherlands, conceptualised the *Multi-Tier Framework* (MTF; Table 1.1) to define and measure access to energy. The article starts with a conceptual background definition of access to energy. Energy access is difficult to define, as it encompasses not only household-level access but also broader energy availability. It can also be applied to *productive engagements* and *community facilities*. Productive engagements are activities that increase income or productivity and encompass the work culture, such as in SMEs.

The main point they repeatedly emphasize is that it is impossible to create a single MTF that accurately captures all electricity usage. For context, many affluent Dutch households average around 7 kWh per day (CBS, 2025), which places them within Tier 4. However, this classification is not due to a lack of grid capacity. The paradox lies in the fact that as devices and homes become more efficient, overall electricity consumption tends to decrease. Thus, this classification arises from high efficiency, thanks to superior insulation and modern appliances, rather than poverty.

The MTF is therefore not a direct measure of socioeconomic wealth and must be interpreted with some scepticism. Furthermore, reliability is incomparable: a wealthy Dutch Tier 4 experiences almost no annual disruptions, whereas the standard permits up to 14 disruptions per week. Therefore, when this report refers to Tier 4, it refers to the specific context of the Global South, distinct from the hyper-efficient, paradoxical Tier 4 found in more developed countries.

Table 1.1
The Multi-Tier Framework
(Bhatia & Angelou, 2015)

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Power Capacity (W)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
Storage Capacity (Wh)		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4kWh	Min 8.2 kWh
Availability (hrs/day)		Min 4 hours	Min 4 hours	Min 8 hours	Min 16 hours	Min 23 hours
Availability (hrs/ evening)		Min 1 hour	Min 2 hours	Min 3 hours	Min 4 hours	Min 4 hours
Reliability					Max 14 disruptions per week	Max 3 disruptions per week (<2 hours)
Quality					Voltage problems do not affect the use of desired appliances	

1.2 The Generator Society

1.2.1 The Shadow grid

BUGS form a vast *shadow grid* spanning the Global South. The IFC report (2019) has mapped key variables, including fuel usage, the number of BUGS, and total capacity. Figure 1.2 shows that the BUGS capacity is highest in Nigeria, India, Pakistan, Chile and Iraq. In these countries, the BUGS account for a significant proportion of the total electricity generated. In western Africa (Nigeria), BUGS account for 40% of total energy consumption. 75% of the sites where generators are deployed are actually *grid-connected*. However, as described in 1.1.1, people cannot rely on the grid to meet their energy needs.

An extensive list of generator statistics is provided in Appendix B.

1.2.2 Health Implications

Fossil-fuelled BUGS pose serious local health risks. Emissions contain thousands of chemicals, including Particulate Matter 2.5 (PM2.5), Black & Organic Carbon, Nitrogen Oxides, Carbon Dioxide, and Methane. These harm health and the environment, emitting much more pollution per unit of fuel than central power plants. Unlike power plants, generators are used near homes and businesses, often indoors (IFC, 2019). Besides toxic emissions, generators produce noise at 95 dB+ which is also harmful in close proximity. In 2015, the Nigerian government unsuccessfully attempted to ban BUGS (IFC, 2019).

An extensive list of generator pollutants is provided in Appendix B.

1.2.3 The Fossil Kings

98% of the BUG fleet consists of small, portable BUGS in the 0-5kW range. These are the small, pull-start machines. They are very inexpensive to purchase up front. A micro-entrepreneur can buy a 2kW petrol generator for under $150 (Rateau & Choplin, 2022). Today, it is also possible to buy generators on online marketplaces such as Jumia and Alibaba. Cheaper 2-stroke generators can be bought online for less than $50 (Huahe Heavy Industries, 2025). There is also a large influx of second-hand ‘western brand’ generators that are supposed to guarantee a longer lifespan than newer Chinese brands.

At the very bottom of the *energy stack* is the sub-1kW, 2-stroke engine. In West Africa, this machine is so culturally ingrained that it is universally known as the *I better pass my neighbour* generator (Rateau & Choplin, 2021). Dominated by ultra-cheap imports like the Tiger TG950 (Figure 1.3), it represents the absolute lowest barrier to entry for independent power.

However, when a micro-entrepreneur needs the capacity to run heavier loads, such as a sewing machine or power tools, they will gravitate towards the 2kW to 5kW range. Here, the market is dominated by 4-stroke *Honda clones* produced by brands such as Sumec, Firman, and Elepaq (Rateau & Choplin, 2021); see Figure 1.4.

Ultimately, the mechanical backbone of the *Generator Society* is not made of massive industrial plant machinery. It is built entirely on these cheap, modular, and highly recognisable everyday machines.

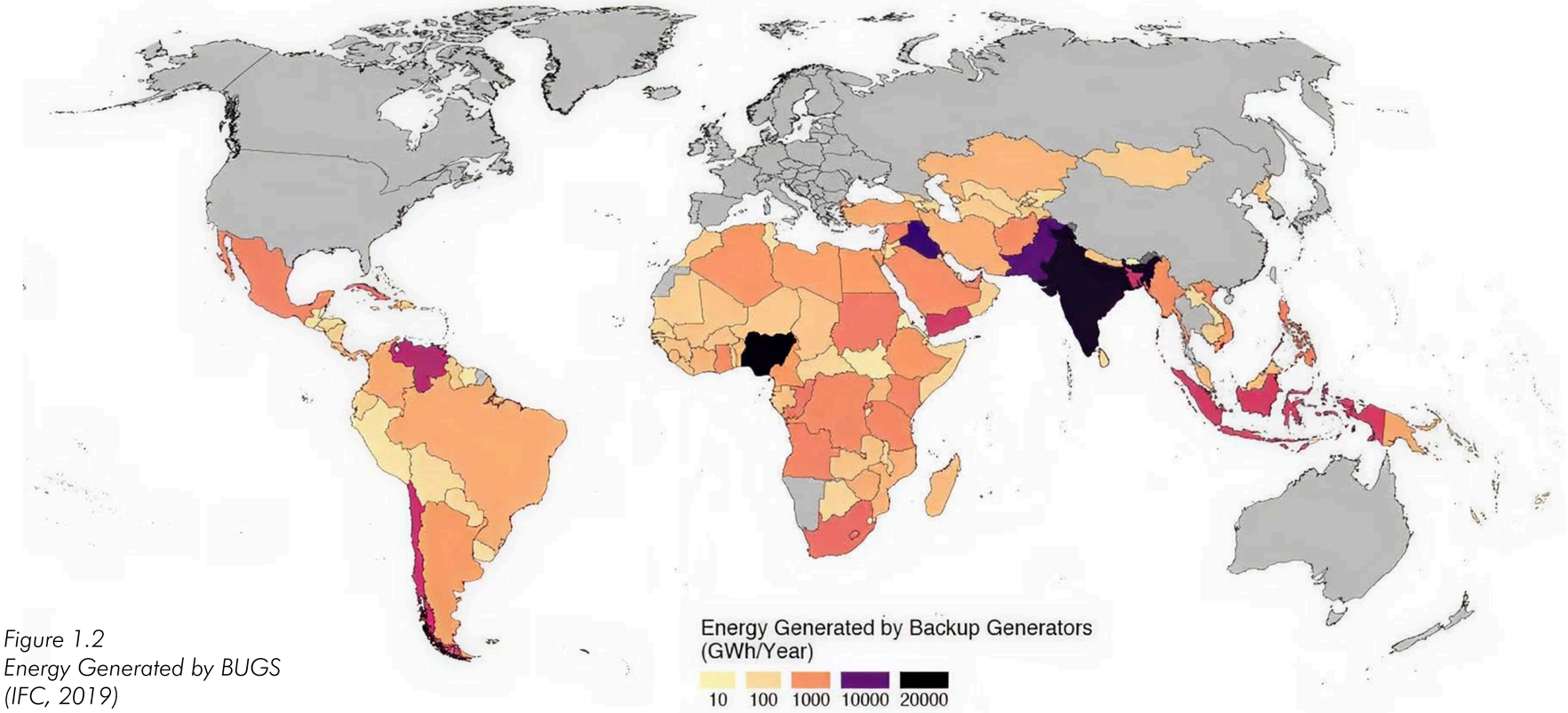


Figure 1.2
Energy Generated by BUGS (IFC, 2019)

Figure 1.3 & 1.4
BUGS Examples

1.2.4 The Informal Economies

At the base of the generator lies the *Internal Combustion Engine* (ICE). This is the term for the motor assembly that transforms chemical energy into rotational momentum. The fundamental technology of *ICEs* is the same across generators, scooters, motorbikes, and cars, with the major difference being in the power of the combustion (displacement in cubic centimetres) and the number of cylinders in which that displacement occurs.

Official repair centres for specific brands of motorcycles and engines exist everywhere, but more interesting is the widespread existence of *informal economies*. This term refers to independent enterprises that can fix almost anything with a motor. Unlike authorised service centres, “informal” mechanics can often fix equipment regardless of the brand. These repairers typically possess a deep *basic understanding of the machine* acquired through years of experiential and situational learning rather than formal technical training.

The informal economy serves as a vital safety net for users of *unaffiliated* (generic or copycat) products that lack manufacturer representation, as well as for branded products that have aged beyond their warranty periods (Cross & Murray, 2018). An interviewee in Bali noted that, for many in the Global South, especially business owners, the informal repair system is preferred because it offers instant fixes. Many would rather pay a local workshop for an immediate repair than wait weeks for a free, authorised manufacturer's warranty service.

Krebs & Weber (2021) say that even when an object is deemed unfixable, it retains "use value" as a source of spare parts. This is seen on a massive scale at sites like the Alang shipbreaking yards in India, where decommissioned vessels are dismantled by hand to provide materials for second-hand markets stretching for 10 kilometres. In these markets, materials rejected by the “Western world”, ranging from furniture and crockery to generators and engines, are sold at a fraction of their original price and reintegrated into the local economy.

During my observations in Bali, I saw many places like the one in Figure 1.5, called *Bengkel* in the local language. Local enterprises that, on the one hand, seem chaotic workplaces, but in the chaos, there is order. Mechanics are present from dusk till dawn, fixing old bikes. Because small BUGS are not really popular in Bali, I did not spot any mechanics fixing generators. The generators in Bali are often large, stationary systems, such as the one shown in Figure 2.4.

Figure 1.5
Bengkel in Denpassar

1.3 The Solarpunk Dream

1.3.1 The Solar Leapfrog

Technological leapfrogging is a concept articulated by the scientist José Goldenberg in 1998, who suggested that developing nations need not follow the same historical steps as industrialised nations (Thurber, 2024). There are three criteria for a successful leapfrog, demonstrated in the article with the example of mobile phones:

- **Demonstration in Mature Markets:** The technology must have been fully commercialised and proven in mature markets many years before being implemented in emerging ones. Phones have been in widespread use for decades, but many regions in the Global South have never had landlines. Now, virtually everyone owns a smartphone.
- **Usefulness as a *workaround*:** It must serve as a functional alternative that avoids the massive cost and difficulty of building out traditional, expensive, or obsolete infrastructure (such as landlines or centralised power grids).
- **Equivalent or Superior Functionality:** The technology must provide the user with functionality that is equal to or better than that of the technology being bypassed. For instance, mobile phones provided uninterrupted access to information that landlines could not.

Thurber (2024) continues to assess various energy technologies as potential leapfrog technologies. Large-scale solar and wind farms are considered successful leapfrogs in low-cost bulk electricity generation. For example, in Kenya, grid-scale wind and solar account for more than 20% of electricity generation capacity, a significantly higher share than that achieved in mature markets at an equivalent stage of development. Thurber (2024) considers residential solar a partially successful leapfrog because it serves as a critical workaround for unreliable or expensive grid power.

However, its main shortcoming as a true leapfrog is that it often cannot match the functionality of modern grid power or diesel generators. Thurber is correct in recognising the limitations of current residential solar installations in the Global South, because current (cheap) OGS installations are mainly focused on Tier 1 and 2 electricity users, where the grid and generators can supply Tier 3-5 energy users.

1.3.2 The surge of Solar in the Global South and Pay-as-you-Go Economics.

Solar costs have declined substantially over the past few decades (Kavlak et al., 2018). Figure 1.5 shows that the price has declined by 99.5% over the last 45 years, from $40/Watt to $0.20/Watt (Garroum, 2025; Kavlak et al., 2018). Kavlak et al. (2018) identify the following reasons for the massive decline in costs:

- **Module Efficiency:** Between 1980 and 2012, increased efficiency was the leading cause of cost reduction, contributing approximately 25% of the total decline.
- **Plant Size and Scale:** After 2001, increases in manufacturing plant size became the dominant factor, accounting for nearly 40% of the cost decline during that period alone.
- **Materials and Silicon Usage:** Improvements in wafer thickness and silicon utilisation contributed 14%, while reductions in the cost of non-silicon materials (glass, frames, etc.) accounted for 21% of the overall decline.
- **R&D:** Public and private Research and Development accounted for the largest share of historical cost reductions, estimated at 59%.
- **Economies of Scale:** Large-scale manufacturing and volume purchasing contributed 22%.

The decline in hardware costs coincided with the rise of *mobile money platforms* such as M-Pesa, enabling near-zero transaction costs. Lastly, Garroum identifies the affordability of GSM and *Internet of Things* (IoT) chips as a crucial factor in the rapid rise of solar companies such as Sun king and SunCulture. This turned solar hardware from a luxury into an accessible commodity (Garroum, 2025).

These new companies are turning a linear transaction into a service using the PAYG business model. Garroum (2025) breaks it down into 7 steps:

“

1. A company (Sun King, SunCulture) installs a solar system in your home (Figure 1.7)
2. You pay ~$100 down
3. Then $40-65/month over 24-30 months
4. The system has a GSM chip that calls home
5. No payment = remotely shut off
6. Keep paying = keep power
7. After 30 months = you own it, free power forever

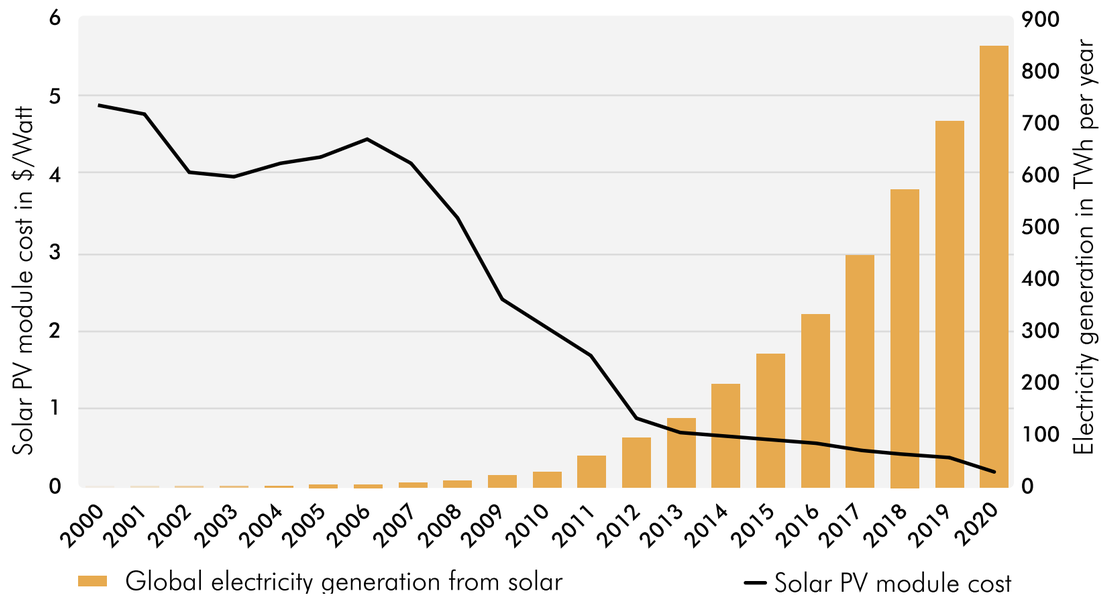
”

Garroum also describes multiple scenarios in which solar-powered irrigation pumps replace diesel-powered pumps, with significant consequences for farmers.

The PAYG model can also be coupled with *carbon credits*, essentially creating a *carbon sink*. Allowing other people to pay for it displaces even more carbon whilst reducing the system's financial burden, allowing it to be financed at a larger scale (Garroum, 2025). Carbon credits are a controversial topic because they may shift the focus from actual climate action towards a positive climate identity, thus making them potentially susceptible to *greenwashing*.

Lastly, Garroum notes the considerable logistical challenges of a wide-ranging PAYG model across many countries and cultures. New entrants to the market cannot simply enter with cheaper panels; they must integrate with the system.

Figure 1.6
Solar Power Soars as Panel Prices Plunge (Garroum, 2025)



1.3.3 The Solar E-Waste Crisis in the GS

In particular, Garroum (2025) portrays the solar landscape as a *Solarpunk* dream. Although factually strong, he ignores a huge rebound effect from all these cheaper solar kits: *Solar E-Waste* (SEW). This is a paradoxical subject because OGS products are celebrated for reducing *energy poverty* and carbon emissions; however, their short lifespans and hazardous materials are creating a mounting waste crisis that many regions are ill-equipped to manage.

Munro et al. (2022) report substantial growth in off-grid solar access, with approximately 200 million products sold over the last decade and 35 million in 2019 alone. Garroum (2025) mentions 30 million solar products sold in 2024, with 400.000 new solar installations every month across Africa.

Cross & Murray (2018) conducted a study of 14 Sub-Saharan African countries and estimated that the off-grid sector generated approximately 3,600 tons of electronic waste in 2017 alone, a figure comparable to the waste generated by the mobile phone industry in those regions. With OGS products containing toxic substances such as Lead, Cadmium, Mercury, and Sulfuric Acid, improper disposal has already resulted in documented cases of soil and water contamination; for example, in Ghana and Nepal, buried or incorrectly discarded batteries have leaked acidic substances into the surrounding environment (Zebra et al., 2021).

As mentioned in 1.3.2, Garroum (2025) states, “You own it, free power forever.” However, these lower-cost solar kits have much shorter lifetimes than residential solar installations in higher-income economies. OGS products in the Global South (figure 1.8) typically have an expected working life of only 3 to 4 years, thereby breaking down shortly after the payment period ends (Munro et al., 2022).

This *planned obsolescence* goes hand in hand with tamper-proof *black box designs*, proprietary screws, and *closed-hardware ecosystems* to protect internal software (e.g., PAYG locking mechanisms). This black-boxing intentionally limits third-party repair, such that when a minor component fails, the entire device is often discarded.

Discarded in this sense does not mean a simple path from use to the dump; instead, they enter a complex *afterlife* (Cross & Murray, 2018). In Kenya, research indicates that 65% of solar products are retained in homes after they cease functioning. Users often store these dead items in drawers or under beds, a practice termed a *first burial*, before they eventually enter waste streams.

Most formal waste initiatives focus on centralised recycling, but the necessary reverse logistics and collection infrastructure are almost entirely absent in rural off-grid markets. Legislation that requires manufacturers to fund recycling often fails to incentivise the design of repairable products. Furthermore, these regulations risk criminalising informal repair workers by characterising them as generators of e-waste, subject to heavy fines or imprisonment if they do not use licensed (and often non-existent) collection centres (Cross & Murray, 2018).

Solar Energy and access to (clean) energy in general generate profound *second-order and grassroots effects* that extend far beyond simple illumination, transforming education, health, safety, and the economic structure of rural communities. Such as: extended learning hours, improved school enrolment, security, agricultural productivity, and healthcare.

For a complete list of second-order and grassroots effects, see Appendix C.

Figure 1.7
E-Waste in Africa
(Schluep, 2023)

1.3.4 Solar Home Systems

A *Solar Home System* (SHS) usually consists of Solar panels and an *inverter* (variable DC → usable AC). In grid-connected and off-grid situations, this is sometimes combined with an *Energy Storage System* (ESS), for example, the EcoFlow Delta (Figure 1.9). The ability to store energy allows users to store energy generated during the day for use at night. In OGS kits, this energy storage is a key component.

However, solar installations across Africa and the Global South aim to lift people from no electricity to Tier 1 or Tier 2 electricity use. The solar installations from Sun King, for instance, supply 7-80 W (Sun King, 2025), sufficient to charge a phone, a few lights, and a small ventilator. Unlike larger SHSs, these low-cost solar installations do not include a DC/AC inverter; instead, they have only a DC converter. Thus, alongside the development of this new industry, a market for *DC-powered home appliances* that are significantly more energy-efficient than their traditional alternating current (AC) counterparts has emerged (GOGLA, n.d.).

The sector focuses on four mainstream products: TVs, fans, refrigerators, and water pumps. In 2024, GOGLA affiliates sold nearly two million off-grid appliances.

By 2030, the investment needed to power enterprises and farms with these devices is estimated at $74 billion (GOGLA, 2024).

High efficiency is critical because it enables smaller, less expensive solar systems to provide services that previously required grid connections or more expensive generators (Bhatia & Angelou, 2015). This emerging market effectively reduces the barriers to the MTF, enabling Tier 2 users to access Tier 3 devices.

However, here is the thing: Tier 3-5 users are still dependent on their *weak grid* connections and fossil-fuelled BUGS to supply their daily tasks and jobs. ESSs (when portable, often called *micro storage*) fill this gap (Figure 1.9). It is a new segment of integrated inverters for powering standard AC loads, with 48,400 units sold in 2024 (GOGLA, 2024). Micro storage units can typically be charged from the grid or through PV. They are designed to fit the modern 'sleek' design language, which can be subjectively appealing but less rugged than that of fossil-fuelled generators. Compared to generators, the price is about 5-10 times higher for a similar power output.

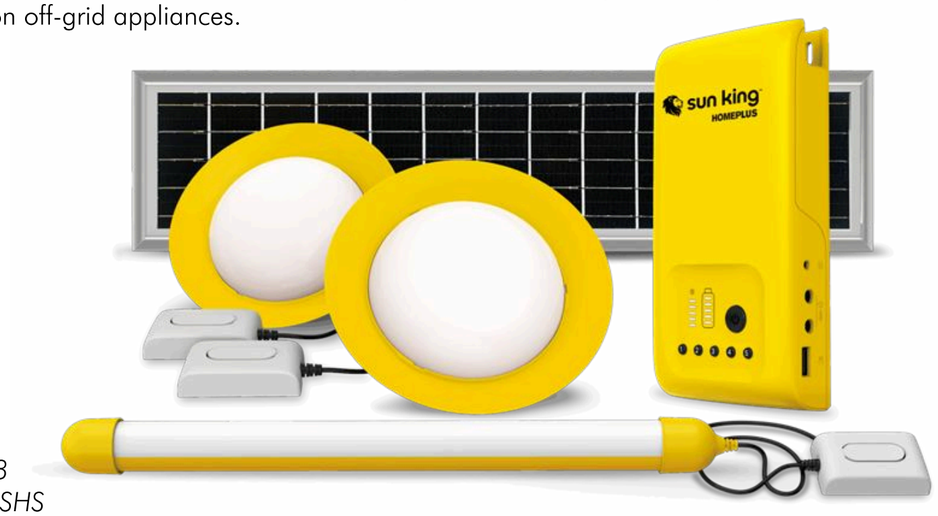


Figure 1.8
Sun King SHS
(Sun King, n.d.)

1.3.5 Black Box Architecture

As with low-cost solar installations, many branded micro storage systems use black box hardware and ecosystems with brand-specific cables and *digital handshakes*. This limits consumer choice and prevents the development of a *repair ecosystem* and *second-hand market* for solar appliances (Munro et al., 2022). Reasons for manufacturers to opt for this type of *proprietary design* can be:

- **Forcing frequent re-purchases**: In combination with planned obsolescence, where products are "made to break", the consumer is "forced" into frequent re-purchases. Even when not explicitly malicious, it can be the unintended result of design decisions that prioritise low market prices over the long-term availability of individual replacement parts (Cross & Murray, 2018). Especially when competing with incredibly cheap fossil-fuelled generators, this can be a challenge.
- **Tamper-Proofing for Warranties**: Many companies require devices to be tamper-proof so that consumer warranties can be honoured; if a user or a third party opens a device, the warranty is typically voided (Cross & Murray, 2018).
- **Innovation Cycles**: High rates of innovation drive frequent model changes (often annually), leading manufacturers to prioritise novelty over designing for a *service life* that exceeds the time it takes to release a newer model (Krebs & Weber, 2021).
- **Lack of Incentives**: Current *Extended Producer Responsibility* (EPR) legislation often focuses on the *end-of-life* recycling phase (shredding and material recovery) rather than incentivising manufacturers to provide repair instructions or spare parts during the use phase (Cross & Murray, 2018).
- **Standardisation Failures:** Historically, attempts to standardise and automate repairs failed because mechanical faults are often unpredictable and situational. Consequently, some manufacturers find it more efficient to replace an entire unit than to support the highly variable and complex knowledge required for component-level repair (Krebs & Weber, 2021).

1.3.6 Supply Chain and Viability Issues

The existing industry is also heavily focused on distribution, with *reverse logistics* for collecting dead batteries or distributing replacement parts being almost non-existent. Currently, micro storage units are thinly distributed across rural areas, making it economically infeasible for companies to retrieve them for recycling or repair without significant subsidies (Cross & Murray, 2018). In some countries, supply chains are choked by high import duties on batteries, intended to protect local industries that may not produce the specialised *deep-cycle units* required for solar. Furthermore, government subsidies for fossil fuels (e.g., kerosene and diesel) reduce the competitiveness of storage due to its high upfront cost (Cross & Murray, 2018).

Micro storage performance is highly dependent on ambient temperature and *battery management practices*. High temperatures in many developing regions accelerate battery degradation. Additionally, if users consume more electricity than planned, a common occurrence, it leads to *deep discharge* and premature battery failure (Baurzhan & Jenkins, 2016). Furthermore, batteries are a major component of the *Levelized Cost of Electricity* (LCOE) because they require replacement every 6 to 8 years (under ideal conditions) or as frequently as every 3 to 4 years for smaller OGS kits. Many financial models fail to account for these recurring costs, leading to project failure when the community cannot afford the second or third battery (Zebra et al., 2019).

When these systems fail, the BUG is likely to be adopted again, despite being more polluting, because it offers a lower capital cost and a more established local repair infrastructure (Baurzhan & Jenkins, 2016).

Figure 1.9
EcoFlow Micro Storage
(EcoFlow, n.d.)

1.4 The Off-Grid Energy Matrix

1.4.1 Generators: A Dirty & Open System

A positive aspect of the *generator culture* is its extensive *repair culture*. When a generator breaks, the user does not call a customer service centre in Europe or China. They go to the local mechanic down the street. The parts (spark plugs, filters, carburettors) are reasonably standardised and available in any village market (Rateau & Choplin, 2021).

In cities such as Ibadan, generator repair workshops constructed from simple sheet metal and generator frames strung around posts are found in almost every neighbourhood (Rateau & Choplin, 2021). The bulk of technical work is performed by *artisanal mechanics* or *skilled personnel* rather than official company representatives. These technicians often perform *component-level repairs*, such as disassembling units to replace specific parts rather than replacing entire modules.

1.4.2 Conclusions

The Backup Generator can be defined as a *Dirty & Open system*. Users hate the machine (for the noise/fumes) but trust the ecosystem (because they can fix it).

ESSs and micro storage can be defined as a *Clean & Closed system*. Users love it because it is silent, clean, and runs on solar energy, but it is designed for obsolescence and is virtually impossible to repair.

Using this framework, a matrix can be visualised (Table 1.2). A user escapes the bad grid and inevitably enters the matrix. The user defaults to the top-left because it is simply the most economical choice. When money is low, a cheap, open system will always come out on top, even when it is dirty. The industry offers *Clean & Closed systems* at higher price points, but a broken *Clean & Closed system* is functionally equivalent to a *Dirty/Closed* one: it is just a toxic object that no longer works.

Table 1.2
The Off-Grid Energy Matrix

DIRTY & OPEN Repairable BUGS, like the Tiger TG950 Survives because the local mechanic can always keep it running.	**DIRTY & CLOSED** Disposable fossil-fuel appliances, badly designed SHSs Broken micro storage and home systems that have not reached their break-even point.
CLEAN & OPEN The goal, a clean, repairable system A system that is both sustainable to run and sustainable to maintain.	**CLEAN & CLOSED** The ‘Black Box’ Current Solar Home Systems. Fails because when it breaks, it becomes toxic e-waste.

Project Formulation

2.0 Project Objective

The objective of this project is to identify a Clean & Open solution for energy supply and storage in the weak grid contexts of the Global South. As demonstrated in Chapter 1, people currently gravitate toward cheap fossil-fuelled systems because they are reliable, easier to maintain, and benefit from a long-standing informal parts-and-repair ecosystem. In comparison, clean battery-based alternatives are often designed to be *tinker-proof* by using digital handshakes, proprietary designs, and invisible mounting of parts.

In parallel with this is the surge in OGS home systems and the corresponding market for energy-efficient appliances. This sudden adoption of renewable energy can be labelled a leapfrog technology, but it primarily targets Tier 1-2 energy users who are either not connected to the national grid or must deal with an unstable one. This leaves a significant market gap for a Clean & Open system that serves Tier 3-4 energy users: a system that is reliable, easy to maintain, and financially viable for productive users in the Global South.

Again, the intention is not to lift people from Tier 0 to Tier 1-2 electricity, but to design a serious alternative to the extensive generator culture of higher Tier users. Within this project, the opportunity is to develop a *TRL-3/4* (Technology Readiness Level; Figure 2.1) product concept that shows what Clean & Open ESS could look like for these users. With TRL 3 as a lower limit for more technical subparts (electronics, UI, manufacturability) and TRL 4 for use-related subparts (affordances, user-friendliness, repairability).

The project aims to help solve a *wicked problem*. This means there is no simple solution, and the requirements are often incomplete, contradictory, and changing, making them difficult to recognise. This Chapter starts by defining the project's boundaries, scope, and target group, and concludes with a structural overview of the project roadmap, supported by the followed methodology.

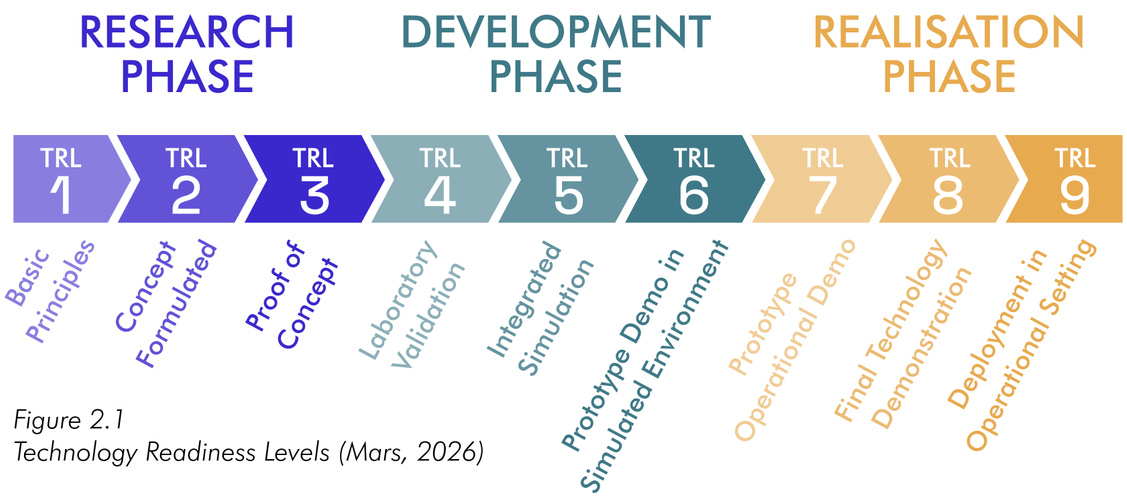


Figure 2.1
Technology Readiness Levels (Mars, 2026)

2.1 Project Boundaries & Technical Scope

2.1.1 Research Areas

The purpose of Chapter 1 was to define a clear narrative and identify a potential market gap. This initial research reveals many factors to examine or exclude from the scope. These potential research areas can be divided into four groups:

Hardware and standardisation

- *Comparable battery architectures:* What types of batteries are out there in comparable ESSs?
- *Commercial build logic:* How are commercial storage units typically built?
- Affordances and behavioural nudges: What are the affordances and behavioural nudges of ESSs, and how do they compare to generators?
- *Interface standardisation:* Beyond the internal cells, what is the standardisation status of other internal components, such as *BMS* (Battery Management Systems), inverters, and external connectors?
- *Proprietary parts and digital handshakes:* How do proprietary parts and digital handshakes act as a barrier to circularity? Can an open architecture ensure safety without sacrificing performance?

Culture and Society

- *The why and how of energy use:* How are people using energy? Is it for basic lighting (Tier 1-2) or for Productive Engagement and income-generating activities (Tier 3-4)? How do people stack their energy sources, and what do they do with broken technology?
- *Repair rituals and tacit knowledge:* How do local mechanics interact with high-tech hardware? Are there any informal repair systems in place for solar and battery technology?
- *The trust gap:* How does the tinker-proof nature of modern batteries affect long-term user trust compared to the Dirty & Open systems that users can see, touch, and fix?

Energy storage technology and chemistry

- *Industry-standard limitations:* What are the technological limitations of the industry-standard battery technology? Can they be recycled properly? Are there clean supply chains in place? Are there any *reverse supply chains* or *downcycling logistics* available in the Global South?
- *The horizon of storage:* What is happening on the horizon of storage technology? Do alternative options, such as *liquid salt* or *sand batteries*, *solid-state batteries*, *supercapacitors*, or *mechanical storage*, have any potential for a project like this?

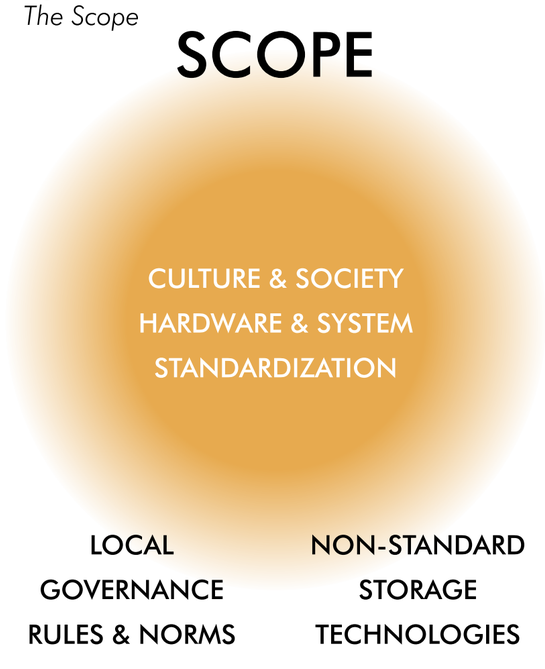
Governance, Rules and Norms

- *Capital hurdles:* The high upfront costs of renewable technologies such as solar mini-grids remain a major barrier. Many systems require substantial subsidies to be financially viable for private investors (IFC, 2019).
- *Fossil fuel lock-in:* Current systems are often stuck with fossil fuels because of artificially low costs driven by government subsidies for diesel and kerosene (IFC, 2019).
- *Policy-driven innovation:* Historical cost reductions in solar technology were driven not just by R&D, but also by market-stimulating policies that encouraged private-sector innovation (Kavlak et al., 2018).
- *Standardisation Incentives:* Hardware standardisation can only happen with a governance incentive. The *GOGLA* (Global Off-Grid Lighting Association) has recently begun advocating for increased standardisation of connectors, electrical components, and firmware to improve the sector's sustainability (Munro et al., 2022).
- *The Right to Repair in the Global South:* Are there emerging regulatory frameworks that penalise tinker-proof designs or reward manufacturers who provide open-source documentation and spare parts?

2.1.2 Technical Scope

Not all of these problems can be solved within the constraints of this graduation project. Future energy storage technologies such as solid-state batteries are interesting to research, but not relevant for this target group in this era. Investigating area-specific Governance, Rules, and Norms opens a Pandora's box of political and legal factors. To ensure the design remains a tangible product-led intervention for weak grid contexts, this area will also be excluded.
The research will mainly focus on the Hardware/Standardisation and Culture/Society pillars to inform the final concept.

Figure 2.2
The Scope



2.1.3 Open Source Hardware and The Industrial Baseline

A modular ESS solution can not exist in isolation. The purpose of this project is not to design *a better battery* where the modularity is just attributed to more attractive user features. **The focus is on a system that allows the user to use solar panels to generate energy for later use across diverse applications. The modular system, therefore, contains three interfaces: generation, storage, and application. The solution should be a glue that binds these three interfaces together.**

Chapter 1 mentions that manufacturers opt for proprietary, tinkerproof designs to force frequent repurchases, rely on warranties, and lack policy incentives. Current research agendas suggest a shift toward open-source hardware and modular product designs to circumvent proprietary barriers and extend product lifespans (Munro et al., 2018).

This is exactly what Biosphere Solar has been doing since the first models of their circular solar panels. This project is also licensed under the CERN Open Hardware License (OHL-S-v2). The license information can be found in Appendix A.

The OHL prioritises impact over market advantage. Should you produce hardware based on this project, you must, where practicable, maintain the source location visible in the products you make using this source. In other words, you can take aspects of this thesis and copy it, as long as you use the same license for your product. To maximise impact and transparency, it is important to establish and strive for the most widely available industrial baseline (where one exists). This industrial baseline is established in the following Chapters.

2.2 User & Contexts

2.2.1 Tier 4 & 5 Productive Users in the Global South

The broad target area is the Global South, described in the literature as "A collection of developing countries and low- and middle-income regions that share specific socio-economic and infrastructural challenges." (IFC, 2019). The group includes Sub-Saharan Africa, South Asia, East Asia and the Pacific (often excluding China), the Middle East and North Africa, and Latin America and the Caribbean (IFC, 2019).

The Global South is characterised by several interlocking factors related to development and infrastructure:

- **Energy Poverty & Weak Grids:** Approximately 13% of the global population lacks access to electricity (Zebra et al., 2021). A much larger share lives in grids prone to frequent blackouts, which inadvertently leads to widespread reliance on fossil fuels (IFC, 2019).
- **Rural Focus:** Over 80% of those without electricity in the Global South live in rural areas, where traditional grid extension is often economically unfeasible (Utoh et al., 2022).
- **Informal Economies:** Much of the technology in the Global South persists through informal markets, where repair cultures and the use of generic products are common strategies for maintaining access to goods (Cross & Murray, 2018).

Chapter 1 introduces the Multi-Tier Framework from ESMAP. PAYG Solar Home Systems focus on lifting Tier 1-2 *consumptive* energy users out of energy poverty. This project focuses on *productive* Tier 3-4 energy users who use 200-2000W to power their households and enterprises. This is the target group now using generators to power their productive activities.

2.2.2 What is Culture?

The target audience for this project spans the southern half of the globe and comprises innumerable societies and cultures, but what exactly is culture? Van Boeijen & Zijlstra (2020) argue that products, services, and other designed manifestations play a symbolic role in society. They say that culture is not inherited, but learned. Influenced by nature but nurtured by people. They describe culture as a dynamic process that develops over a relatively short period. Van Boeijen & Zijlstra (2020) use the definition of Bates & Plog (1976) as a starting point:

"The system of shared beliefs, values, customs, behaviours, and artefacts that the members of a society use to cope with their world and with others, and that are transmitted from generation to generation through learning."

They propose that designers could view culture in a *pyramid with three levels: Individual, group, and universal*. Depending on the design project, one of these lenses might be more important than the others, but they are not separate. Individuals are influenced by culture, and the designer cannot ignore its deeper layers.

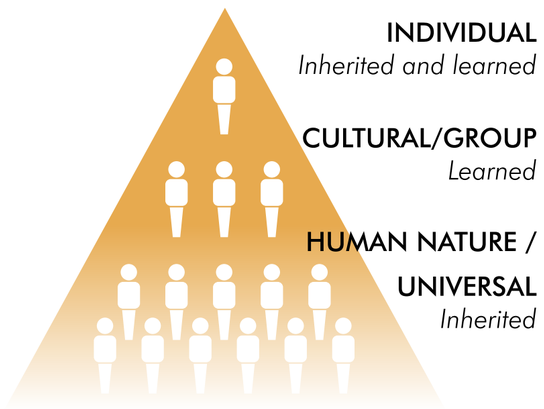


Figure 2.3
The Culture Pyramid
(van Boeijen & Zijlstra (2020))

Figure 2.4
Back-Up Generator in Bali

2.2.3 Ethnorelativism

For this graduation project, two locations in Asia were visited to investigate the two Clean & Closed and Dirty & Open archetypes: Suzhou, China and Bali, Indonesia. To get the most out of these visits, it was important to minimize biases that can influence the research.

Van Boeijen & Zijlstra (2020) use the term *ethnorelativism* to explain how a person experiences their own culture in relation to other cultures. This approach, comprising 6 distinct layers, stems from the developmental model of intercultural sensitivity (DMIS; Milton Bennet, 2004).

Starting at the core: ethnocentrism (perceiving one's own culture as central to reality), working outward through denial, defence, minimisation, acceptance, adaptation, and, lastly, integration. In the final layer: "your experience of self is expanded to include the movement in and out of cultural worldviews" (Van Boeijen & Zijlstra, 2020).

The goal of the analysis phase of this project was to determine the values, needs, and desires of the intended users. Integration is the keyword here. Effective methods for collecting rich, thick data about the targeted design context require in-person visits to the context. It makes sense that real cultural insights into energy-stacking habits, mobility choices, and repair rituals cannot be generated without actually going there in person.

Figure 2.5
Ethnorelativism
(van Boeijen & Zijlstra (2020))

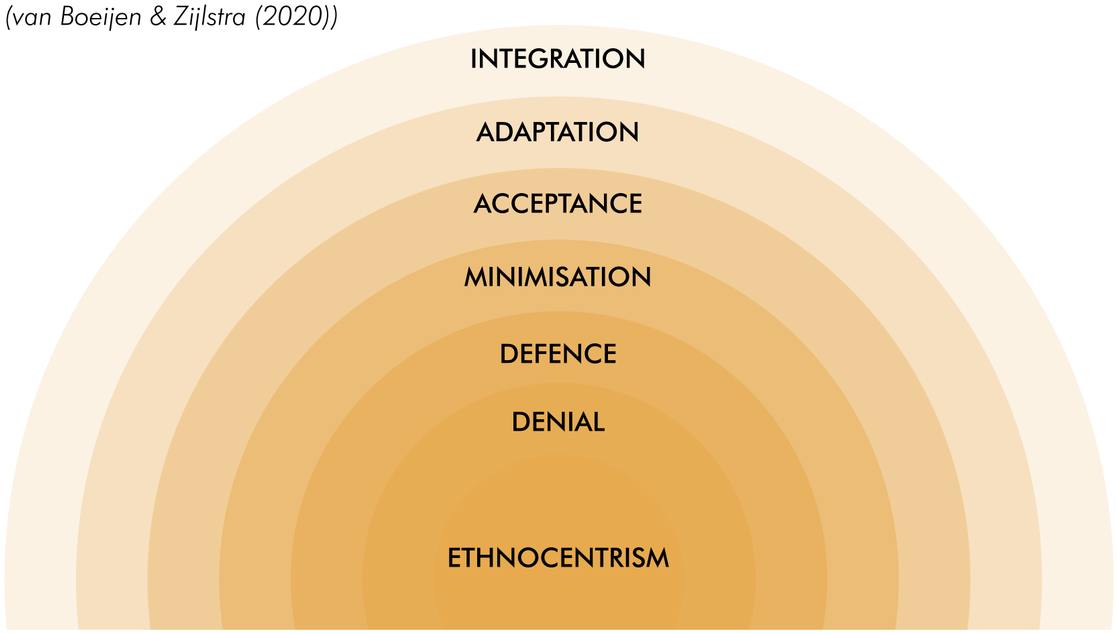


Figure 2.6 & 2.7
Reference pictures for Suzhou & Bali

Suzhou Region
Suzhou is an industrialised city in China, neighbouring Shanghai. Two of the Biosphere Solar founders moved here in the summer of 2025 to establish an overseas production line of their repair-friendly solar panels. This city is not only the hotbed of the world's solar manufacturing engine but also plays a key role in the battery and e-mobility industries.

Biosphere Solar has reached out to a couple of energy storage manufacturing companies to explore potential future products. Suzhou is an excellent place to get inspired by what a fully *electrified culture* could look like, and its extensive industrial nature is investigated to gain deeper insight into the actual motivations behind the closed architecture of current energy storage.

Bali
Bali is a relatively self-governing island in Indonesia, at the start of a transition to clean energy. Bali is an attractive location for Biosphere Solar to roll out its future circular business model and its reverse logistics operations. They will launch their first experiments in Bali in Q4 2026.

Biosphere's existing network in Bali offers a *hook* for direct integration into the local culture. By documenting the tension between Suzhou's industrial closed logic and Bali's informal open repair culture, I managed to identify the specific cultural affordances required to design an ESS that is not an *alien appliance* but a locally owned tool for development.

2.3 Research Objectives & Questions

2.3.1 Research Objectives & Questions
Following the *double diamond model (Figure 2.10)*. The main part of the project is divided into 2 distinctive phases.

Phase 1: Analysis

(Chapters 3 - 6)
Main Research Objective: To deconstruct the technical and social drivers of energy openness and closedness through the analysis of physical artefacts and their (social) contexts.

Phase 2: Product Development

(Chapters 7-9)
Main Research Objective: To design and validate a modular Clean/Open energy architecture that facilitates productive engagement and local serviceability.

Chapter 7 is a presentation of the final product, and can be seen as an introductory Chapter to Chapter 8. Therefore it does not present any Research Objectives and Questions in Table 2.1.

Table 2.1
Research Questions & Objectives

	Research Objectives	Research Questions
The Landscape and Technology of ESS 3	RO3.1 To investigate the technical build-up of an Energy Storage System to understand how the core components function together.	RQ3.1 Which are the main electrical components, and how do they interact to manage the flow of energy within an Energy Storage System?
	RO3.2 To map the current market landscape for micro storage to see what kinds of solutions are currently available.	RQ3.2 Which are the practical differences between battery chemistries and physical cell formats in terms of safety, material availability, and lifespan?
		RQ3.3 Which types of products are available on the portable power and swappable battery markets, and what are their defining features?
The Open vs Closed Archetypes 4	RO4.1 To investigate the *Tiger* generator as a Dirty & Open archetype to see which design features help with maintenance in the informal economy.	RQ4.1 Which mechanical features of the Dirty & Open Tiger generator make it so easy to repair with simple tools in a local workshop?
	RO4.2 To analyse modern battery storage units as a Clean & Closed archetype to find out which physical barriers prevent people from repairing them.	RQ4.2 How do the assembly choices of Clean & Closed battery units turn them into *black boxes* that are hard to fix?
		RQ4.3 How do the Dirty & Open and Clean & Closed archetypes compare in terms of providing individual agency and long-term energy security for users?
Light Vehicles in the Global South 5	RO5.1 To understand the role of light mobility and the shift of the *engine* to the battery in the transport systems of the Global South.	RQ5.1 Why is light mobility so essential for the economy in the Global South, and how does the battery take over the role of the engine?
	RO5.2 To investigate the *Swapping Paradox* where companies promote open standards while using patents to create proprietary walled gardens.	RQ5.2 How does the shift to a Battery-as-a-Service (BaaS) model change the way users interact with their source of mobility?
		RQ5.3 How do the proprietary designs and *walled gardens* of big manufacturers impact the development of a repairable and open energy infrastructure?
Towards a Clean/Open Concept 6	RO6.1 To synthesize the socio-economic drivers and technical needs of Tier 3-4 users	RQ6.1 Which are the specific power-use profiles, mobility patterns, and repair expectations of Tier 3-4 productive users (SMEs and households)?
	RO6.2 To synthesize the technical benchmarks from Chapter 3, 4 and 5 with the user research into a viable, feasible and desirable product concept.	RQ6.2 Where is the gap between technical findings and persona needs, and what design opportunity does this create?
		RQ6.3 How can the proposed product concept be structurally mapped to function as a central hub bridging micro-storage and a mobile battery-swapping ecosystem?
Concept Development 8	RO8.1 To design the product architecture, aesthetic identity, and mechanical connection features of the split-module system.	RQ8.1 Which physical configuration and form factor best translate the hybrid requirements into a functional, split-module architecture?
	RO8.2 To develop the physical embodiment, structural housing, and internal layout arrangements for the modules.	RQ8.2 Which mechanical locking and alignment features enable secure, user-intuitive coupling between the modules?
		RQ8.3 How are the modules structured to accommodate the internal components and battery placement interfaces?
Final Concept & Validation 9	RO9.1 To validate the physical performance of the mechanical coupling mechanism and the integrated thermal management system of the docking module.	RQ9.1 How intuitive is the physical alignment and latching interface of the split-module coupling mechanism for independent users?
	RO9.2 To assess the functional feasibility of the hybrid product system within a simulated operational environment.	RQ9.2 How effectively does the integrated thermal management system of the docking module dissipate heat?
		RQ9.3 To which degree does the integrated hybrid product system satisfy the established performance baselines within a simulated operational environment?

2.4 Methodology & Roadmap

2.4.1 Phase 1: Analysis

The analysis uses a multi-disciplinary qualitative *research for design* approach to bridge the gap between industrial production and local application. Apart from continuous *literature review*, the methodology draws from several methods from *culture-sensitive design* by van Boeijen & Zijlstra (2020).

1. **Artefact analysis:** Understanding the artefact is essential for understanding the cultural meaning of form and in developing the direction of form (van Boeijen & Zijlstra, 2020). In their respective contexts, this means mapping the observed environment using pictures and videos and asking questions such as "Where is the product stored?" or "Who is the owner?" and "What do you like or dislike about the product?"

2. **Disassembly mapping:** The Disassembly map is a visual design tool and architectural structural model used to assess and enhance product repairability (de Fazio et al., 2021). In this case, comparative Disassembly Mapping is used to quantify the *serviceability gap* between Open/Dirty and Clean & Closed. Two archetypal artefacts have been selected for this study:

- *"Better pass my neighbor" Tiger TG950 knockoff*, specifically the Güde GSE951, as the industrial benchmark for a repairable fossil-based system. It is a classic 720W, 2-stroke petrol generator. For consistency, this will be referred to as the "Tiger".
- *Bluetti Elite 30 V2* is an ESS that mirrors the Tiger generator's mobility and power. It can supply 230V/600W and can charge via standard AC or a small solar panel.

For an introduction to disassembly mapping, see Appendix H.

Figure 2.8
The "Tiger" generator (Güde, n.d.)

Figure 2.9
The Bluetti Elite ESS (Bluetti, n.d.)

3. **Factory Visits**
In and around Suzhou, four manufacturers were visited:
- *BTR:* Makes batteries for Light Electric Vehicles (LEVs) that can be taken out and used in combination with battery-swapping systems.
- *Zoolnasm:* A sodium-ion battery (SIB) manufacturer that is quickly scaling into one of the biggest sodium-ion manufacturers of China.
- *Weiheng:* Make large-scale and residential ESSs.
- *NeoVolt:* Make high-quality residential ESSs.

4. **Context mapping:** *Context mapping* is used to uncover users' needs that go beyond simple technical specifications. By mapping how energy and mobility artefacts travel through a typical day in a Bali SME, this method identifies the product's functional ecosystem. This reveals the situational constraints (e.g., motorbike transport, exposure to humidity, communal sharing) that dictate the necessary form factor and interface of a potential design intervention. Three types of *probes* were used to gather thick data:

- *Sensitising Booklet* (Appendix D1): A probing tool that is meant to be given to subjects as homework. It provides insight into daily life and sets the stage for later interviews.
- *Preference Booklets* (Appendix D2): Similar in content to the topic cards, but now presented in booklets of opposites to find out preferences.
- *Topic Cards* (Appendix D3): A valuable tool to make interviews more tangible. They cover subjects related to the thesis topic. Each card has a sketch to visualise the topic.

5. **Socio-cultural dimensions for design:** The *Socio-cultural Dimensions* (SCD) framework is a visual tool for analysing how cultural values shape people's perceptions and use of products. It consists of a set of scales used to compare different cultural contexts and serves as a checklist to help understand current value orientations and how they can be influenced by design. The *SCD framework* is used to document the tension between the industrial standards of the closed standards of storage systems and the open values of the generator. This analysis focuses on dimensions such as *Agency vs. Dependence* and *Individual vs. Collective Ownership*.

6. **Culture mapping with the onion model:** The final stage of the analysis phase uses the *Onion model* to synthesise the findings. It is a method for visualizing culture as a series of layers, moving from visible artefacts on the outside to deep-seated values at the core. The layers between (Rituals, Heroes, Symbols) explain how those values are expressed through daily actions and the objects people use. This method will be used to synthesise all findings into a final design brief, ensuring that the new Clean and Open system aligns with the users' core cultural values while adopting the functional rituals of the informal repair network.

7. **User Personas:** The interviews conducted during the context mapping process informed the development of two personas. Van Boeijen & Zijlstra (2020) give an explanation that cannot be clearer: "Personas are representations that will be involved intentionally in the new design. They are presented as real people in order to motivate the designers and other stakeholders to empathise with them". It is, of course, impossible to encompass the entire Global South into two personas, but they help bring the target group to life.

2.4.2 Phase 2: Concept Development

The concept development phase is broken down into component-level processes that were used to design the final concept. In earlier stages, component sourcing and sketching are used to group physical components into functional clusters. The housing is then designed around those functional clusters using CAD modelling. Iterative prototyping is used to develop individual functional clusters to TRL 3/4 and to conduct Proof of Concept validation. Finally, all functional clusters are integrated into a semi-functional prototype to validate cross-functional capabilities.

Although the concept generation was highly iterative and partly driven by designer intuition, the underlying process shows strong parallels with the *Fish Trap model* by Muller (2001) (DDG; van Boeijen et al., 2020). To clarify the design choices made, the generated ideas are retroactively structured in this section as *topological*, *typological*, and *structural variants*. Specifically, topological variants explore the spatial arrangement of the system's main components (8.2.1-8.2.4), while typological variants define their basic geometric forms (8.2.5-8.2.6). Finally, structural variants detail the physical architecture and functional mechanisms required to make the concept work (8.3, 8.4 & 8.5).

2.4.3 Report Roadmap

Figure 2.10 shows the project's roadmap. The structure is loosely based on a larger double-diamond model comprising small research and design phases. The analysis phase is split into the Clean & Closed and Dirty & Open related topics.

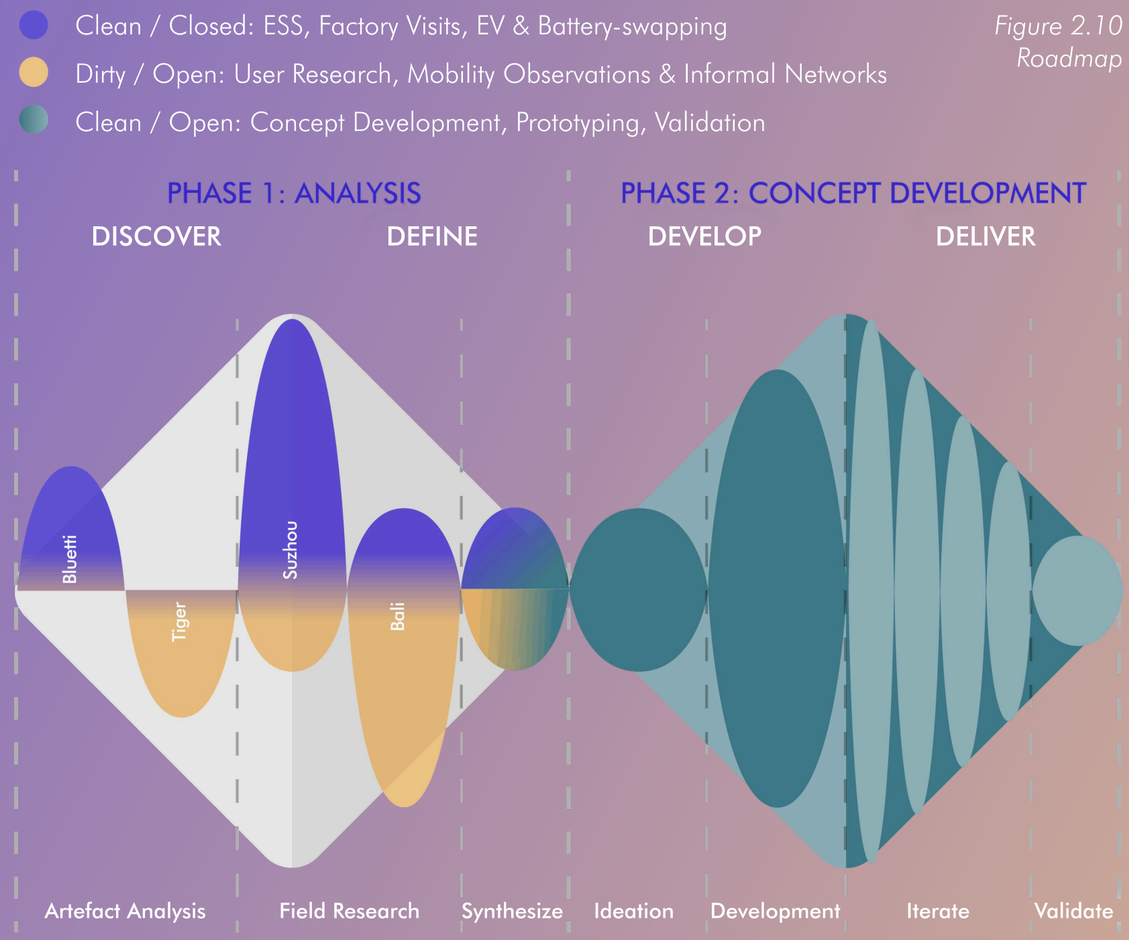


Figure 2.10 Roadmap

The Technology & Landscape of ESS

3

Phase 1: Analysis

3.0 Introduction

The goal of this project is to design an ESS that is more open and modular, empowering informal repair ecosystems in the Global South. For this purpose, it is essential to have a baseline understanding of what an ESS really is. For this reason, **RO3.1** is to *investigate the technical build-up of an Energy Storage System to understand how the core components function together*. For this objective, There needs to be an understanding of the underlying electrotechnical foundation. This will provide insight into why manufacturers choose certain parameters as baselines for their *Energy Management System*. For instance, the influence of battery voltage on the product's efficiency and output power. This research objective also examines practical differences between battery chemistries and physical cell formats in terms of safety, material availability, and lifespan. The manufacturer's choice of battery cell type is often context-dependent, so understanding fundamental battery chemistries and cell types is essential when designing a storage system for the Global South.

Another objective of this chapter is to map the current market landscape for micro storage to see what kinds of solutions are currently available. **RO3.2** is explored by analysing two storage systems with different target audiences.

Many insights from this Chapter were drawn directly from the company visits in and around Suzhou. These were very beneficial for understanding the product architecture and provided a broad overview of current industry developments.

Research Objectives

RO3.1	To investigate the technical build-up of an Energy Storage System to understand how the core components function together.
RO3.2	To map the current market landscape for micro storage to see what kinds of solutions are currently available.

Research Questions

RQ3.1	Which are the main electrical components, and how do they interact to manage the flow of energy within an Energy Storage System?
RQ3.2	Which are the practical differences between battery chemistries and physical cell formats in terms of safety, material availability, and lifespan?
RQ3.3	Which types of products are available on the portable power and swappable battery markets, and what are their defining features?

3.1 The Energy Storage System

3.1.1 What is an ESS?

The term *Energy Storage System* (ESS), or simply storage system, is widely used throughout this project. ESS is a broad term, and the limits of the definition are not clearly defined. If you just look at the direct meaning, the term could refer to anything that stores energy. It could be a small AAA battery, a power bank, or a scooter battery. But professionally, the term refers to (often stationary) systems that store electricity as an alternative to grid power. Examples can be seen in Appendices F3 and F4. These are produced by companies that were visited in Suzhou. The term *micro storage* is defined in Chapter 1 as a portable ESS.

The whole system consists of a *Battery Pack*, *BMS*, *Central Power Controller* (CPC), and *User Interface*. The user interface differs radically by type, but usually includes a *battery percentage* and a *time-to-full calculation*.

The CPC and User Interface differentiate the ESS from smaller systems such as e-mobility batteries. E-mobility batteries use the same battery technologies and are also designed with closed plastic casings and tamper-proof, black boxed product architecture (Cross & Murray, 2018). Because e-mobility batteries share a large part of the architecture, they are also considered as storage systems in this Chapter.

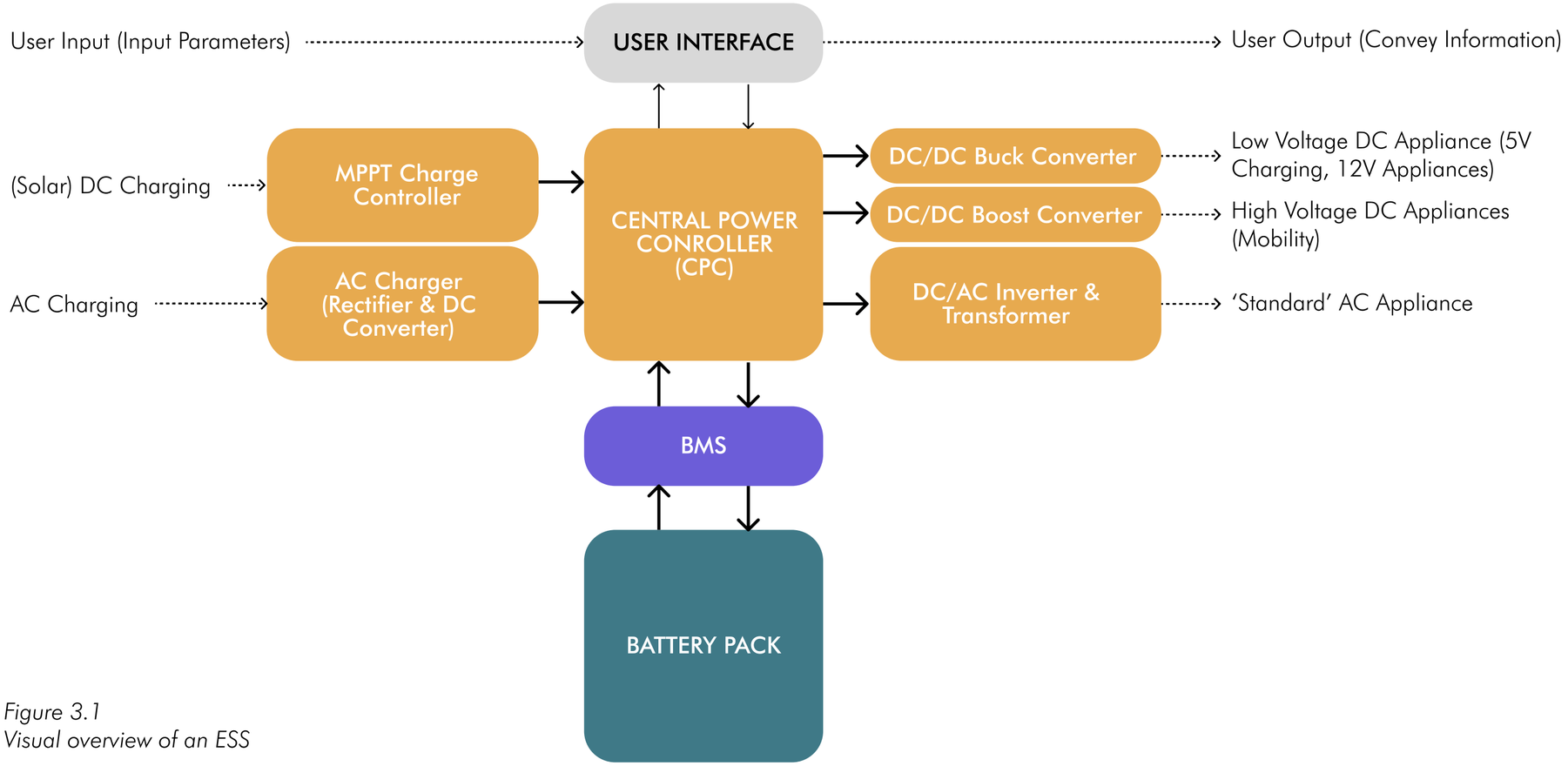


Figure 3.1
Visual overview of an ESS

3.1.2 Central Power Controller

The CPC is just a generic name for a set of components that work together as the system's core. It can be seen as the main board of the unit and comprises a *PCB* with many components, such as transistors, capacitors, IC chips, and spools.

A better way to view the CPC is as a combination platform of different types of current regulation & stabilization, split into inputs for charging the battery, and outputs for using the battery to power or charge other electronic devices. All these components also exist separately, for instance, solar inverters or phone chargers.

Inputs

- *MPPT Charge Controller:* The output of solar panels is direct current with a varying voltage. The output of a solar installation depends on the amount of available solar potential, which in turn depends on the weather, time of day, and placement. The *Maximum Power Point Tracking* (MPPT) charge controller's job is to take that varying output and create a stable current.
- *AC Charger:* Required to charge the battery with AC power. It essentially combines two steps into one. It rectifies 230V AC into DC power used in the CPC.

Outputs

- *DC/DC Buck Converter:* Because the CPC's circuitry operates on a specific DC voltage, a buck converter is used to reduce it to 5V, the standard for USB charging ports.
- *DC/DC Boost Converter:* Because the circuitry in the CPC uses a specific DC level, a boost converter is used to increase that voltage, for instance, 12 or 24V, used for other purposes, like the home appliances discussed in Chapter 1.4.
- *DC/AC Inverter & Transformer:* This component takes the DC current from the CPC and inverts it to 230V AC for powering standard AC appliances.

Other

- Sometimes ESSs use additional inputs and outputs, such as a *cigarette lighter port*, to charge the unit from a car outlet. An example is the Bluetti discussed in the next chapter.

3.1.3 The Power Triangle

Before diving deeper into the components of an ESS, it is important to understand the relationship among the three most important battery specifications. These three parameters are called the *Power Triangle* because they influence the unit's performance and capacity. They are related, and if you change the value of one, the whole system changes. The relationship is described with the following formula:

$$P = U \times I$$

Introducing time factor
$\rightarrow W\ (Wh) = V \times Q\ (Ah)$

$W = P \times t = Wh\ (Work)$
$Q = I \times t = Ah\ (Capacity)$

$P = Watt$
$U = Voltage$
$I = Ampere$

Wh describes the work done. It is a function of power (in Watts) and time (hours). If *A* (Amperes) is the unit of current, *Ah* describes the capacity, which is literally the amount of electrons available in the system. The link between them is the system voltage. It is the primary lever you can use to change the system's utility. *V* is the drive or push of the system. Ampere is the number of *buckets* the system is carrying, while voltage is the *amount of water* (energy) in those buckets.

For example, take two battery packs with the same physical volume of 20Ah, but one is rated at 12V and the other at 48V. The 12V battery has 240Wh, and the 48V battery has 960Wh, which is four times as much energy.

In ESSs, *Wh* is used as the primary parameter for runtime, while *V* is used for engineering purposes. Increasing the voltage directly relates to the power that the system can offer.

But how come the electrons in the system can carry less energy if the voltage potential is lower? If you draw the same power from two batteries with different voltages, the current from the lower-voltage battery will increase, as described by the formula on the left. To understand what happens to 75% of the energy, we have to look at *Joule's Law*. It describes the power loss as a function of the square of the current and the resistance of the load.

$$P_{loss} = I^2 \times R$$

$P_{loss} = loss\ in\ Watts$
$R = Resistance\ (Ohm)$

The choice of voltage is a battle against energy losses in the form of heat. The losses increase with the square of the current, meaning that energy losses grow very quickly as the voltage decreases. In the example of the two batteries, 75% of the electrons in the 12V battery just heat up the copper in the wiring. This can be countered by dramatically decreasing the wire's resistance, for example, by increasing the copper thickness. But you'd have to increase the thickness to battle against the squared current, resulting in very thick, expensive wiring. The better choice is to increase the Voltage, which also yields a more powerful system.

3.1.4 The Implication for ESSs

With a basic understanding of the *Power Triangle* and *Joule's Law* established, let's move on to some practical implications for storage systems.

During company visits to ESS manufacturers in and around Suzhou, it became clear that for stationary ESS, 96V is the norm. Micro storage systems, such as the EcoFlow Delta 2 (discussed in 3.3), mostly use lower-voltage 48V ratings. The voltage is determined by the number and type of battery cells. Most Lithium cells will supply 3.2-3.7V. This voltage will slightly decrease as the battery is drained. When stringing batteries in series, the voltages are added. 26 cells in series add up to 96V. If you want to increase capacity without increasing voltage, simply add a second string in parallel with the first.

If you want to increase the voltage without increasing the capacity, you have to choose smaller cells so you can utilise the same volume or space but get a higher voltage.

Table 3.1 compares various examples from this chapter and the next. It assumes an example load of 1kW, for example, a vacuum cleaner. It is a hypothetical situation, since the Spark (see 3.4) battery simply does not have the power to supply such a load. It also lacks an AC outlet for that reason. But a baseline is necessary to demonstrate the comparative efficiency of higher-voltage systems.

Efficiency is thus a function of the load. The higher the load, the less efficient a low-power system can be.

Table 3.1
Influence of Battery Voltage on Relative Heat Loss

Example System	Nominal Voltage	Current for 1kW	Relative Heat Loss
Spark Battery (3.4), threshold for home-power	12.8V	78.1A	100% (Baseline)
Bluetti Elite 30 V2 (4.2), small powerstations	16V	62.5A	64%
Bosch PowerTube (ApdxE), E-bike standard	36V	27.8A	12.7%
Ecoflow Delta 2 (3.4), micro storage, mopeds, medium power mobility	48V	20.8A	7.1%
Powerful mobility applications	72V	13.9A	3.2%
NeoVolt / SESS (Apdx F) norm for off grid utilities	96V	10.4A	1.8%

3.2 Batteries and BMS

3.2.1 Battery Management Systems (BMS)

A battery pack cannot simply be plugged into the AC or DC inverter. Although that could theoretically work, it would pose safety hazards during battery charging and discharging. There needs to be a system in place that manages the batteries and decides when to stop charging, for instance, or supplies the rest of the components with a stable current. This is where the Battery management System (BMS) comes in.

The BMS acts as an electronic controller that manages the rechargeable battery cells. It is a prerequisite for ensuring the battery's safety, stability, and longevity, particularly in high-demand applications (Gabbar, 2021). Rahmawatie et al (2017) say that the BMS has two main functions: *monitoring and protecting*.

- *Monitoring:* The BMS collects data on 3 main parameters: voltage (energy potential; state of charge), current (how much electricity is flowing in and out), and temperature.
- *Protecting:* These are reactions to monitoring data and include automatic switching (to prevent overcharging, for instance), *thermal management* (to keep cells within operating temperatures), and *optimisation* (to keep cell health optimal).

Cell balancing is also a key protection measure to ensure all cells age at the same pace, because the weakest link determines the overall battery pack health. This is called the *cask effect*.

Unlike lithium cell types, BMSs lack international standardisation, leading to a high degree of proprietary designs and hindering interoperability. According to Kirpes et al (2019), a key issue is the absence of standardised data models for battery health. Manufacturers frequently employ proprietary software locks and black-box designs that block third-party tools from accessing diagnostic data. In their report, Rahmawatie et al (2017) aim to lay the foundations for an industrial standard for Indonesia.

Rahmawatie et al. (2017) compare international standards, such as those from *ISO* and *IEC*. All the requirements focus primarily on safety. As discussed in Chapter 2, extensive research into standards across the Global South is outside the scope, but it is important to realise that when the absence of operational or serviceability standards clashes with affordable manufacturing, the black-box architecture emerges, locking out third parties.

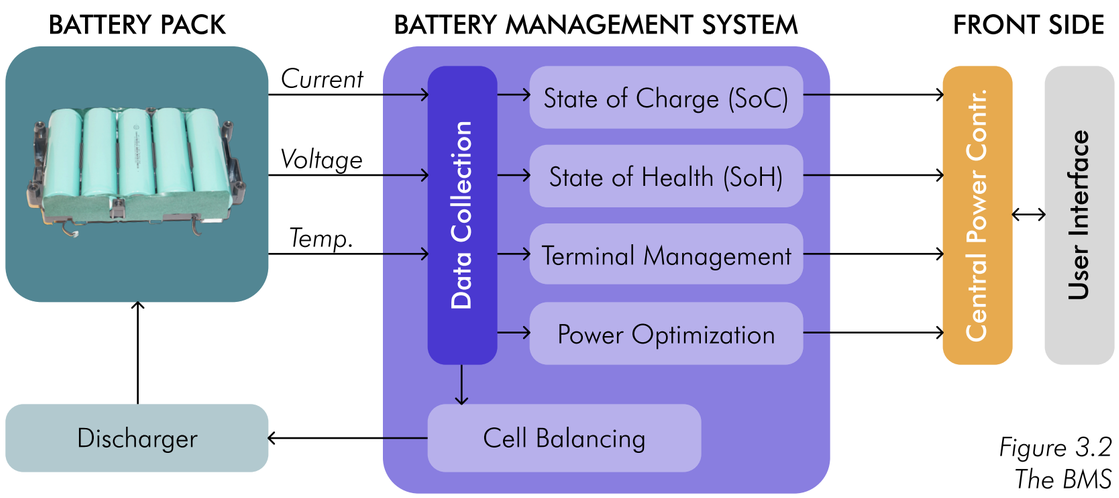


Figure 3.2
The BMS

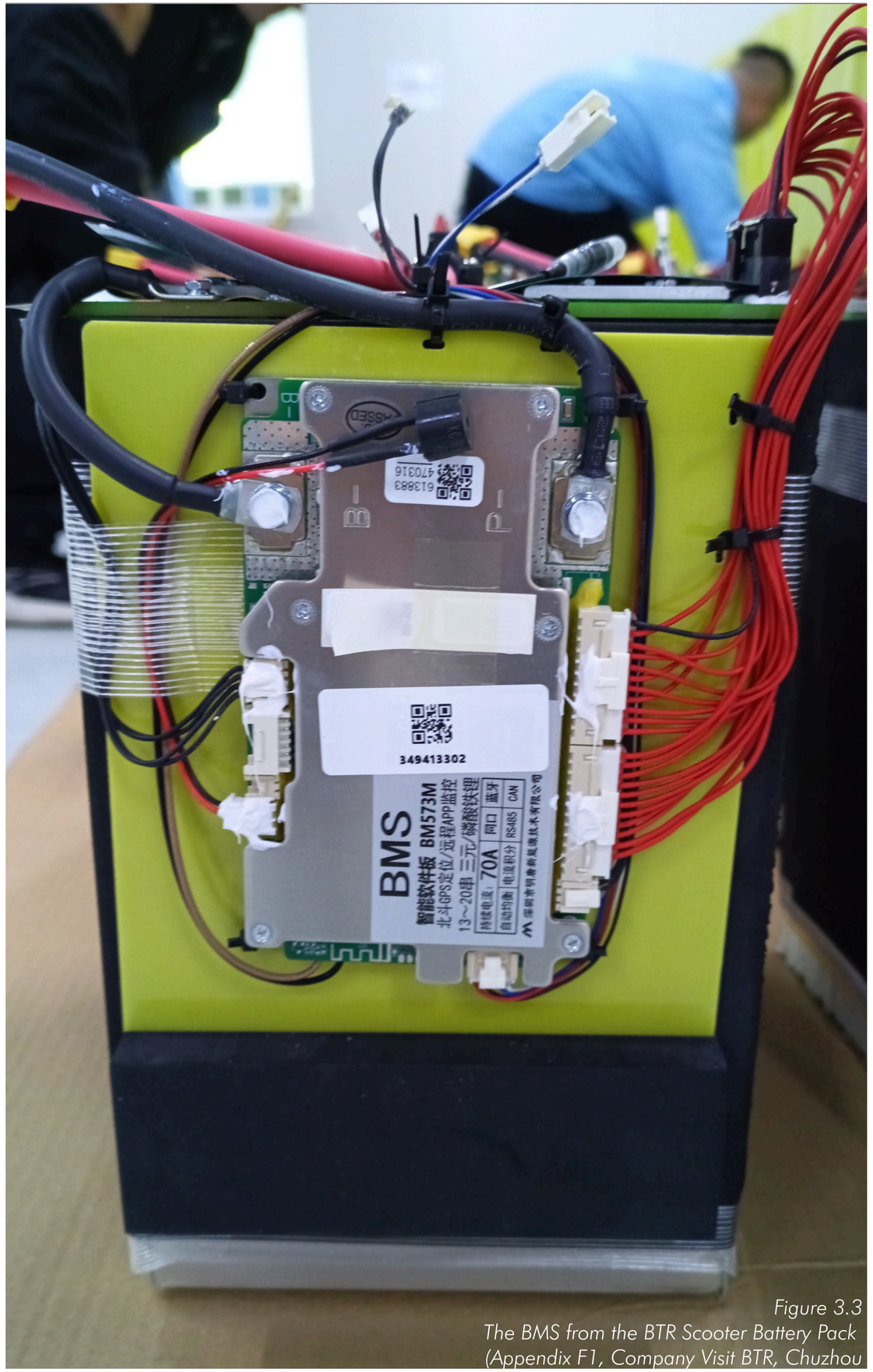


Figure 3.3
The BMS from the BTR Scooter Battery Pack (Appendix F1, Company Visit BTR, Chuzhou

3.2.2 Standardised Cell-Types

Apart from differences in battery materials, there is a wide range of standardised cell formats on the market. By rolling or folding layered anode and cathode sheets in different ways, the shape and characteristics of the cell can be altered. Battery cell types can be divided into three main formats. Flat cell formats, such as the *prismatic* and *pouch* formats, are more space-efficient than *cylindrical* formats, but are a bit harder to manufacture and more expensive. They are gaining popularity in the EV market, especially in scooter batteries. BMW and Volkswagen are also known to have used these formats in their EVs (Baazouzi et al., 2023). Cylindrical cell types are more popular in broader applications. In the cylindrical format, the anode and cathode sheets, along with their separator sheets, are simply rolled into a *jelly roll* encased by a cell housing, which is then closed off by a can and cap (Baazouzi et al., 2023). The naming of the cell type (e.g., 18650) is based on the cylinder's diameter and length (Li et al., 2025). Below are the most popular cylindrical cell formats.

18650 (18 × 65mm)
Debuted by Panasonic in 1994, this cylindrical format became the most popular worldwide. It is used extensively by Tesla (Models S and X), consumer electronics, e-mobility, and in space applications like the Mars Express (Quinn et al., 2018). It is associated with *NMC* and *NCA* *(Table 3.2)*, but more recently also SIB (Hwang et al., 2017).

21650 / 21700 (21 × 70mm)
This larger format was developed to increase capacity. The 21700 is now a modern standard for high-performance EVs, offering roughly 50% more energy content than the 18650 (Quinn et al., 2018). It is usually associated with NMC and NCA.

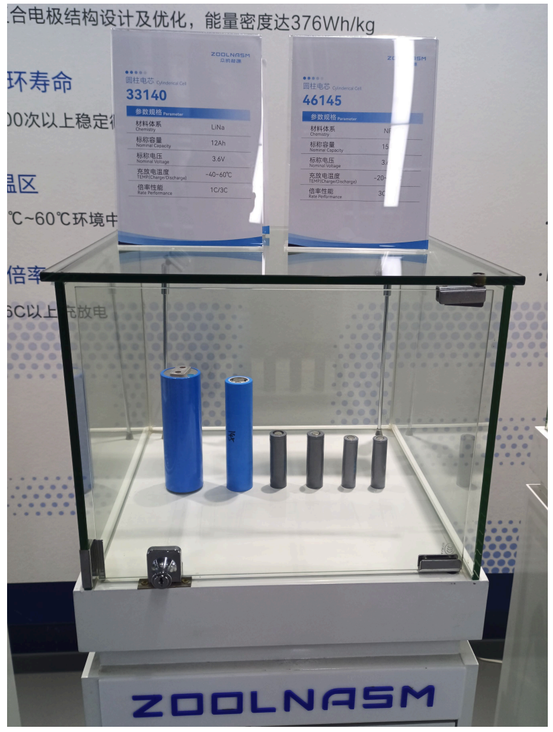
26650 / 26700 (26 × 70mm)
These wider formats are often associated with *LFP* and *SIB* technologies to compensate for the lower energy density.

40135 (40 × 135mm)
A larger format that is a more popular option for LFP cells in ESSs. (Figure

4680 (46 × 80mm)
Introduced by Tesla in 2020, it has a diameter of 46 mm and a height of 80 mm. It is 5.5 times larger in volume than the 21700 and features a specialised *tabless design* to manage heat in the larger form factor (Baazouzi et al., 2023).

Figure 3.4
Cylindrical Cell Types
(Becell Battery, 2025)
(Redway & Redway, 2024)
(Yigetech, n.d.-b)

Figure 3.5, 3.6 & 3.7
Top Left, LFP Pouch Cells from BTR Company Visit Chuzhou
Top Right: Cylindrical Cell Types from Zoolnasm in Suzhou
Bottom: Prismatic Cell Type from Zoolnasm in Suzhou



3.2.3 Promising Battery Technologies

The type of energy storage chemistry is the most fundamental factor determining the qualities of the energy storage system in its context. In the past, most off-grid systems relied on lead-acid batteries, which contain hazardous materials such as lead, cadmium, mercury, and sulfuric acid. While lead-acid batteries are currently more common due to their low cost and decades of use in petrol and diesel cars, *Lithium-ion batteries* (LIBs) offer better performance, higher depth of discharge, and a significantly longer operating lifetime (Zebra et al., 2021).

LIBs have a very high *energy density* compared to *lead-acid* and *nickel-metal hydride*, the other big player of the last few decades (Vishnumurthy and Girish, 2021). It is for that reason that LIBs have been the number one choice for small electronics up to EVs. But within the lithium family, there are many different subtypes that differ drastically in their strengths and weaknesses. Vishnumurthy and Girish (2021) state that to date, the majority of electric vehicles use lithium-ion batteries based on *LMO*, *LFP*, *NCA*, and *NMC* battery technologies. In all these batteries, positively charged lithium ions migrate between the cathode and the anode during charge and discharge cycles. All of them also use graphite as the anode material. The fundamental difference between these battery types lies in the cathode's chemical composition, while the lithium-based charging mechanism and basic structure remain the same. (Vishnumurthy and Girish, 2021).

While LIBs are celebrated for their high energy density, they also have several notable disadvantages. From a technical perspective, LIBs are susceptible to thermal runaway, which can lead to uncontrolled self-heating and significant performance degradation, particularly at extreme temperatures.

Economically, the limited availability and high costs of essential raw materials like cobalt and lithium hinder their broader adoption, particularly in the transportation sector. Additionally, the social and ecological implications of LIB extraction can lead to water depletion and human rights issues, especially in regions of the Global South. Furthermore, the widespread use of LIBs poses a substantial e-waste challenge, as these discarded units often contain toxic materials that are not managed effectively at the end of their lifecycles.

Sodium-ion Batteries (SIBs) initially emerged alongside lithium technology in the last decades of the 20th century, but were largely abandoned due to the rapid commercial success of lithium-ion technology. For the reasons above, there has been a recent revitalisation of interest in sodium (natrium) as a globally abundant and inexpensive alternative. Natrium (Sodium) is the fourth most abundant element in the Earth's crust and is evenly distributed globally, unlike lithium. In comparison, they sacrifice some energy density and typically have slightly lower output. On the contrary, they are easily recyclable, more stable over a wider temperature range and almost immune to thermal runaway. This makes SIBs excellent for e-mobility and ESS applications that do not prioritise weight over energy density and thermal stability.

The 5 different types of battery chemistry are compared in Table 3.2.

I visited one of China's largest sodium-ion manufacturers. Notes can be found in Appendix F3.

Table 3.2
Battery Technologies Compared (NoteBookLM, 2026)
Orange Refers to the Best Performer(s) in that Category

	LFP	NMC	NCA	LMO	SIB
Composition	LiFePO4 / Graphite	LiNiMnCoO2 / Graphite	LiNiCoAlO2 / Graphite	LiMn2O4 / Graphite	Sodium Oxides / Hard Carbon
Energy Density	90–120 Wh/kg	150–220 Wh/kg	200–260 Wh/kg	100–150 Wh/kg	~90 Wh/kg
Cycles	2,000–3,000+	1,000–2,000	~500	300–700	1,000–2,000+
Puncture/ Crush	Very safe. Smokes but rarely flames.	Dangerous. High risk of fire.	Dangerous. High risk of fire.	Extreme Risk. Violent, "jet" flames.	Excellent. Very low reactivity to air/ moisture.
Vibration/ Bumps	High. Physically robust chemistry.	Moderate. Layers can shift if hit hard.	Low. Very sensitive to cell damage.	Moderate. Stable crystal structure.	High. Very structurally stable.
0V Discharge	Fatal. Damaged if left empty.	Fatal. High risk of failure/instability.	Fatal. Can become dangerous to recharge.	Damaging. Leads to capacity loss.	Immune. Can be fully drained to 0V safely.
Thermal Runaway	Starts at ~$270°C$ (Hard to reach).	Starts at ~$210°C$.	Starts at ~$150°C$ (Very sensitive).	~$250°C$ (Quite stable).	Excellent. Very high ignition point.
Toxicity/Ethics	Clean. No Cobalt or Nickel.	Dirty. High Cobalt content.	Dirty. High Nickel/ Cobalt content.	Clean. No Cobalt.	Cleanest. Uses salt and abundant metals.
Temp Range	Poor at 0°C	Optimal 20-35°C	Heat Sensitive	Very Stable	Wide Range
Applications	OGS, ESS, Heavy EVs, light EV	Phones, Laptops, Light EV, EV	High performance EV	Budget EVs	ESS, EV in colder climates

3.3 Suzhou Company Visits

3.3.1 Company Visits

During the visits to various factories in Suzhou that manufacture OEM (Original Equipment Manufacturer) and ODM (Original Design Manufacturer) ESSs, it became clear that understanding the components discussed in this chapter is sufficient to develop a system with these manufacturers. Typically, a design and requirements, such as system voltage, are provided, and the manufacturer handles the rest. Large departments are responsible for designing and testing the electronic circuit boards for their products, located just one floor above the manufacturing assembly line. This setup ensures that the entire supply chain is within close reach, allowing for remarkably fast product development.

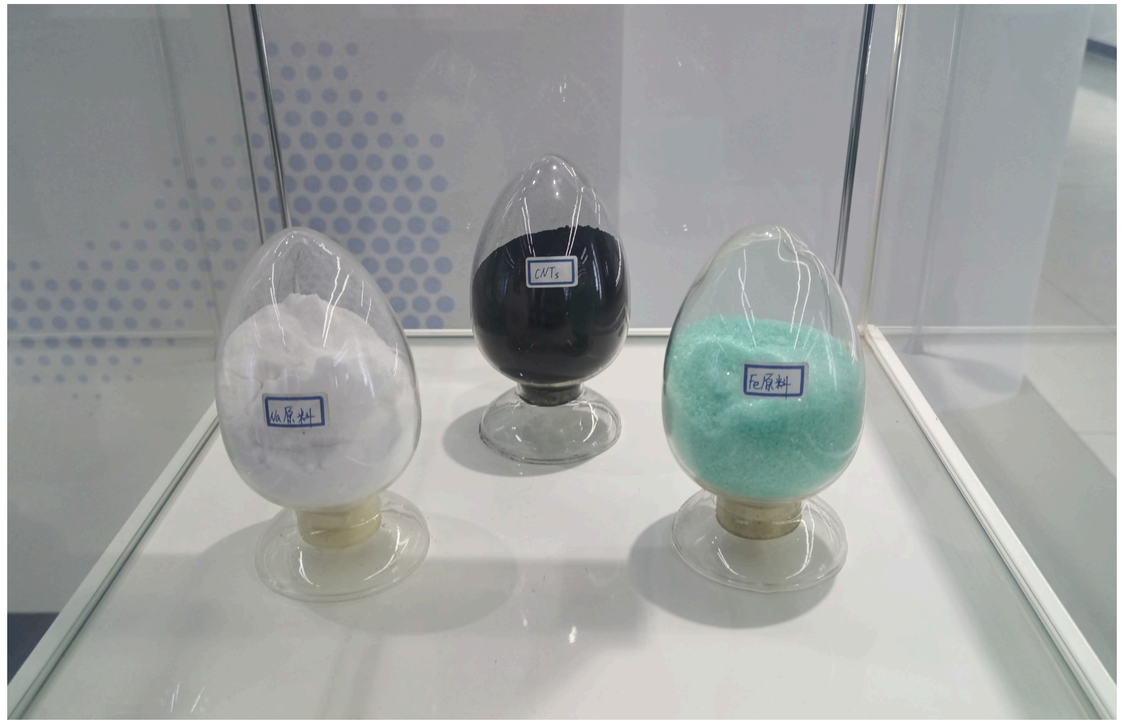
From the four companies I visited, two stand out the most: Zoolnasm and Neovolt. See Appendix F for the complete visit notes.

NeoVolt
NeoVolt's quality of the inverters and storage systems it makes exceeds that of its competitors. There are a couple of aspects showing that they put in that extra R&D effort to make a more solid product. An example is using the entire housing as a heatsink instead of a dedicated heatsink. Another example is the optimised dashboard for diagnosing individual faulty parts and the remote monitoring capability. In an industry where manufacturing efficiency is often prioritised over service throughout the product life cycle, this extra focus is a major driver of a more open and circular approach.

Zoolnasm
Zoolnasm manufacture SIBs with natrium and iron. Iron is a by-product of steel manufacturing, and both materials are among the most abundant on Earth. At the end of life, the anode and cathode can be separated by dissolving the jelly layer in water. Both layers can be used to remanufacture the cells. This is truly inspiring technology and will likely grow significantly in the coming years. The only downside is that the energy density is lower, as can be seen in Table 3.2. But for stationary applications, this is not an issue.

Figure 3.8
NeoVolt's Energy Storage Systems

Figure 3.9
SIB Raw Materials



3.4 Micro Storage Market examples

Here, the two models are selected to represent the Tier 1-2 VS Tier 3-4 Micro Storage units.

3.4.1 Market Example: SPARK

Spark is a Dutch company that designs and manufactures solar home kits for the Global South using a PAYG business model. The backbone of their kits is the modular 20–30W, 42Wh LFP battery pack, paired with small solar panels and a few DC home appliances. They are directly competing with Sun King, but have a more clever design that allows greater flexibility. According to Spark, four lights can run for up to 8 hours on a single full battery. Each battery has two USB ports for connecting smaller electronic devices and two 12V outputs for larger DC appliances.

The battery unit is paired with a screen that houses the *IoT chip* and displays the current battery level and the number of days until the next payment is due. Through the screen, the users validate their payment and activates the battery unit. The whole module is blocked if a payment is not made in time.

The screen and IoT unit are connected externally, creating a slightly more sustainable architecture.

This matters because, in most systems, the battery and the brain are in one sealed box. If the IoT chip fails, the whole battery is often discarded. The clever part of the Spark system is its ability to scale. The smart battery units are stackable or daisy-chainable and can easily be hung on a wall. This means the system does not just grow in capacity but also in power output, enabling it to handle more devices simultaneously. During the day, the batteries store the solar power that you do not use.

The design language is high-tech and user-friendly, using bright colours and easy-to-understand features. The Spark focuses on lifting people from Tier 0 to Tier 1–2 energy levels and, therefore, is not a serious option for larger households and SMEs and does not directly compare to the power of BUGS.

Data on repairability is not available, but this specific unit shows six accessible hex bolts on the back, potentially allowing component replacement. But the PAYG business model is almost an automatic disabler for tinkering.

Figure 3.10
The Spark Battery (Spark, n.d.)

3.4.2 Market Example: ECOFLOW Delta 2

EcoFlow is a Chinese company established in 2017 that develops portable power stations, smart devices, and home energy systems. In its brief existence of less than a decade, EcoFlow has grown to become the market leader in larger-capacity micro storage systems. Their product line includes many storage options in various sizes, as well as foldable and flexible solar panels to accompany the storage units.

For this example, the *Delta 2* model was selected because its 1800W AC power output is comparable to that of a 4-stroke 'Honda' generator (see 1.2.3). This higher AC power fits the Tier 3-4 energy user category and is therefore a direct, clean competitor to the generator industry.

The battery technology is also LFP, and the Delta 2 has a capacity of 1024 Wh (EcoFlow, 2025), equivalent to about 25 Spark Batteries. It can charge through solar power as well as the grid and has all the smart features you would expect from a contemporary SHS, such as WiFi, Bluetooth, and smart charging.

Through its four USB-A, two USB-C, and four AC outputs, it can charge a smartphone about 80 times and can run a 42 inch LED TV for almost 20 hours.

The weight is about 12kg, which is 5kg less than a Tiger generator, yet it can supply more power. Like Spark, it is also daisy-chainable. But with the EcoFlow unit, you need the extra battery unit, which is basically the same unit but without the outputs.

The design language is also high-tech, using a sleek plastic casing and a Red Dot aesthetic. The screen clearly shows the battery percentage, input and output power, and the number of hours remaining at the current power output.

Surprisingly, EcoFlow has proudly published a disassembly video on YouTube. Pliers are used to crack open the top, which reveals six screws. Underneath, the motherboard, backboard, BMS, battery pack, and screen assembly are four different parts. The BMS also has a protection film to prevent accidental shorts. However, all these parts are proprietary, and no repair guides or parts are available.

Figure 3.11
Ecoflow Delta 2 (Ecoflow, n.d.)

3.5 Chapter Conclusions

RQ3.1 What are the main electrical components, and how do they interact to manage the flow of energy within an Energy Storage System?

At the bottom of the stack, you find the battery pack and the Battery Management System (BMS). The BMS is a crucial safety board that monitors the voltage, current, and temperature of the cells. The BMS also protects the cells by preventing overcharging and managing temperature.

The Central Power Controller (CPC) is a term for the collection of electrical components that manage the flow of energy in the system. Since the system supplies both AC and DC loads, the CPC is split into separate AC and DC sections or boards.

A user needs to interact with the device, whether through input and output ports, or a user interface. The user interface displays the important data from the BMS, such as State of Charge (SoC) and State of Health (SoH).

RQ3.2 What are the practical differences between battery chemistries and physical cell formats in terms of safety, material availability, and lifespan?

The majority of battery-powered devices use either Nickel Manganese Cobalt (NMC) or Lithium Iron Phosphate (LFP) as anode and cathode materials. NMC has the advantage in energy density (Wh/Kg), making it the optimal choice for applications where weight is a limiting factor. LFP is the more popular choice for ESSs because it can handle more charge cycles before the capacity starts to decline. LFP is also less prone to thermal runaway and therefore a safer option for residential applications. A promising upcoming technology is the Sodium Iron Battery (SIB). Instead of precious metals, they use readily available sodium. SIBs have better temperature resistance than lithium-based batteries, making them virtually impervious to thermal runaway. They're far more sustainable and safer but have a lower energy density.

Cell types can be divided into 3 main categories: Prismatic, pouch and Cylinder. Cylindrical cell types are highly standardised and widely adopted in devices and vehicles, but are being increasingly replaced by prismatic and pouch cells due to their higher spatial efficiency.

RQ3.3 What types of products are available on the portable power and swappable battery markets, and what are their defining features?

With the understanding of the Power Triangle from 3.1.3 and 3.1.4, it makes sense why products like the Spark battery require more efficient DC appliances compared to high voltage AC appliances. Because it is not only the power that saves energy, a more efficient DC refrigerator also means lower energy losses.

In the E-bike market (Appendix E) the Infinite battery is a beacon of light in a world of black box designs. It shows that battery cells can be replaced while maintaining safety in the event of a thermal runaway In theory, individual cells can be replaced, but if one cell is replaced, all the cells will still perform at the level of the weakest link, called the *cask effect*. Unfortunately, in reality, all the cells would have to be replaced at once.

The Open & Closed Archetypes

4

Phase 1: Analysis

4.0 Introduction

As mentioned in Chapter 1, ultra-cheap imports like the Tiger TG950 represent the absolute lowest barrier to entry for independent power. **RO4.1** is to *investigate the Tiger generator as a Dirty & Open archetype to see which design features help with maintenance in the informal economy.*

Chapter 3 introduced the architecture of a typical ESS and its components. **RO4.2** is to *analyse modern battery storage units as a Clean & Closed archetype to find out which physical barriers prevent people from repairing them.* In this Chapter, the Bluetti Elite V30, a small ESS with a similar output to the Tiger, represents the Clean & Closed mirror of the lowest barrier to entry for clean, independent power.

The Research Questions are answered through *comparative disassembly mapping*, the open vs closed archetypes are visualised and compared. This creates a baseline for designing an open system in phase 2.

Research Objectives

RO4.1	To investigate the Tiger generator as a Dirty & Open archetype to see which design features help with maintenance in the informal economy.
RO4.2	To analyse modern battery storage units as a Clean & Closed archetype to find out which physical barriers prevent people from repairing them.

Research Questions

RQ4.1	Which mechanical features of the Dirty & Open Tiger generator make it so easy to repair with simple tools in a local workshop?
RQ4.2	How do the assembly choices of Clean & Closed battery units turn them into black boxes that are hard to fix?
RQ4.3	How do the Dirty & Open and Clean & Closed archetypes compare in terms of providing individual agency and long-term energy security for users?

4.1 Artefact Analysis: the Tiger

4.1.1 Why this model?

The *BUG industry* is a quintessential mature market. Unlike emerging clean technologies, fossil fuel generators have reached a point where the cost of electricity they generate is unlikely to fall dramatically due to technological improvements (IFC, 2019). For decades, these generators have been the only viable option for people living in areas with weak or broken grids. Their design, while intended for intermittent service, has been refined to the point where they are regularly used for thousands of hours a year in the most challenging environments (IFC, 2019).
The industry globally recognises four distinct categories based on fuel type and capacity (IFC, 2019):

- *Small Petrol/Gasoline:* Typically serving loads of less than 3 to 5 kW (corresponding to Tier 3-4 energy users; this is the scope of this project) (IFC, 2019).
- *Small Diesel:* Rated capacity less than 60 kW or 75 kVA (IFC, 2019).
- *Medium Diesel:* 60 to 300 kW (IFC, 2019).
- *Large Diesel:* Greater than 300 kW (IFC, 2019).

As mentioned in the introduction, the market is dominated by small, portable petrol or gasoline BUGS up to 5 kW. Within this sub-category of BUGS, the Tiger generator is a dominant and the fastest-growing type of generator (IFC, 2019). High production volumes and accessible pricing have made this model a cultural and technological default. Estimates for Nigeria indicate approximately 3 million sites powered by these generators, comprising 2.8 million residential and 210,000 commercial locations (IFC, 2019). That is over 15% of the 20 million small gasoline generators estimated to be deployed across the Global South (IFC, 2019). Decades of iterations, industrial refinement, and high production have established this globally understood technological archetype.

4.1.2 Specifications, Affordances & Use

With its compact dimensions of 380 × 310 × 370 mm, the Tiger has a footprint equal to a beer crate. It is quite heavy, weighing 17 kg excluding fuel, but can be lifted by the handle with one hand. It stands securely on four shock-dampening feet and has a rated power of 750W. It has one standard 230V/50Hz AC outlet that can supply 2.83 Amperes.

It ships with a wrench for removing the spark plug, which, according to the manual, needs to be cleaned with a brush periodically. Surprisingly, the standard Phillips screwdriver needed to clean the air filter is not included in the box.

The entire blue top is the 4L gas tank. By putting the tank on the very top, the gasoline is *gravity-fed*. As long as the fuel valve is open, the weight of the gas and atmospheric pressure push the gas down through the hose and into the carburettor. The fuel needs to be mixed with *engine oil* to lubricate the internal engine parts. In the mobility sector, the fuel and oil are usually separated, but here they need to be mixed before being poured into the tank.

The blue colour of the tank and the AC outlet is a *visual affordance*. It communicates directly that this is the user zone. It is also a brand identifier and helps to make the unit visible so people do not trip over it in a dark workshop or at a night market. The rest of the device is black and requires a certain level of operational knowledge before use. This clear *visual mapping* divides the use into two levels of interaction.

For a full list of specifications and maintenance instructions, refer to Appendix H.

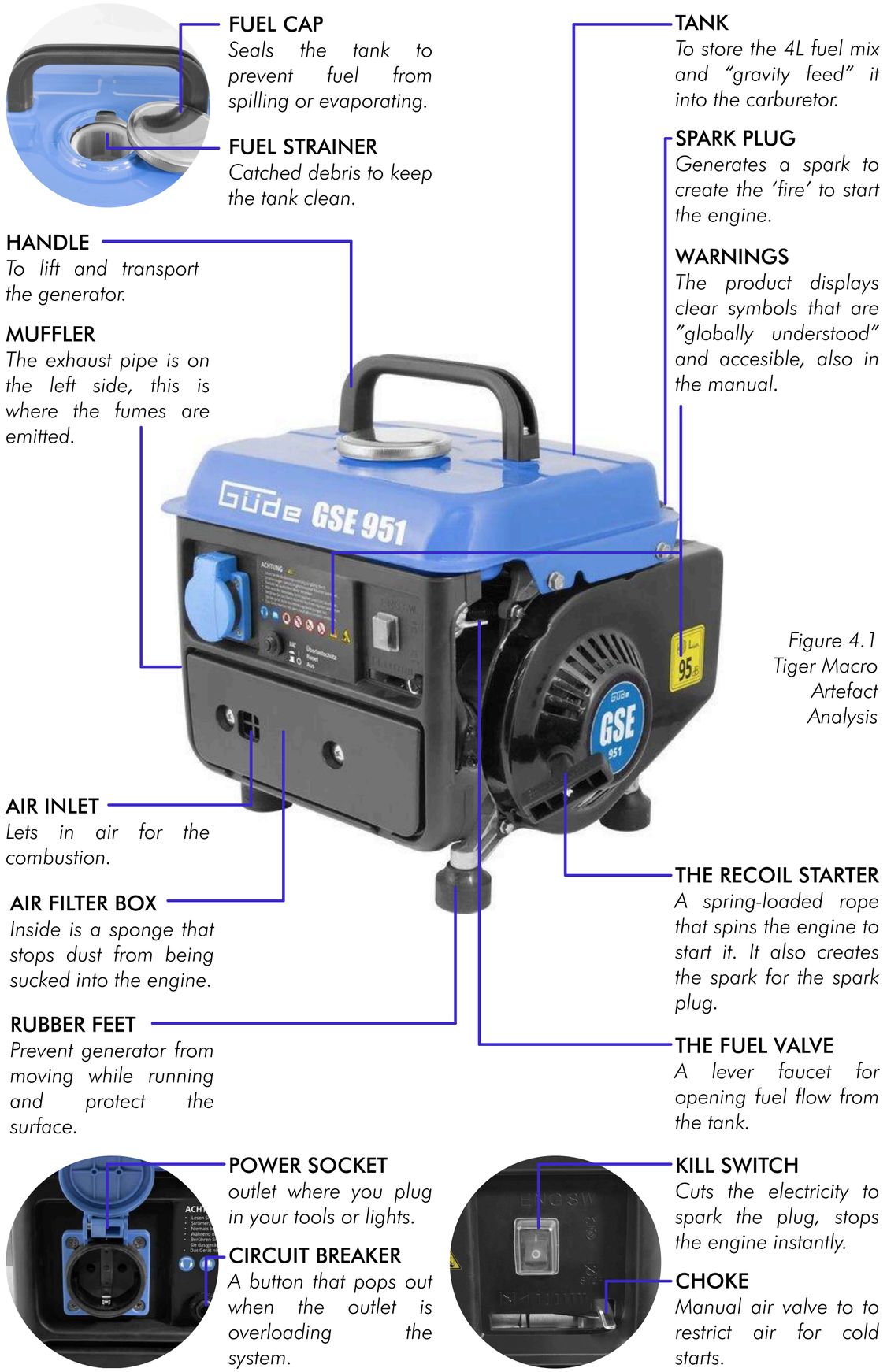


Figure 4.1 Tiger Macro Artefact Analysis

4.1.3 Disassembly Mapping

A disassembly map was performed in accordance with the format of de Fazio et al. (2019). The purpose here was not to identify hotspots of this specific model, such as the *carburettor*, since the objective is not to optimise the repairability of this specific model.

The assumption is that the vast majority of failures occur outside the *motor block*. Disassembling the *motor block* requires splitting the entire *crankcase* and removing numerous intricate parts. This repair can take a mechanic hours, which does not stack up to the low cost of buying a new generator and keeping the old one for extra spare parts. The disassembly map of the Bluetti assumes the PCBs to be single parts. But in reality, PCBs are composed of hundreds of smaller components, soldered onto a board. In the disassembly map of the Tiger, the motor block can be seen as the PCB. The disassembly map, therefore, regards the motor block as one part.

During disassembly, the total tool count was five, including uncommon tools such as the *flywheel remover*. A total of 10 different bolts or screws are used in this assembly. All tools are standard wrenches or a regular Phillips screwdriver. Some critical connectors, like the *flywheel bolt*, require excessive force or an extra tool or person to remove.

What stands out immediately in the disassembly map is the *horizontal and shallow distribution*, which suggests easy access to parts. 12 parts can be removed in parallel during the first disassembly layer. Beneath, two clusters can be found. The left cluster is the front panel and houses the electrical output and components. The second cluster contains all the parts that are connected to the motor block. Here again, the horizontal distribution indicates that most parts can be replaced in parallel.

Steps needed towards critical target components:

- *Spark Plug: 1 step (needs periodic cleaning and replacing)*
- *Carburettor: 6 steps (prone to clogging from low quality fuels, needs periodic maintenance)*
- *CBB61 Run Capacitor: 7 steps (weakens and burns out over time)*
- *Recoil Starter: 4 steps (vulnerable due to repeated physical pull-starting)*

Most critical components can be removed in a few simple steps, and the Tiger's design suggests this is also part of *periodic maintenance*. The use of visible, standard connectors suggests trust in local ownership and empowers individuals to extend the generator's lifetime.

Figure 4.2
The 10 Different Screws.

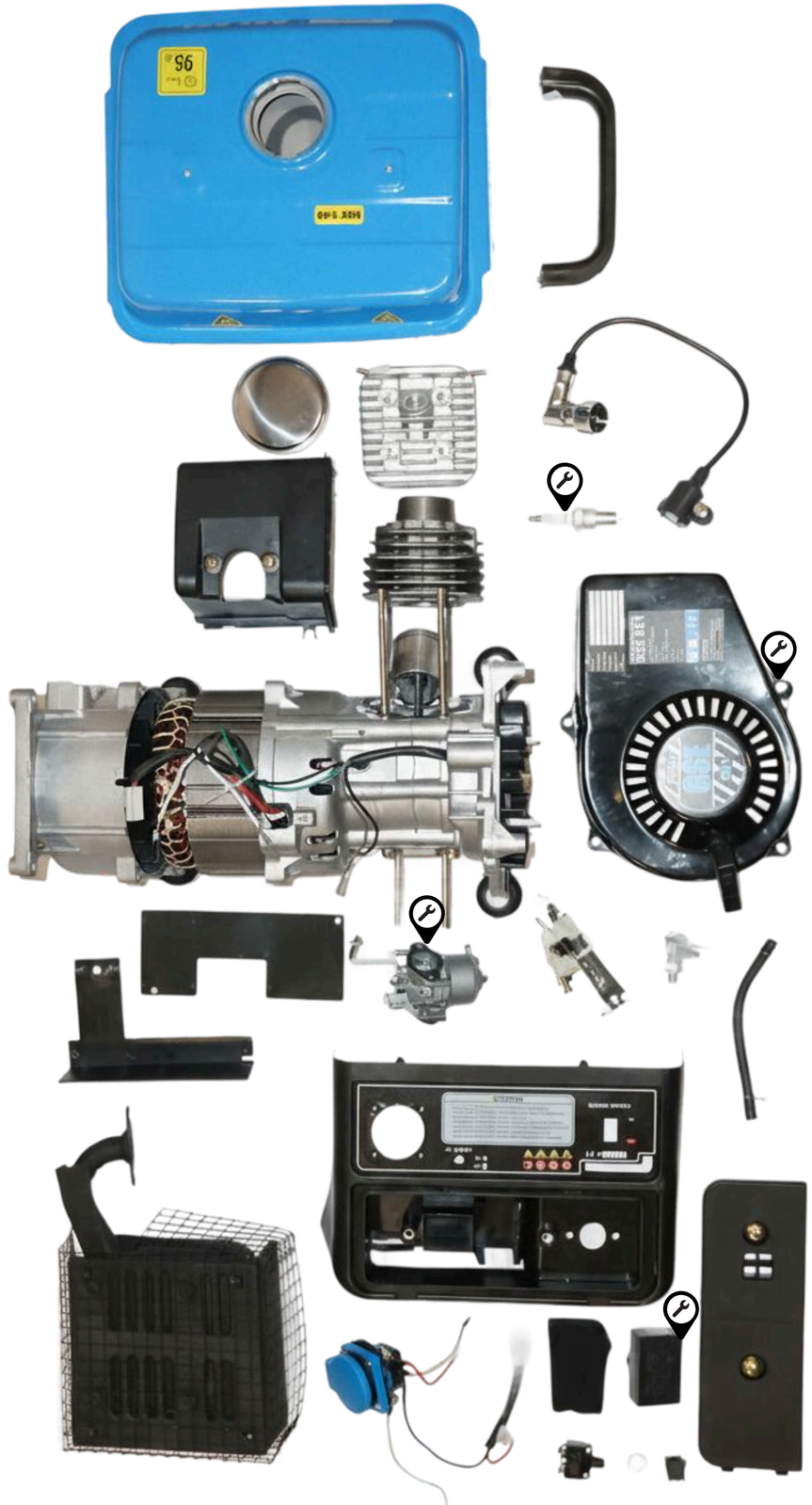


Figure 4.3
Top View of all the Parts

Figure 4.4
Tiger Disassembly Map

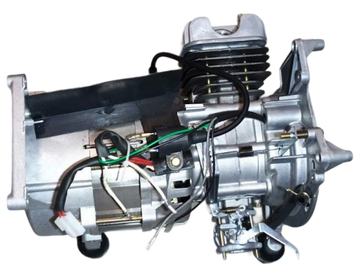
Complete Assembly

HEX8 (Wr)
PH2 (Sc) X2
F.F. (H)
8, 9
10
&
HEX10 (Wr) X4
F.C. (H) X4
B.C. (H)
&
F.C. (H)
PH2 (Sc) X2
12
13
F.C. (H)
PH2 (Sc) X4
15
16
PH2 (Sc) X3
17, 18, 19

F.F. (H)
T.D (H)
6
1, 5
HEX10 (Wr) X4
HEX8 (Wr) X3
HEX8 (Wr) X2
PH2 (Sc) X2
F.F. (H)
F.F. (H)
S.C.. (H)
22, 23
24
2
27
7
HEX14 (Sc)
HEX4 (Sc) X4
4, 11
3

S.C. (H)
HEX8 (Wr) X4
HEX12 (Wr)
HEX12 (Wr)
PH2 (Sc)
HEX8 (Wr) X4
PH2 (Sc)
HEX10 (Wr) X4
F.F. (Fr, Hm)
F.F. (Sc, Hm)
F.F. (H)
20
31
34
7, 25
21
30
28, 29
&
32, 34, 35, 36

Front Panel Assembly



Motor Assembly

Components

1. Fuel Cap
2. Handle
3. Spark Plug
4. Fuel Tank
5. Fuel Filter
6. Circuit Breaker Cap
7. Spark Plug Cable
8. Air Filter Cap
9. Air Filter Sponge
10. Engine Kill Switch Cap
11. Fuel Valve
12. Engine Kill Switch
13. AC Output Cap
14. CBB61 Motor Capacitor
15. Circuit Breaker
16. Grounding Cable
17. AC Outlet
18. AC Outlet Wiring
19. Front Plastic Cover
20. Carburetor Washer
21. Recoil Starter Side Panel
22. Muffler
23. Muffler Gasket
24. Cylinder Head Cover
25. Stator Guard
26. Fuel Tube
27. Rubber Feet
28. Cylinder
29. Cylinder Head
30. Carburetor Assembly
31. Spool Cover
32. Rotor Fan
33. Rotor Bearing
34. Flywheel
35. Outer Spool
36. Inner Spool

Legend

Motion type

Multiple Motion Tool

Single Motion Tool

Hand Motion

Force Intensity

Low Mid High

Penalties

= Product Manipulation

= Low Visibility/Identifiability

= Uncommon Tool

= Non-Reusable Connector

Target Components

= Failure Indicator

= Environmental Indicator

Connectors

HEX8 = 8mm HEX Bolt
HEX10 = 10mm HEX Bolt
HEX12 = 12mm HEX Bolt
HEX14 = 14mm HEX Bolt
HEX22 = 22mm HEX Bolt
PH2 = Phillips Screw #2
S.C. = Spring Clamp
F.C. = Faston Connector
F.F. = Friction Fit
T.S. = Thumb Screw
T.C. = Threaded Cap
B.C. = Bullet Connector

Type of Tool

(H) = Hand
(Sc) = Screwdriver
(Wr) = Wrench
(FR) = Flywheel Remover
(Hm) = Hammer

= Economic Factor

4.2 Artefact Analysis: Bluetti Elite

4.2.1 Why This Model?

The *Tiger archetype generator* discussed in Chapter 3 was a clear choice informed by the literature review. It is the lowest barrier to serious off-grid energy and provides a decent level of power for Tier 3-4 Energy users. In contrast, the micro-storage market lacks a clear model that has undergone decades of adoption in rural areas of the Global South. While EcoFlow is a market leader, its adoption numbers do not yet compare to traditional generators.

The Bluetti Elite V30 is not a highly specific choice like the Tiger; it is simply one of the many entry-level storage units available online. It was selected because its 600W AC power output is comparable to that of the Tiger. Both can be used for the same level of appliances, such as small power tools, fridges, TVs, and sewing machines. However, for high-power appliances like coffee makers or for industrial applications, a larger system would be necessary.

EcoFlow is a more user-centric company, as shown in the disassembly video mentioned in the previous paragraph. For this reason, their units are also quite expensive. The EcoFlow model, with specifications similar to the chosen Bluetti unit, is almost twice as expensive. The assumption here is that, for cost-reduction reasons, Bluetti has made technical compromises to speed up production, with less regard for repairability. Therefore, it is an excellent choice to prove the siloed product architecture and proprietary parts.

Furthermore, the general internal components of micro-storage systems remain roughly the same regardless of capacity. For the purpose of this artefact analysis, the small size of the unit is sufficient, especially since larger units pose greater danger due to higher currents.

4.2.2 Specifications, Affordances & Use

With its compact dimensions of 250 × 178 × 167.5 mm, the Bluetti has a footprint equal to a large Tupperware lunchbox. At 4.3 kg, it is four times lighter than the Tiger and can be lifted by the handle with one hand. It is one solid unit with a rated power of 600W and a *surge power* of 1500W. It has one standard 230V/50Hz AC outlet, plus two USB-C ports and two USB-A ports. Apart from the standard ports, it also has two standardised 12V *barrel ports* (DC5521) and a 12V cigarette output similar to that of a car. It is charged via a standard AC C13 connector or an *XT60 cable*.

It ships with the standard C13 AC cable, a car charging cable, and a grounding screw for connecting a ground cable if necessary. A solar charging cable or a cable to charge lead-acid batteries can be bought separately.

The design is high-tech, sleek, and functional. Unlike the Tiger's handle, which sticks out, this handle is part of the body's footprint, signalling that the unit can be tucked away or stacked when not in use. It is a dense, high-impact grey *polycarbonate box* designed for spatial efficiency rather than the open-frame design of a generator.

The front panel is strictly categorised into *input* and *output* zones. Each output section has a dedicated physical button with a green LED indicator. The screen displays input and output wattage, battery percentage, and a *time-to-empty/full calculation*. There is also a compatible app that provides additional features, such as *ECO mode* and *Turbo charging*. The upside is that the app is not required for standard functionality, though it is necessary for that extra functionality. When the device is in sleep mode, the green LED on the power button remains lit, indicating that the device is still on. These LEDs and the screen are the only points of colour, indicating where you interact with the device.

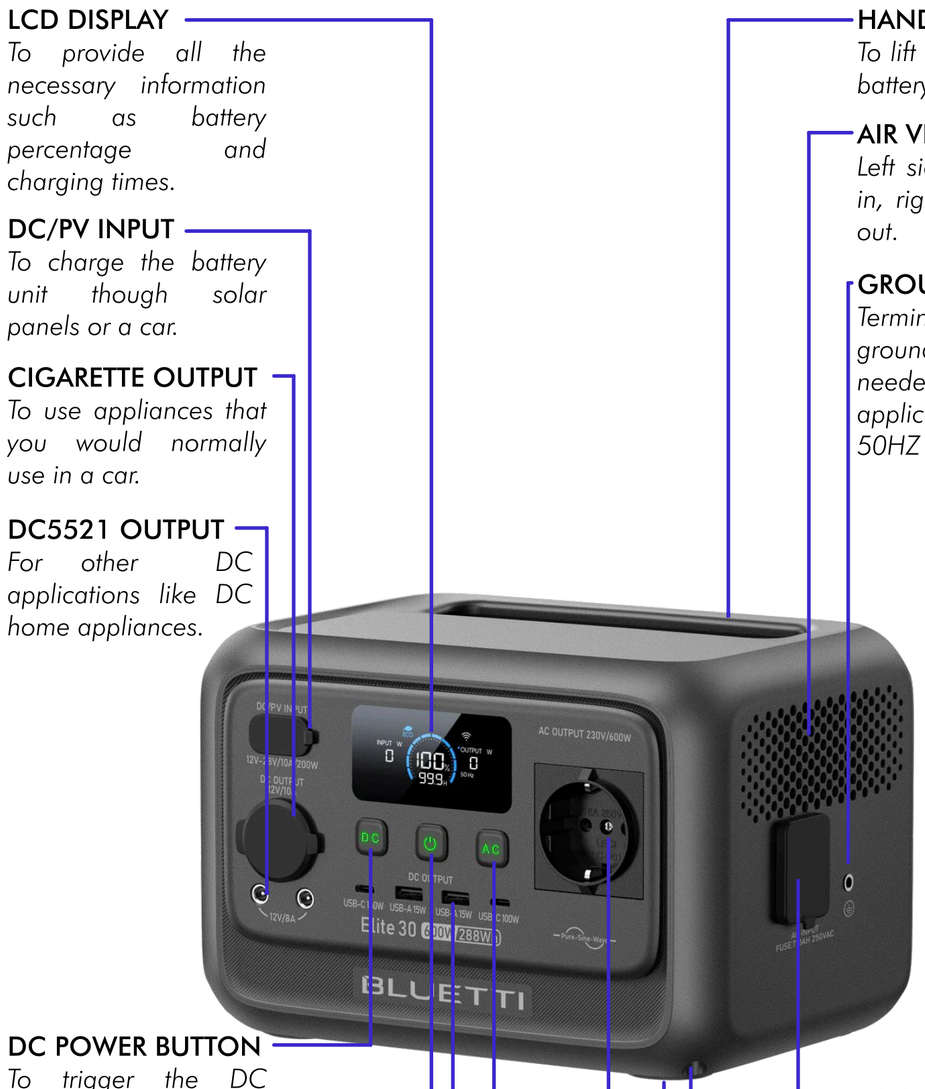


Figure 4.6 Bluetti Macro Artefact Analysis

4.2.3 Disassembly Mapping

A disassembly map was performed in accordance with the format of de Fazio et al. (2019). The purpose here was not to identify *hotspots* in this specific model (such as the LCD), since the objective is not to optimise its repairability. For that same reason, some parts were not fully disassembled if the step would risk breaking the connector, like the AC outlet or the handle.

During disassembly, the total tool count was eight, including uncommon tools such as a *soldering iron*, a *desoldering pump*, and a heat gun for loosening silicon glue. A total of eight different screws are used in this assembly. For some steps, multiple different screws were used for one part; for instance, the motherboard was connected with three different screw types. The implication is that the disassembler must document which screws go for reassembly.

The most surprising part encountered is the *NFC antenna* (Near Field Communication), which uses the same technology as a bank card or OV card. This antenna feeds directly into the BMS and serves as a *digital gatekeeper*. Most likely, official technicians can use a tag to read the antenna and retrieve data from the BMS. Access may be necessary to service the device or replace battery cells; on the disassembly map, this is marked with the middle finger icon.

The unit contains three different PCB boards. The main board carries the AC load and the AC transformer; the *DC/DC sub-board* handles the DC load. The *Control/UI* board houses the *LCD* and the buttons for interaction. The BMS has no dedicated board and is most likely integrated into the main board.

Steps needed towards critical target components:

- *LFP Battery Pack: 8 steps (cells wear down)*
- *Control/UI Board: 9 steps (ports are subject to wear and could need replacing with excessive use)*
- *LCD Screen: 12 steps (display is unprotected and prone to cracking)*

The disassembly map shows deep *vertical silos* for accessing the parts most likely to need replacement. As mentioned in 4.1, LFP batteries are rated for 2,000–3,000+ charging cycles depending on the charging behaviour. This specific model is rated for 3,000 cycles. The battery pack is the most likely point of failure. To replace it, all other parts need to be removed first.

Another hostile design choice is the way the Control/UI board was connected with screws and directly soldered to the *cigarette port*, which in turn is fastened to the front panel with hidden snap fits and glue (marked by ⟶ in Figure 4.9). In other words, the Control/UI board could only be removed by desoldering the solder joint at the cigarette port using a desoldering pump. The implication of this is that if the screen breaks, the most logical step is to replace the entire *front panel assembly*.

Figure 4.7
The eeight Different Screws.

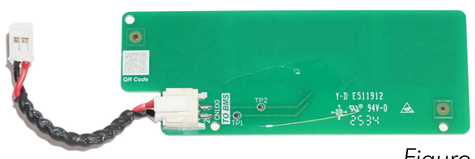


Figure 4.8
The NFC Antenna

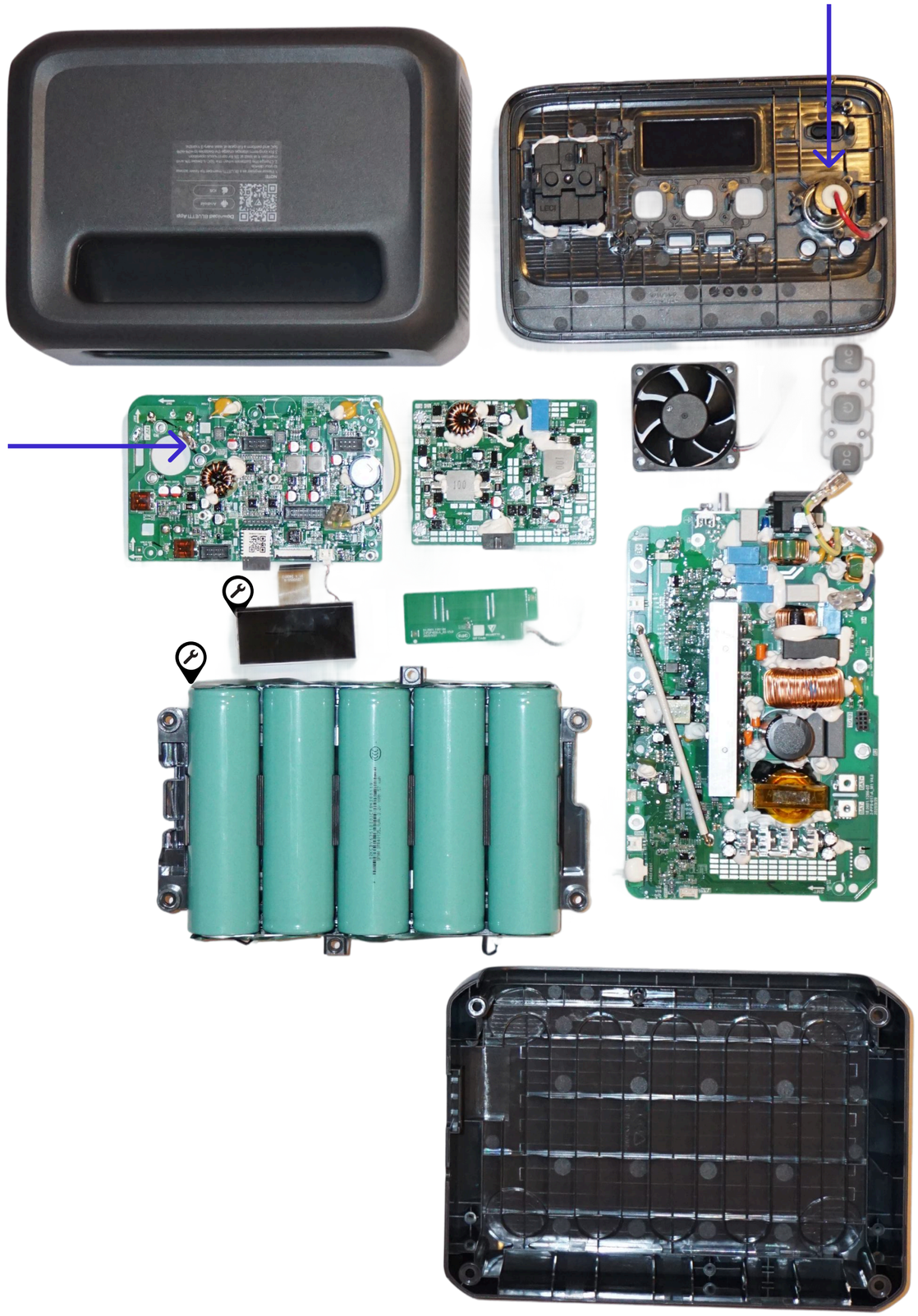


Figure 4.9
Top View of all the Parts

Figure 4.10
Bluetti Disassembly Map

Complete Assembly

D.T. (Sp) X4 → 5

HEX4 (Sc) X4 → 6

PH2 (Sc) → 4

F.F. (H) → 1, 2, 3

Front Panel Assembly

5 → ND7 (Sc) X2 ⚠; F.C. (H) X4 → 11, 12, 13, 14

11, 12, 13, 14 → PH2 (Sc) X5 → 13

13 → PH1 (Sc) X7; B2B (H) X4; SLD (SI) ⚠; SLD (DSP) ⚠; F.C. (H) → &

& → 12

12 → FLX.Plug (H); C.Plug (H); S.F. (H) X4; SLD (DSP) ⚠; S.F. (Sp) X4; S.F. (Sp) X3 → 14; 11

14 → 18

18, 14, 11 → &

& → 19, 20

Bottom Assembly

6 → PH2 (Sc) X3; C.Plug (H) → 9; 8

9 → PH1 (Sc) X2 → 10

10, 8 → &

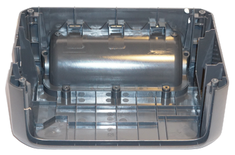
& → PH2 (Sc) X8; PH1 (Sc) X3 → 15

15 → PH2 (Sc) X6 → 16

16 → 17

Top Assembly

C.Plug (H) X2; PH2 (Sc) X2; PH1 (Sc) X3; S.F. (Sp) X3 ✕; S.F. (H) X3 ✕ → 7



Components

1. AC Input Flap
2. DC Input Flap
3. DC Output Flap
4. Grounding Terminal
5. Rubber Feet Pads
6. Top Plastic Cover
7. Handle
8. NFC Antenna
9. Plastic Protection Sheet
10. Fan
11. Cigarette Port
12. DC/DC Sub-Board
13. Content/UI Board
14. AC Outlet
15. Main/BMS/Inverter Board
16. LFP Battery Pack
17. Bottom Plasic Cover
18. LCD Screen
19. Buttons
20. Front Plastic Cover

Legend

Motion type

- Multiple Motion Tool
- Single Motion Tool
- Hand Motion

Force Intensity

Low Mid High

Penalties

- = Product Manipulation
- = Low Visibility/Identifiability
- = Uncommon Tool
- ✕ = Non-Reusable Connector

Target Components

- = Failure Indicator
- = Environmental Indicator

Connectors

PH1 = Phillips Screw #1
PH2 = Phillips Screw #2
HEX4 = 4mm Allen Key
ND7 = 7mm Nut Driver
F.F. = Friction Fit
S.F. = Snap Fit
C.Plug = Cable Plug Connector
FLX.Plug = Flex Cable Plug
F.C. = Faston Connector
SLD = Soldered
B2B = Board to Board Connector
D.T. = Double-Sided Tape
S.G. = Silicon Eletronics Glue

Type of Tool

(H) = Hand
(Sc) = Screwdriver
(Sp) = Spudger
(SI) = Soldering Iron
(DSP) = De-Solder Pump
(HG) = Heat Gun

- = Economic Factor
- = (Digital) Gatekeeper

4.4 Chapter Conclusions

RQ4.1 Which mechanical features of the Dirty & Open Tiger generator make it so easy to repair with simple tools in a local workshop?

The component that is most likely to be replaced is the spark plug. The tool to replace this component was provided in the box. Other parts that need to be replaced when prolonging the Tiger's lifespan are the carburettor, recoil starter or the motor capacitor. These parts can all be replaced using a Phillips screwdriver and a set of wrenches.

Whilst they are environmentally dirty, decades of industrial refinement have created a highly repairable product architecture and vast networks of informal repair ecosystems and spare parts markets.

RQ4.2 How do the assembly choices of Clean & Closed battery units turn them into *black boxes* that are hard to fix?

The Bluetti uses deep-sunken screws that are hard to reach. The cigarette port is glued in the body and soldered to one of the boards, making replacement of the display, buttons or input/outputs very hard. The main hostile design choice is the integration of an NFC antenna functioning as a digital gatekeeper. The large number of proprietary parts, combined with a repair-hostile design and a lack of reverse logistics, leads to significant e-waste. The disempowerment of local target audiences for the Global South creates a trust gap: people are expected to keep their generators running themselves, but are not trusted to do the same with battery units

RQ4.3 How do the Dirty & Open and Clean & Closed archetypes compare in terms of providing individual agency and long-term energy security for users?

As discussed in 4.2.3, the disassembly map of the Tiger is characterised by a very horizontal, shallow distribution. 12 parts can be removed from the outside alone, after which another horizontal distribution is revealed underneath. The only slightly vertical part is the front panel, which houses some of the electronics. The map of the Bluetti, as shown in 4.3.3, is very vertical and deep. Many steps are necessary to reach the critical parts, and some parallel processes are involved as well. Comparing the two maps, the horizontal distribution is a direct giveaway of an *open-system architecture*. The vertical architecture also supports the hypothesis of a *closed product architecture* for ESSs.

Other Conclusions

The differences in design language and affordances are a representation of the target audience. While the Tiger might be a poor example, since it lacks the typical metal bars that form an *exoskeleton* around the machine, the generator is seen as a heavy machine for serious purposes. The micro storage units are designed more for Western contexts like campervans and look more like a modern *consumer gadget*.

When placing a micro storage unit, such as the EcoFlow or Bluetti, in the user context of this thesis, that sleek, *gadget-like* design becomes a fundamental mistake. Imagine someone in Lagos, Nigeria, transporting the unit on the back of a three-wheeler or motorcycle, and it falls. Immediately, the product cracks and loses any *waterproofing*, which makes them ill-suited to supporting the livelihoods of Tier 3-4 energy users in the Global South.

Light Vehicles in the Global South

5

Phase 1: Analysis

5.0 Introduction

BUGS often use two- or four-stroke engines that burn a mixture of gasoline and lubricating oil and are technically similar to those used in light vehicles such as motorcycles or mopeds. The product architectures are nearly identical, as they both convert chemical energy into rotational energy. Where motorcycles provide propulsion, generators use the same principles to generate electricity. The emissions from BUGS are also nearly identical to those from car and motorcycle engines, containing thousands of chemicals and the same primary pollutants. The open architecture of generators and their informal ecosystems is interwoven with the mobility industry. Even on a social level, they are similar to cars: the power, size, and noise of a unit convey information about its owner's rank and success. For this reason, **RO5.1** is focuses on *understanding the role of light mobility and the shift of the engine to the battery in the transport systems of the Global South*.

This mobility parallel also extends to clean alternatives in the mobility industry. Where fossil fuelled vehicles share the ICE logic, EVs have a lot in common with energy storage systems. In my observations in China and Indonesia, I noticed a transition from *informal refuelling economies* towards battery swapping (*Battery-as-a-Service*). But the Clean & Closed trend extends to this industry as well. **RO5.2** is *to Investigate the Swapping Paradox where companies promote open standards while using patents to create proprietary walled gardens*.

Research Objectives

RO5.1	To understand the role of light mobility and the shift of the engine to the battery in the transport systems of the Global South.
RO5.2	To investigate the Swapping Paradox where companies promote open standards while using patents to create proprietary walled gardens.

Research Questions

RQ5.1	Why is light mobility so essential for the economy in the Global South, and how does the battery take over the role of the engine?
RQ5.2	How does the shift to a Battery-as-a-Service (BaaS) model change the way users interact with their source of mobility?
RQ5.3	How do the proprietary designs and walled gardens of big manufacturers impact the development of a repairable and open energy infrastructure?

5.1 Transport in the Global South

5.1.1 The Mobility Scales

Unlike the focus on private passenger cars in the Global North, the Global South is seeing rapid implementation in micro-mobility, such as e-rickshaws, scooters, and e-bikes, as well as public transit. In 2022, EV sales of motorcycles and bikes more than tripled in India, Thailand, and Indonesia, reaching a combined 80,000 units. Thailand's market share reached roughly 3%, while India and Indonesia averaged around 1.5%. The term Light Vehicle is often used in the context of electricity, specifically regarding Light Electric Vehicles or LEVs (Elektrisch Vervoer - LEV - Nederland, n.d). The definition refers to electric motorised vehicles with two or three wheels that are lighter than cars. The number of different vehicles in this category across the Global South is enormous. This paragraph provides an overview of the main vehicle categories within the larger LEV category.

Bicycles

These are very common in the Netherlands but not very common in the Global South. In China, pedal bikes are very popular as a sharing system through mobile apps where users can pick up and leave a bike virtually anywhere, though people do not typically own them. Observations suggest only a handful of personally owned e-bikes exist there. While it is possible to rent e-bikes in Bali (Bali Fat Bike Cycling, n.d.), they are not a common sight in person. In 1999, the Chinese government created a standard for E-bikes to promote the use of pedal-driven bicycles (Motorised Menace, n.d.). The result was that manufacturers fitted heavy mopeds with pedals to circumvent the need for a license. This is very similar to the fatbike trend in the Netherlands. Based on the observations, E-bikes only make sense when there are certain regulations. The context is really centred around high-speed mobility and status; people want scooters. The pedal E-bike does not fit into the picture for the Global South, unless there is a grey area in that nation's standards.

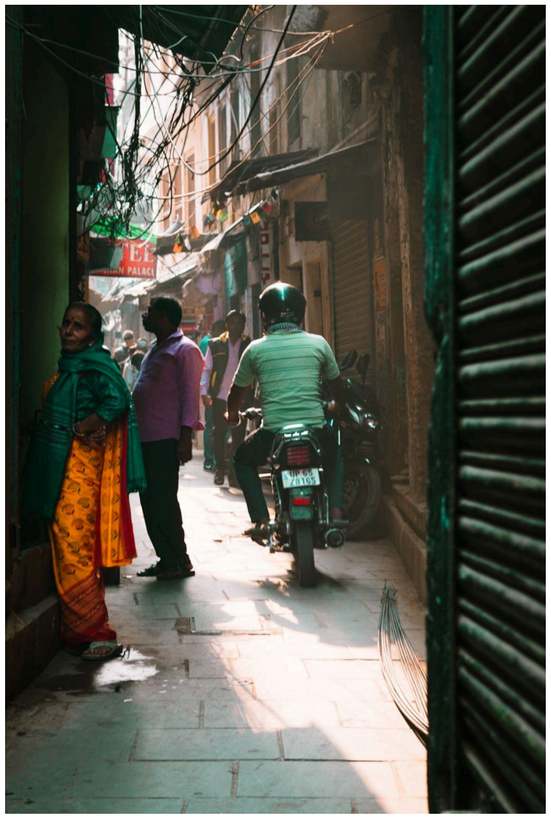
Scooters & Motorcycles

In my observations in China, I encountered only electric scooters and motorcycles. To counter air pollution, China has banned gasoline motorcycles in medium and large cities since the 90s, and as of the early 2020s, approximately 185 to 200 Chinese cities have either full or partial bans on gasoline motorcycles in their urban centres. I was told they were phased out, and the remaining ones that were still functioning were sold off to rural areas. China is applying a similar strategy to petrol cars; for example, buying a petrol car can involve roughly $50,000 in extra fees, whereas electric cars receive significant government subsidies. Aside from social status, there is little reason left to purchase a petrol vehicle in that context.
In the Global South, scooters are the primary form of personal transport because they are fast, reaching around 100 km/h, convenient, and cheap. Refuelling a bike in Bali costs around 3 Euros and lasts for over 250 km, which is roughly 100 km per Euro. The vast majority of low and mid Tier bikes observed were Hondas, while higher Tier bikes were usually Yamahas. Interviews indicate that the brand of motorbike carries significant status. A large 160cc Yamaha provides higher status within a social group, even if the context does not require it.

Three-Wheelers

The most typical vehicles in this category are *rickshaws* or *TukTuks*. They are extremely popular in countries like India, Thailand, Nigeria, Cambodia, Vietnam, and Malaysia as taxis for locals and tourists. In Indonesia, they are found in big cities like Jakarta, but in Bali and smaller locations, residents typically use scooters or cars. In India, they are used in both large cities and smaller villages. These are slightly more powerful than standard scooters, at around 200cc, featuring two rear wheels and a small cabin. Apart from transporting people, three-wheelers are a popular option for transporting small amounts of goods.

Figure 5.1, 5.2 & 5.3
A Father and Son With Their Rickshaw in Delhi, India
A Person on a Lat Night Drive in Shanghai, China
Someone Driving a 350cc Royal Enfield Through the Tiny Streets of Varanasi, India



5.1.2 The Informal Refuelling Economy

Bhatia and Angelou (2015) state that the fuel needed to run transportation equipment is usually supplied along the routes in almost all cases. Weinert et al (2008) argue that this is the major reason *ICE motorcycles* remain the dominant choice for personal mobility in most of Asia. Although this source is nearly 20 years old, it resonates with observations in Indonesia, where the possibility of refuelling a scooter every few hundred meters offers unparalleled convenience.

Beyond convenience, the consumer price of fuel is often artificially lowered by government subsidies, particularly in oil producing regions like Nigeria. This makes petrol more competitive than cleaner energy alternatives (IFC, 2019). In countries like Nigeria, the infrastructure for energy products is highly visible; small gasoline generators are sold in retail markets and operated in dense clusters where they can be seen leaking fuel and lubricating oil directly into roadside stormwater trenches (IFC, 2019).

Previous travels in Thailand, Laos, India and Cambodia, as well as a research trip to Indonesia, provided first-hand experience with local mobility via rented scooters. While a low fuel level initially caused slight anxiety, this was misplaced because roadside refuelling options typically appear within a minute. Cheap petrol allows for another 200 plus kilometres of travel regardless of whether one is in the city or the mountains. The *informal refuelling network* has nestled deep into the furthest reaches of society.

In Indonesia, roadside shops or restaurants are usually called *Warung*, which literally means roadside stall. These locations offer quick refuelling options like the *Pertamini* from Figure 5.5. Another phenomenon you often see is racks holding glass or plastic bottles filled with petrol where users can refill a bike using the accompanying funnel.

This convenience sets the bar for transitioning to electricity as a fuel. For electricity to replace petrol, it must match this level of frictionless, brand agnostic distribution.

Figure 5.4
Roadside Warung Bottles Fuelstation

Figure 5.5
Pertamini Roadside Warung Fuelstation

5.2 The Battery as the Engine

5.2.1 The Three Parameters of Power

Initially, when comparing *ICEVs* (Internal Combustion Engine Vehicles) with EVs, one might assume the electric motor and the ICE are similar technologies. It might seem that since the battery stores energy, it is equivalent to the fuel tank, but in reality, this is a little different.

In ICEs, power or torque are often stated in terms of the cylinder head's displacement volume. The more *cubic centimetres* (cc), the more gasoline can explode in the cylinder to create rotational momentum in the axle. The ICE, therefore, first transforms chemical energy into air expansion, which is then translated into motion.

EVs work differently, as the motor transforms electrical current into motion using two magnetic spools. The actual current is the equivalent to the expansion in the ICE. As discussed in the power triangle, the voltage of the battery is what causes its real power. The most logical comparison of battery voltage (V) is therefore the displacement in the cylinder head (cc).

However, the battery also serves as the fuel. In the ICEV, the fuel tank is not considered part of the engine, but in the EV, the fuel tank is what determines the power. Traditionally, the power or momentum of the ICE can be expressed in *HP* (Horsepower), but when comparing with EV, it is more logical to use the output in Watts.

5.4.2 The Mobility Requirement

The majority of bikes observed in Bali were Honda and Yamaha types. It is estimated that at least 90% are the *Honda Beat*, *Scoopy*, and *Vario*, or the *Yamaha PCX*, *NMAX*, or *XMAX*. These bikes all range from 110 to 160cc. While these specifications may seem like overkill for solo city transportation, they are necessary for carrying a family of four up a steep hill or for transporting heavy loads to support livelihoods in the Global South.

Table 5.1 compares different light vehicles, ranging from a 50cc moped to a 650cc heavy twin bike. For bikes on this scale, the comparison is to an equivalent voltage if the vehicle were electric. A vehicle could always carry more batteries in series to multiply the voltage. Based on insights from China, many battery-swap systems use 50 or 72V batteries.

As discussed in 3.1.3 and 3.1.4, the system's efficiency increases exponentially with power. It was also noted that the norm for stationary ESSs is 96V, as this strikes a balance between power and efficiency. Smaller systems like the EcoFlow use 48V.

Based on the power requirements for mobility and the efficiency requirements for a home system, 72V would be the perfect balance.

ICEV: Fuel Tank (L) → Engine: Carburetor → Cylinder Head (cc) → Rotational Momentum (HP/W)

EV: Battery: Storage (Wh) & 'Engine': Power (V) → Electric Motor / Rotational Momentum (W)

Table 5.1 ICE displacement and Voltage Equivalent (Gemini 3.1 Pro was used to make the comparison between cc and V)

Example Models		Application Context	Peak Power	ICE Displacement	Voltage Equivalent
	Tiger TG950 (reference)	Small BUGS. LED Lights, Phone charging, Fan, Household appliances	0.8 kW	63cc	12V
	Moped, Blue License Plate in NL	Flat city cycling paths; 25-35 km/h limit.	1.5 kW	50cc	36V
	Moped, Yellow Licence Plate in NL	Urban street commuting; 45 km/h limit.	3.0 kW	50cc	48V
	Scooter, Honda Beat, Honda Scoopy	Agile city transit; Hills possible but stressed.	6.5 kW	110cc	60V
	Scooter+, Honda Vario 125	Suburban use; Highway limit; Reliable hills.	8.2 kW	125cc	60V - 72V
	Utility Bike, Yamaha NMAX, Yamaha PCX, Yamaha XMAX	Professional taxi; High-torque cargo; Hill ease.	11.0 kW	150cc - 160cc	72V
	Three-Wheeler/ Rickshaw/ TukTuk, Bajaj RE, TVS King	High-torque passenger taxi; urban cargo.	9.0 kW	200cc - 240cc	72V - 96V
	Touring Bike, Royal Enfield 350 (India)	Long-distance cruising; high-torque comfort.	15.0 kW	350cc	96V - 110V
	Enduro Bike, Royal Enfield Himalayan 450	High-speed highway (130 km/h+); rough terrain.	30.0 kW	450cc	120V+
	Heavy Twin Bike, Royal Enfield Interceptor 650	High-speed highway; Performance overtakes.	35.0 kW	650cc	144V+

5.3 The Swapping Paradox

5.3.1 Battery-as-a-Service (BaaS)

What became apparent during the visit to China is that it has turned into a massive digitised convenience culture. Your livelihood is supported 100% by apps like *WeChat* and *Alipay*, from transportation to ordering food at restaurants to booking a train. Without a smartphone or internet, you cannot do anything, often not even open your front door, which is locked with a smartphone app.

So to prevent running out of battery power, you can find a wide range of power bank sharing stations, as you can see on the left side of Figure 5.6. Much like the Warung fuel stations, these power bank stations are located every couple of meters or so. Each restaurant, shop, hotel, or café has at least one brand available to use; for example, the yellow brand is the most widespread. This convenient system makes owning a power bank yourself almost invaluable.

The same is happening with scooter batteries. *Battery-Swapping Stations* (BSS) are facilities that allow EV users to quickly exchange a depleted battery for a fully charged one, typically within seconds or minutes. Swapping is significantly faster than charging, which currently takes at least half an hour. This allows drivers to continue their journey almost immediately, effectively mirroring the experience of refuelling at a gas station. The swapping stations often use a generic metal locker system that can be opened using a QR code.

Although there are already quite a few swapping stations across multiple brands in China, for now, they are only used for B2B, especially by delivery drivers. This also resonates with the current implementation of swapping stations in Indonesia, which are mainly focused on *Gojek/Grab* riders (Appendix I, Interview 1).

This development is still in the early adoption phases, with China and Taiwan currently in the lead. Taiwan is home to the world's densest network of swapping facilities, led by the *Gogoro Network*. Their *GoStations* have become so widespread that they now outnumber traditional fuel stations in some areas. By ensuring a dense network of stations, BSS technology alleviates consumers' fear of being stranded with a dead battery, much like the informal refuelling stations in the Global South.

The system has a couple more advantages. Firstly, many BSS models use a *Battery-as-a-Service (BaaS) construction* that separates battery ownership from the vehicle, reducing the consumer's initial purchase price. Secondly, fast charging a battery can shorten its lifespan. Batteries at a depot can be charged at lower power levels, which is less stressful on the battery chemistry and can result in longer cycle lives. Thirdly, stations act as energy storage hubs that can support the electrical grid. Through *Vehicle-to-Grid strategies* or V2G, stations can discharge excess energy during peak-demand periods, known as *peak shaving*, and recharge during off-peak hours when electricity is cheaper and more abundant.

A downside is that building and maintaining a network of stations requires significant upfront investment and land rental. By combining BSS with solar energy, peak shaving can generate an additional revenue stream for the BaaS company, effectively lowering or offsetting logistical costs. Another downside is that the system requires more batteries than vehicles ensuring a charged unit is always available for the next customer.

Figure 5.6
Battery-swap Station in Suzhou

Figure 5.7
A handful of different proprietary BSSs
(Ahmed, 2025) (Alibaba.com: Manufacturers, Suppliers, Exporters & Importers From the World's Largest Online B2B Marketplace, n.d.) (Battery-swapping Intelligent Cabinet, 2026) (CoLtd, n.d.) (Hunan Chalong Fly Technology Co., Ltd., n.d.) (Parikh, 2025) (Randall, 2024) (Tycorun battery-swap station, 2023)

5.3.2 The Paradox of the Market

As mentioned in the previous paragraph, many different brands of battery-swapping stations were spotted in China. We also visited BTR, a factory that makes its own OEM battery and swapping cabinets. To use that generic battery, you need a scooter that fits its dimensions. To realise that, they use a brandless off-the-shelf scooter with a custom fitting for that battery. As I understand it, based on an interview with Interviewee 1, a battery-swapping company that emerged in Bali, *Alva*, also used a generic scooter from China under its brand. Figure 5.7 shows that the market is saturated with many different types of EV batteries that fit only specific brands and generic motorcycles. Most of the batteries are quite primitive and must be placed in a locker and physically connected to a connector. There are a couple that are better designed, especially the *Gogoro* and the *Honda e:swap*, which stand out from the competition. They are both around 50V with a 126 to 185Wh capacity and use NMC cells.

Gogoro

Briefly introduced in 5.3.1, Gogoro is a Taiwanese company that has grown into one of the industry's major players, at one point capturing over 80% of Taiwan's electric scooter market (Aqidawati et al., 2020). Chien & Hsieh (2025) note that some recent reports state that the network includes approximately 2,520 stations. They also state that these stations can discharge excess power back into the grid during peak demand periods, potentially reducing peak electricity consumption by 110.1%. Besides Taiwan, they're also active in other countries, including Indonesia, India, China, the Philippines, and even Germany and France. Gogoro's acceptance rate among users exceeds 80%, driven by the aesthetic quality of their design and the convenience of the swapping process (Huang, 2020).

Their scooters have many sensors and a full digital dashboard, and they are managed via a smartphone app that provides onboard diagnostics and station navigation. The battery itself uses 18650 or 21700 cells and is encased in a strong extruded aluminium shell (Chien & Hsieh, 2025). Where they really differ from the competition is in the ease of use. The batteries can be slid into the slots in any of the four possible orientations and are powered by the proprietary *concentric connector* (Figure 5.8). This allows the battery design to be clean and minimal, appealing to a wider range of people. The whole swapping process takes about a minute, which is even shorter than refuelling a petrol bike (Life Where I'm From, 2023). They've truly nailed the balance of aesthetics, convenience, and simplicity in their technology, setting the bar for the battery-swapping industry. Recently, they've also opened up their BaaS for third-party EV manufacturers (CNBC International Live, 2024).

Figure 5.8
The Gogoro Coincentric Connector
(Williams, 2016b)

Honda

Honda is arguably one of the biggest engine manufacturers of all time. Since the battery is inevitably replacing the engine (5.2), it makes sense that Honda has invested heavily in developing solid technology for the next generation. Much like the Gogoro batteries, they're smart and connected, using an app to display information and find swapping stations.

They aren't as widespread as the Gogoro system yet, mainly active in India (Honda e:Swap, 2023b), where they partnered with Hindustan Petroleum Corporation and metro stations. In Indonesia, they partnered with Pertamina (Figure 5.4). A smart card is used at the station to start the swapping process. Much like Gogoro, the batteries slide into slots without opening a cabinet door or physically unplugging/plugging them in. Unlike Gogoro, the Honda battery uses a pinned blind mate connector, which does not allow orientation-agnosticism. The battery is encased in hard plastic and has a guiding rail, so it can slide in only one orientation.

Honda's power lies in its global networks. Where Gogoro needed to start from scratch, Honda is a familiar name in the furthest regions of the Global South.

Alongside the battery, Honda has released multiple EVs ranging from mopeds up to three-wheelers and small cars (Honda Introduces Initiatives for the Utilisation of Honda Mobile Power Pack, Portable and Swappable Batteries, n.d.). They also launched a smart charger and two product concepts for micro storage and stationary storage using the swappable batteries, but these haven't been released yet (Honda Power Pod E: | Honda 公式サイト, n.d.).

It is clear that Honda paves the way to capitalise on the entire swappable storage energy market, from small-scale home storage and stationary home storage to peak shaving, to personal transport and commercial transport. They even partnered with companies that use the system for excavators, harvesting robots, floodlights and other professional power applications.

Figure 5.9 & 5.10
Honda e:swap (Elvidge & Elvidge, 2020; Honda e:Swap, 2023)

5.3.3 The "Open" Walled Gardens

Back in 2022, the four major Japanese motor manufacturers, *Kawasaki*, *Suzuki*, *Honda* and *Yamaha,* started a new company called *Gachaco* (Gachaco, Inc., n.d.), also called *SBMC* (Swappable Batteries Motorcycle Consortium). The goal of this company is to create one "open standard" for battery-swap systems: the Honda e:swap system. They say that Gachaco aims to contribute to a decarbonised, "recycling-oriented society" by building a battery-based power supply network as infrastructure for electric mobility, which all electric mobility users can use safely without worrying about running out of battery.

The Honda swapping stations started rolling out in 2022. The other applications, as discussed in in the previous paragraph, are still mainly in a conceptual phase. This initiative to create a single open standard is a very good development that resulted from the incredible market fragmentation discussed in 5.3.2. However, open in this case means that companies can partner with Honda to use its system. In the meantime, Honda holds approximately 500 patents to keep their swapping system under their own control. Similarly, Gogoro has over 1,100 patents to protect its proprietary hardware. Both companies effectively act as walled gardens, using these patent portfolios to ensure their battery technology remains exclusive and protected from outside use (no sources state these numbers directly; *Gemini 3.1 Pro* was used to search for patents and count the filings). It is important to be aware of the most relevant patents to avoid infringement when designing a repairable open-source standard; a selection of these is provided in Appendix J.

From a capitalistic perspective, this makes perfect sense. Protecting your technology not only means you own the BaaS, but also means you can capitalise fully on the service. If the battery is a walled garden, only Honda-certified mechanics can service the system. But this is in complete contrast with the open system they want to create. Some of the patents really point to irreparable product architecture, such as pouring thermal potting glue to seal all the batteries into a solid block of epoxy-like material. Other patents are meant to maintain competitive advantage, such as Gogoro's *orientation-agnostic connector*.

Based on the research in the previous Chapters, here is the hypothesis for the physical construction of the batteries: They are built for manufacturing efficiency. The housing is completely tamper-proof and cannot be opened, even by authorised service personnel. The battery cells are glued into place, much like the Bosch batteries discussed in Appendix E. When the battery is at the end of its life, the optimal choice is to recycle the whole unit, meaning it is shredded. This resonates with the "recycling-oriented society" that Gachaco aims to create. This is a society that is better than the petrol-consuming one, but this is not the circular, carbon-neutral society that we need to move to. Carbon neutrality can be realised by using sustainable electricity and peak-shaving technology, but the batteries are still linear walled gardens. Yes, they can invest in recycling technology, but that does not mean that they make optimal use of the value chain.

5.4 Chapter Conclusions

RQ5.1 Why is light mobility so essential for the economy in the Global South, and how does the battery take over the role of the engine?

Light vehicles are absolutely essential to supporting the livelihoods of people across the globe, especially in developing countries in the Global South. Public transport is bad or simply does not exist, and people can't move around in a flexible way without their vehicles. In a way, it reminds me a lot of how owning a pedal-bike in the Netherlands is imminent. Someone told me that in Indonesia, kids learn to ride a motorcycle when they're 8 years old, since you don't need a license for it. Children are often sent to do the grocery shopping, even if the bike in question has a top speed of 100+ km/h.

When people don't own light vehicles themselves, there is a network of cheap shared transport, such as rickshaws in India and Nigeria. For some people, their vehicle is not merely transport, but it is their life support. They run their whole business from the back of their bicycle. Even when people are not connected to a reliable electricity grid, they seem more likely to own a motorcycle just to get around.

In China, I could not spot a single bike still using an ICE because they have been outlawed in the city. The opposite was true for Indonesia. Although I was told that companies now sell them, I did not spot a single LEV on the streets. This contrast was very interesting to notice, especially the context that surrounded it.

RQ5.2 How does the shift to a Battery-as-a-Service (BaaS) model change the way users interact with their source of mobility?

In Indonesia, gasoline-powered bikes are supported by an extensive network of informal Bengkel mechanic workshops, and you can refuel your bike almost every few meters at a Warung using prefilled PET bottles or at Pertamini fuel stations. It became apparent which types of motorcycles are the most popular. After which they were compared with to the power of an electric system. In China, you can recharge your EV at roadside charging stations or subscribe to a battery-swapping service if you're eligible for that. In China, the swapping stations are mainly focused on B2B solutions, but in Taiwan, Gogoro is leading the way with a consumer-centric system. There, swapping stations outnumber fuel stations, and consumers can swap out their batteries in under a minute.

RQ5.3 How do the proprietary designs and walled gardens of big manufacturers impact the development of a repairable and open energy infrastructure?

Besides Gogoro, the other promising player is Honda, a very trusted engine manufacturer in the Global South. With their heavily patented battery system and deals with Suzuki, Kawasaki and Yamaha, they want the world to keep using Honda engines, even if the engines become batteries. But the transition is a chance for them to reclaim the part of the industry that they lost to the informal economy: *the local mechanic*. By making their battery a standard, they can also capitalise on the service that the new market will inevitably need in the foreseeable future.

Companies like Gogoro and Honda realise that replacing cells in a battery pack is not worth the extra R&D and reverse logistics. They are operating in a sustainable industry but with a linear mindset. The batteries that they produce can never be opened, and the precious metals like *Lithium* and *Cobalt* can never be separated. sustainability and carbon neutrality might be important drivers, but they're still heavily overshadowed by profit. They are marketing their BaaS as an "open system", but under the surface, their products remain black boxes.

Towards a Clean & Open Solution

6

Phase 1: Analysis

6.0 Introduction

The goal of Chapter 6 is to synthesize the findings of the preceding chapters into a product concept formulation. To support this concept formulation, **RO6.1** is *to synthesize the socio-economic drivers and technical needs of Tier 3-4 users*. This objective is researched by comparing the Bali interviewees' views across subject clusters. These insights are then used for the *Socio-cultural Dimensions framework* (SCD), *Culture Mapping with the Onion Model*, and two distinct *User Personas*.

The second half of this chapter focuses on formulating the concept as a hybrid solution between micro storage and the mobility sector as a product concept for further development. This corresponds to **RO6.2**: *To synthesize the technical benchmarks from Chapter 3, 4 and 5 with the user research into a viable, feasible and desirable product concept.*

Research Objectives

RO6.1	To synthesize the socio-economic drivers and technical needs of Tier 3-4 users.
RO6.2	To synthesize the technical benchmarks from Chapter 3, 4 and 5 with the user research into a viable, feasible and desirable product concept.

Research Questions

RQ6.1	Which are the specific power-use profiles, mobility patterns, and repair expectations of Tier 3-4 productive users (SMEs and households)?
RQ6.2	Where is the gap between technical findings and persona needs, and what design opportunity does this create?
RQ6.3	How can the proposed product concept be structurally mapped to function as a central hub bridging micro-storage and a mobile battery-swapping ecosystem?

6.1 Contextual Analysis of Bali

6.1.1 Insights from the Bali Interviews

A total of 5 people were interviewed in Bali. The interviewees were randomly selected, aged between 20 and 40, and living their day-to-day lives. The interviewees differ widely in financial assets and livelihoods. The recorded interviews were transcribed, summarized and clustered using *OtterAI, Gemini 3.1 Pro* and *NotebookLM*. Appendix I provides a broad overview of all the interviews and their connections. All interviewees gave explicit approval for the interviews to be recorded and for the use of *Personally Identifiable Information* (PII), but the data have been anonymised nonetheless.

Context Mapping

A few days before the interviews, the interviewees received a *sensitising booklet* (Appendix D1). These homework booklets helped the interviewee think about the relevant topics. The filled-out booklets can be found in Appendix K. Although a translator was present, the *preference booklets* (Appendix D2) were especially valuable given the language gap. The format of a preference booklet was a great *probe* for discussions. The *topic cards* (Appendix D3) were used less since the interviews flowed very well with just the preference booklets.

For a complete summary of the relationship between the interviews, as well as individual summaries of all the interview can be found in Appendix I.

6.1.2 Socio-Cultural Dimensions for Design

As described in Chapter 2, the *Socio-cultural Dimensions* (SCD) framework is a visual tool for analysing how cultural values shape people's perceptions and use of products (Van Boeijen & Zijlstra, 2020). In this instance, it is used as a synthesising tool for the interviews conducted in Bali.

When interpreting the framework, it is important to note that it is a **generalisation** at both the individual and societal levels, as it essentially quantifies qualitative data. For instance, four of the five participants insisted on the “one man, one bike” rule, while one participant promoted sharing a bike with the family. The result in the framework is a heavily individual-leaning representation. Secondly, on a societal level, this framework can never encompass multiple cultures within a country, let alone across the Global South. It gives an impression of the local context in which I conducted the research, but should not be interpreted as the absolute truth for the entire target audience. With this caution made clear, let's proceed to the argumentation for each dimension.

Figure 6.1 & 6.2
Interviews

- *Hierarchy:* "Big Dog" brands like Honda and Yamaha hold the formal market; the daily reality is a low-hierarchy network of local mechanics. Users value the informal network for its accessibility, which effectively bypasses corporate hierarchies.
- *Identification:* Ownership is the norm for autonomy. The "one man, one bike" culture defines personal freedom and economic participation. Sharing models (Zipcar/ sharing apps) are consistently rejected because they fail the "instant availability" and customisation needs of the Balinese user.
- *Time:* There is a clear "Solar Aspiration" toward a green future, but it is tempered by the historical reliability of petrol-based infrastructure and by the current adoption being dictated by unattractive ROI and a lack of government initiatives.
- *Aim:* The primary driver for energy storage is business continuity and "circulating cash flow" for SMEs. The priority is a tool that achieves operational stability during grid blackouts.
- *Gender:* Despite universal mobility needs, the "corrupt government" and society are highly patriarchal. The systemic "danger" for women on the road suggests that while use is equal, the supporting infrastructure and safety norms are not.
- *Space:* Fear of theft and pest damage (rats) keeps technology strictly protected and locked. Charging is preferred at home rather than in public stations to ensure the security of the asset.
- *Attitude:* ESS and scooters are primarily viewed through the lens of utility and "duty" to maintain one's livelihood. The "roar" of the engine provides some emotional fun, but "comfort" and "silence" are increasingly seen as functional duties.
- *Expression:* The "Price of Silence" reveals a strong emotional reaction to the "annoyance" of generator noise. Users are willing to pay a premium specifically for the peace of mind and comfort that silent technology provides.
- *Truth:* Rules and warranties are understood as "Absolute," but "Contextual" urgency usually wins. If the product breaks, a user needs their business and livelihood back immediately. They will void a product warranty without hesitation if a local, quick fix gets the job done.
- *Financial Model:* For grid power, the *Pulsa* (token) system is a cultural pillar, prioritizing manageable, weekly cash-flow management over large, intimidating bills. Meanwhile, for material purchases, people prefer lump sums because of the deep-seated distrust in instalment plans.
- *Maintenance Philosophy:* While authorized centers exist, the Bengkel culture, taking "little pieces of things and making them work", is the dominant lifeline.
- *Institutional Trust:* Innovation in the *shadow grid* often starts illegally; the formal system is seen as a "legal portal" that only catches up once the economic benefit is proven.
- *Environmental Resilience:* The fear of "Banjir" (floods) makes electric tech seem fragile; users trust gasoline because they know how to manually fix a submerged engine.

Next to the dimensions for the contextual analysis of Bali, A relative dimension for the Netherlands was added as a reference point. This is not based on academic research, but on intuitive experience. It is useful to see the contrast between the two contexts, but it is important to keep the relativity of the generalisation in mind when interpreting Figure 6.3.

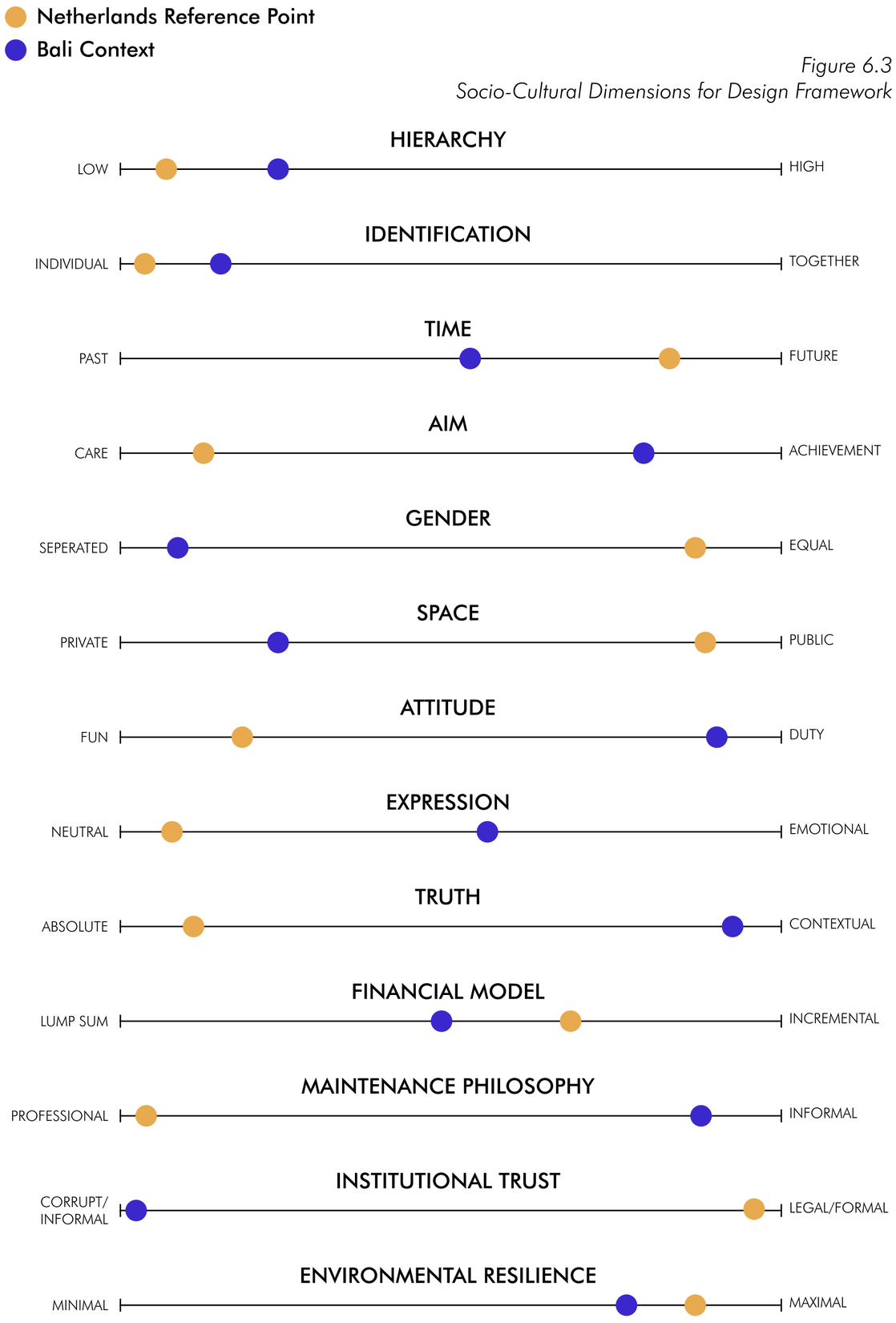


Figure 6.3
Socio-Cultural Dimensions for Design Framework

6.1.3 Culture Mapping with the Onion Model

Culture Mapping with the Onion Model is a method for visualising culture as a series of layers, moving from visible artefacts on the outside to deep-seated values at the core. Here, the concepts previously discussed or visualised are organised according to the hierarchy. The visual is a simplification of what the culture entails (Van Boeijen & Zijlstra, 2020). The sole purpose of the visual is to serve as an inventory of relevant values and related practises. Just as the SCD framework should be interpreted with caution, the visual should be interpreted with caution. It is an extreme generalisation of a system that is too complex to convey in a report.

All Symbols, Heroes and Rituals sprung from local observations, sensitizing booklets, interviews and the research in the previous chapters. For instance, the "Neighbour" can be spotted in the returned sensitizing booklets in Appendix K.

Some of the Symbols, Heroes and Rituals that have not been explained in prior chapters are highlighted at the bottom of the figure.

Figure 6.4
Culture Mapping with the Onion Model

6.1.4 User Personas

The SME Entrepeneur

Name: Agung
Age: 45
Religion: Muslim
Home: Lives in a village near Denpasar with wife and son.
Role: Owner of a B2B Wooden Crockery & Furniture Business

Agung He manufactures, buys and sells wooden restaurant supplies (plates, cutting boards) and furniture for B2B clients. To optimize costs and garage space, he shares a single *Yamaha Nmax* with his wife and son.

He wants off-grid solutions to ensure his workshop remains operational during grid blackouts. He needs mobile power for electric tools when working on furniture installations at client sites. He aims to eventually power his entire home and shop with solar energy.

He finds the high upfront cost of full solar/ battery systems prohibitively expensive for a growing business.

He avoids proprietary technology because he cannot afford to wait weeks for official manufacturer service. He views the national grid as an expensive utility that lacks the reliability his production requires.

He prefers buying second-hand equipment and having it serviced by a local Bengkel or fixing it himself. He has already installed two small solar panels for lighting as a Proof of Concept for his business. He prefers daily or weekly installments over large lump sums to keep his circulating cash flow healthy.

Figure 6.5
Agung (Nano Banana Pro / Gemini 3.1 Pro)

The Mobile Professional

Name: Ibu Putu
Age: 32
Religion: Christian
Family: living with her family in an urban Denpasar neighbourhood.
Role: Manager at a Billiard/Pool Venue

Her family follows a "one person, one bike" standard; she has operated her own *Honda Scoopy* since age 12. Her mobility is essential for her late-night shifts and managing household errands.

She values "Big Dog" brands like Honda or Yamaha because she trusts their established service networks. She requires technology that is physically secure and can be locked to prevent theft in public areas. She seeks a "silent" and "simple" daily environment, preferring batteries over noisy generators.

She has a deep aversion to installment plans that increase the total price, preferring to save and pay in cash. She fears the risks associated with electric vehicles during "banjir" (floods), specifically electrocution or short circuits. She finds driving in heavy road dust unhealthy and prefers the "cleaning" effect of the rain, despite the hassle.

She is highly comfortable using the pulsa (token) system to manage and monitor her home electricity consumption. She insists on charging all batteries inside the home to keep them out of sight and protected from theft. She covers her bike to protect the paint and would carry an extra battery if swap stations were unavailable.

Figure 6.6
Ibu Putu (Nano Banana Pro / Gemini 3.1 Pro)

6.2 The Hybrid Opportunity

6.2.1. Bridging Micro Storage and Mobility

The previous Chapters framed the mobility and autonomous energy sectors as overlapping at both the technological and use levels. On the Open/Dirty side, the ICEs of the generator and the motorcycle are phrased as two sides of the same coin. It is just the last step of the chain that differs: generators generate electricity, while motorcycles generate propulsion. On the Clean/Open side, things are also very similar. Home storage systems and EVs function under the same triangle of power rules that define the system's power and efficiency. There, the difference again lies in the final step of the chain: home storage systems use electricity to power external appliances, whereas in EVs, that energy is used for propulsion.

Demonstrated by China's transition to LEVs and driven by the global need for lower emissions and government initiatives, the transition to EVs is imminent. Local people in Indonesia have expressed the belief that all vehicles in the country will be electric in the future. The previous Chapter demonstrated the widespread use of light vehicles in the Global South and their absolute necessity for supporting local livelihoods.

The need for local, autonomous energy supply was demonstrated in the introductory Chapter, which explained that people rely on BUGS for their daily needs due to poor or weak grids. These BUGS run on the same fuel as the scooters, making petrol the universal energy supply that drives the growth of local refuelling economies and informal, non-authorised repair economies. The parallel to the efficient energy distribution of petrol is the upcoming battery-swapping systems for EVs. While right now mainly focused on B2B, they are the most likely future replacement for these informal economies.

Because of the widespread use of personal Dirty & Open mobility and the need for a clean replacement for local autonomous energy, it is evident that a *hybrid solution* is a compelling opportunity. A hybrid solution for a Clean/Open system would mean ultimate local empowerment in energy use, not only for home appliances but also for the mobility market. This would result in a blend of the cleanliness of micro storage, the ruggedness and mobility of a generator, and the flexibility and utility of a battery-swap system.

Figure 6.7
Someone in Bali Lighting His Beach-Warung with a Lead Acid Battery

6.2.2 The Economic Enabler

Because of the developing nature of many countries in the Global South, it is important to pay extra attention to the financial viability of a product like this. Although the prices of solar have been declining at an enormous rate (Figure 1.5), storage system prices still cannot compete with those of a cheap generator. Also, given the lack of serviceability and reverse logistics for black-box product architectures in storage systems, it is not the most logical financial investment at the moment. But a different financial approach that has been proven in the solar industry could offer a solution. This is how a Clean/Open system could be viable in the Global South.

- *Lifetime is important:* The interviews repeatedly showed that people, at least in Bali, care about a product that is higher quality and lasts longer, because that often means it is better serviceable in local economies. Even if the product is more expensive, if its quality and lifespan are better, it is worth saving up for the better product.
- *The Instalment Rejection:* Some interviewees explained that it can be financially challenging to buy a new bike or battery, often leading to the need to adopt an instalment plan to pay it off, especially for starting businesses. But there is a deep-seated distrust of instalment plans. They say that instalment plans are more expensive in the end, with a lump of the total sum going to interest. One interviewee still preferred this, since "circulating cash flow" is preferred in managing a business.
- *Technical Level:* The whole purpose of this project is to design an alternative that rejects the proprietary nature of many products in this category. The open-source repairable nature of this product concept is encouraging the transition of the informal economies from ICEs to EVs and batteries.
- The *Energy Token (Pulsa)*: At an integrated level, Indonesians are already used to a continuous *micro-instalment* system for grid energy. Every week or month, depending on their plan, they must buy energy tokens at a Warung and use a pin pad at home to top up their prepaid energy. This system is so ingrained that distrust does not exist there. Paying for electricity is just as normal as doing groceries, and even the kids share this responsibility from time to time.
- Owning > Sharing: All interviewees rejected sharing bikes. It is unclear whether this also extends to sharing batteries, as in the Gogoro system, but it was made clear that, at least in Bali, people strongly preferred ownership due to the flexibility.

The Proposal

A transparent product requires a transparent financial model. 1.3.2 introduced the Pay-as-you-Go system that has been widely adopted in the solar industry. This is essentially a less obscure micro-instalment plan with more autonomy. It also reflects the Pulsa system since electricity stops working if the user does not pay.

In the PAYG system, there is also an inflow of subsidies from "western" countries and investors who use the system as a *carbon sink* or for *Corporate Social Responsibility* (CSR). To shed deep-seated distrust in instalment plans, there is a need for a PAYG system with a *transparent dashboard* that shows exactly where money flows, how much CO2 is compensated for, or how much money is generated with peak shaving. Transparency should extend from the back end to the front end, allowing investors to see the impact of their investment and users to see how much they save and how much electricity they generate. Biosphere Solar is currently developing such a PAYG system called *Corporative Finance*. This system is designed to work with their panels as well as with future ESSs.

6.2.3 Concept Vision: Node Bawa

The concept of the *Node Bawa* starts making sense when seen in it's entire functional context. Figure 6.8 shows the concept in the centre. The top half of the figure could be seen as a traditional stationary ESS. The bottom half is the swapping system that we saw in Chapter 5. The Node Bawa is a hybrid solution between the two sectors. This figure shows why it is called the Node, meaning *a central point in a network*.

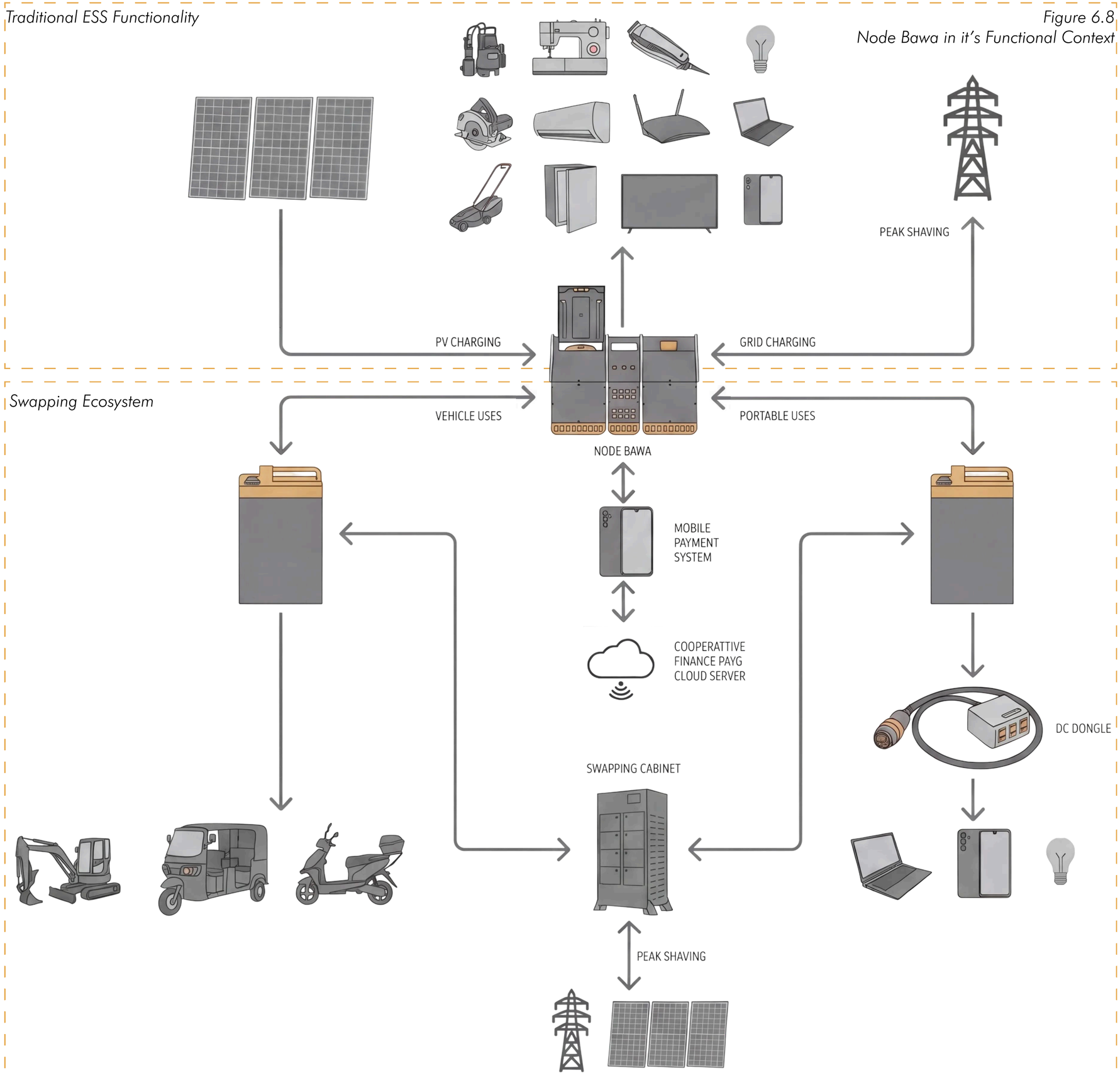
Note that in previous paragraph it was discussed that in the researched context, ownership is preferred over subscription based swapping. In this figure, a swapping cabinet was still added, because it was not validated that ownership is preferred in the whole context of the Global South. Also it opens up the possibility of having *community-owned* swapping cabinets for living situations that don't allow for individual PV charging.

In figure 6.8, peak shaving (5.3.1) has been simplified by annotating where in the chain that would take place.

Apart from rickshaws and scooters, an excavator was added to show that swappable batteries can power more than just mobility. Honda is also doing this with their e:swap system.

Figure 6.7 shows someone in Bali lighting his beach-Warung with a lead acid battery. To account for these kind of low-power mobile uses, a *dongle* can be used. Output of this dongle is limited, since the battery needs to be actively cooled to sustain higher loads.

Figure 6.8
Node Bawa in it's Functional Context



6.3 Chapter Conclusions

RQ6.1 What are the specific power-use profiles, mobility patterns, and repair expectations of Tier 3-4 productive users (SMEs and households)?

The first part of the Chapter started with a summary of the user interviews in Bali. The results have been processed using the two methods from *Culture Sensitive Design* by van Boeijen & Zijlstra (2020). The SCD framework provides a clear, but generalised, view of the target audience's norms and values. The Culture Map using the Onion Model offers a more visual approach to the cultural values and practises of people in this region. The most important insights from these parts are:

- Even though people seem to prefer lump sums for products, micro instalments are the common tool for energy access.
- People are usually willing to save up for a better, longer-lasting product.
- The bike is an essential expression of autonomous mobility and flexibility.
- People highly prefer silent batteries over generators, even if they are more expensive.
- There is a clear anticipation of and aspiration for more sustainable forms of energy, such as solar and EVs

RQ6.2 Where is the gap between technical findings and persona needs, and what design opportunity does this create?

The Chapter continued by synthesising all previous Chapters into a product concept. The clear gap that emerged from the extensive analysis is the need for a hybrid solution that bridges Tier 3-4 energy storage and the mobility sector. With battery-swapping becoming the most viable market standard because it mirrors the informal refuelling sector, and solar energy on the horizon, a product concept that applies to both makes the most sense.

RQ6.3 How can the proposed product concept be structurally mapped to function as a central hub bridging micro-storage and a mobile battery-swapping ecosystem?

Figure 6.7 maps the product as a central hub that combines the functionality of an ESS with the upcoming swapping ecosystems in the global south. In the top half, the core unit operates as a traditional stationary ESS (ESS), capturing input via PV charging or grid charging, and distributing power to common home and business appliances. It also integrates with the utility grid to perform peak shaving.

In the bottom half, the unit functions as a decentralized “node” for mobility and portable use. It outputs energy to power light electric vehicles (such as scooters, rickshaws, and small excavators) through standardized battery packs, or provides low-power portable energy to mobile devices via a specialized DC dongle.

Linking these two spaces is the cloud-based Biosphere Solar Cooperative Finance PAYG server and mobile payment system that is currently being developed. This system provides the financial transparency required to make the physical asset economically viable for users in the Global South.

Final Concept

7

Phase 2: Concept Development

7.0 Introduction

Chapter 6 concluded the analysis phase by conceptualising a hybrid solution that combines a micro storage system with swappable EV batteries. The concept, named Node Bawa, is essentially a modular micro storage system that does not have built-in battery cells but utilises the emerging battery-swapping market. Even though the market is still emerging, it is already oversaturated with different brands that all try to push their own version of the battery, swapping cabinet, and mobility.

To develop the concept, the Tycorun 72V LFP battery was chosen as the swappable battery for the system. At the time of writing this report, Biosphere Solar is in the process of partnering with this company to determine whether the company is interested in collaborating. However, since the partnership has not been definitively established, the battery will just be used as a brand-agnostic archetype for a swappable battery. But since one of the requirements is that the concept must be compatible with multiple battery types with minimal conversion effort, the choice for this specific battery is not of the utmost relevance.

The concept development phase of this project will take a *top-down* approach. Because the product concept comprises multiple modules, it is helpful to first provide a general overview. The first half of this Chapter provides that overview of the product modules and their configurations. The second half of this project situates the product concept in a few possible contexts across the Global South.

7.1 Final Concept

7.1.1 The Modules

To facilitate the various use cases of mobile and stationary energy storage across the Global South, the concept consists of separate, modular components. These modules can be connected to each other using a *modular coupling mechanism*. The modules are electronically linked by a *100A Chogori Banga X100 cable* designed for high-power applications such as these. Both modules convey the open-source licencing on the back of the concept, following the licencing agreement found in appendix A.

Inverter Module (Figure 7.2, left): Contains the Central Power Controller (3.1.2) and the user interface. It is the brain of the product. It is where the user interacts with the inputs, outputs and display.

Docking module (Figure 7.2, right): This module can be opened to load and unload the battery. It can be adapted to different battery types from different brands and is actively cooled. It is also designed so that water (from sudden monsoon downfalls) is separated from the electronics and can exit the system.

Roll Cage (7.1, bottom): Turns the system into a mobile, rugged powerhouse. The roll cage has robust caster wheels and 30mm metal bars. When the roll cage is used, it directly reflects the use cases of the generators in the Global South.

In theory, the system can be extended with more docking modules, but for Tier 3-4 users, one to two batteries would already suffice (Table 7.1).

Figure 7.1
The Different Configurations

Stationary Use Cases

Mobile Use Cases

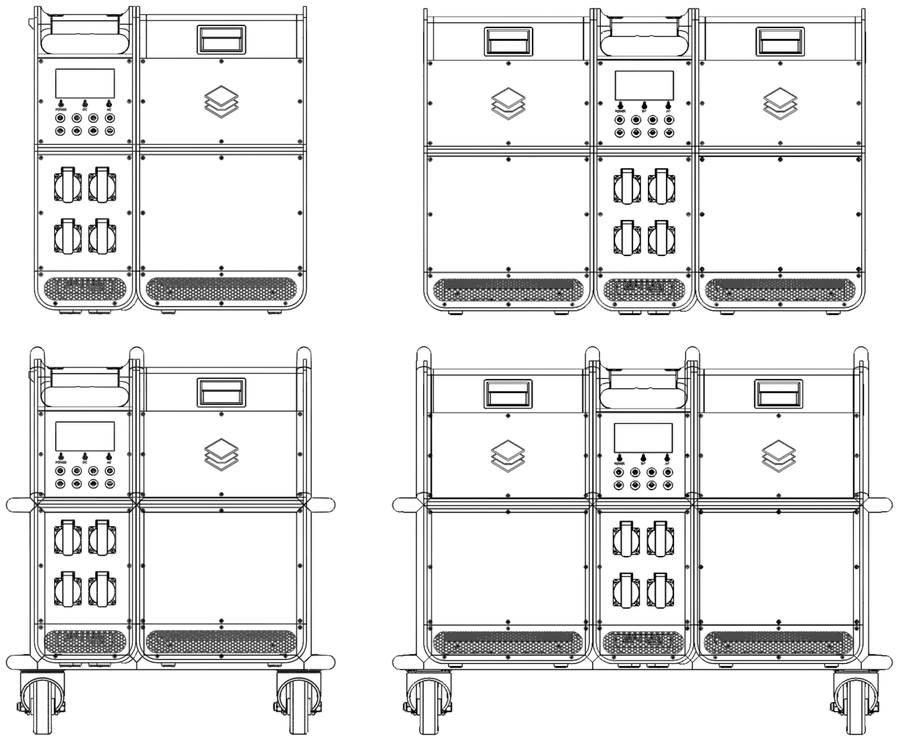


Figure 7.2
The Two Main Modules: Inverter and Docking

7.1.2 Choosing a Swappable Battery

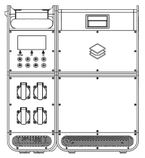
Chapter 5.3.1 showed the market saturation of different brands and types of swappable batteries. The midterm product concept (Appendix M) included a repairable redesign of a swappable battery and Appendix L2 shows the requirements for this battery. Although there is a need for a repairable, open-battery standard across the industry, the focus of this project must remain on facilitating local energy and mobility.

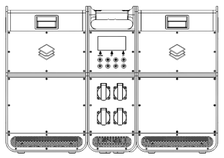
To develop a meaningful concept, the *Tycorun battery platform* was chosen as a starting point for designing the product concept. Appendix N shows a table comparing various battery platforms. Tycorun was chosen because, compared to competitors, Tycorun uses a transparent communication protocol and is open for collaboration with other companies. Specifically, the *72V 30Ah model* (Figure 6.7) was chosen (spec sheet in Appendix O). Apart from the 72V output established in 5.4.2, this model was chosen because it is relatively large. Designing the concept around a larger battery makes it easier to adapt to other types of swappable batteries in the future, maintaining the concept's open, modular nature.

Figure 7.3
Tycorun LFP 72V 30Ah Battery

Table 7.1 compares the power and storage capacity of the MTF (Chapter 1.1.3) against the configurations described in the previous paragraph. It is evident that the configuration using one battery falls within Tier 3, and the configuration using two batteries within Tier 4.

Table 7.1
Tycorun Configurations and MTF Requirements





	Tier 3	Tier 4	1 Battery	2 Batteries
Power Capacity (W)	Min 200 W	Min 800 W	2160 W (continuous)	4320 W (continuous)
Storage Capacity (Wh)	Min 1.0 kWh	Min 3.4kWh	2.3 kWh	4.6 kWh

7.2 Program of Requirements

7.2.1 Introduction

All the insights from the analysis phase have led to a *Program of Requirements* (PoR). Gemini 3.1 Pro was used to add more requirements that would be relevant for further development. The PoR intends to give a complete list for the *market-ready product* (TRL 9), not necessarily for the TRL 3/4 scope. The PoR describes what the product must be to succeed in the real world. The *Relevant Requirements* are displayed in black, whilst the Requirements for Further Development are displayed in grey.

The requirements have been split into four categories:

The *Performance* category focuses on the product's technical specifications. The choice of the swappable battery determines the power-related requirements in this category. It can be validated accordingly, but other requirements, such as AC-to-DC efficiency, are intended as input requirements for manufacturing parties for further development of the inverter module.

The *Repairability/Openness* category is focused on creating the horizontal distribution that was discussed in Chapter 4.

The *Safety* category is mostly relevant for future stages beyond the scope of this project. But some aspects, such as water separation from the electronics, are included in the concept.

The *Use/Ergonomics* category is the most relevant for this stage of the process and contains the most requirements that can be validated within this project.

PERFORMANCE

- P1 • Can supply a continuous power of at least 200W (minimum Tier 3, MTF).
- P2 • Has a power capacity of at least 1 kWh (minimum Tier 3, MTF).
- P3 • Can be charged through PV or AC inputs.
- P4 • AC and DC outputs can be turned on and off independently.
- P5 • Must be capable of charging at least 2 batteries simultaneously.
- P6 • Docking module is actively cooled when the battery reaches an ambient temperature above 40°C.
- P7 • Inverter is actively cooled to maintain ambient temperatures of 40°C.
- P8 • Internal batteries store off-peak grid energy and discharge it to swappable packs during peak demand.
- P9 • Is compatible with 48-72V batteries.
- P10 • AC-to-DC conversion efficiency must exceed 92%. to minimize thermal waste and maximize cost-effectiveness.
- P11 • Operational capability in ambient temperatures ranging from -20°C to +60°C.

REPAIRABILITY / OPENNESS

- R1 • Has exposed and easy-to-reach screws.
- R2 • Does not make use of single-use snap fits.
- R3 • Casing and internal modules must utilise a maximum of three standardised fastener types (e.g., Hex).
- R4 • Routine component replacements must be achievable by one technician in under 30 minutes.
- R5 • Docking module is compatible or easily adaptable to different swappable batteries.
- R6 • The physical architecture must look "understandable" and approachable to a local technician or operator.
- R7 • Does not make use of proprietary digital handshakes.
- R8 • Uses only open-source communication platforms.
- R9 • Must feature an external diagnostic port and over-the-air API.

SAFETY

- S1 • Uses IP-certified input and output ports.
- S2 • Electronics are separated from places where water could enter the docking module, for instance, when switching the batteries in the rain.
- S3 • Water in the docking module is redirected to exit the device.
- S4 • Ventilation inlets and outlets should not be easily blocked under standard use practises.
- S5 • Has an IP rating of at least IP54.
- S6 • The outer shell must achieve an IK10 impact rating.
- S7 • Must feature Ground Fault Circuit Interrupter (GFCI) protection and hardware-level surge isolation.
- S8 • A high-visibility, easily accessible mechanical shut-off button that instantly severs all grid and internal power routing.

- Relevant Requirements (TRL 4)
- Requirements for Further Development

Requirement Sources

- CHAPTER 1
- CHAPTER 2
- CHAPTER 3
- CHAPTER 4
- CHAPTER 5
- CHAPTER 6
- Gemini 3.1 Pro

USE / ERGONOMICS

- U1 • Has the footprint of a comparable, 4-stroke generator: 500-700mm squared.
- U2 • Has at least 4 AC outputs.
- U3 • Has at least 4 USB-C ports.
- U4 • Has at least 4 12V barrel ports.
- U5 • Has a DC PV input.
- U6 • Has an AC input.
- U7 • Has an interface for monitoring the batteries' SoC.
- U8 • Has an interface for monitoring the batteries' SoH.
- U9 • Has an interface for monitoring the time-to-full/empty of the batteries.
- U10 • The casing geometry must act as a protective bezel or shield for the interface components during handling.
- U11 • Interface must display relevant information pertaining to the PAYG financing model.
- U12 • Has swivel-style caster wheels.
- U13 • Ventilation filters can be removed and cleaned by using widely available tools.
- U14 • Makes use of colour-coded affordances to nudge the user on how to interact with the device.
- U15 • The physical architecture must be modular to accommodate different configurations that support the diverse livelihoods of people in the Global South.
- U16 • The locking handles must provide sufficient physical clearance for a secure, comfortable grip.
- U17 • The battery-specific sleeve geometry must allow for physical alignment tolerances, ensuring the battery guides smoothly into place even with minor entry variations.
- U18 • The clamping mechanism must provide adequate compression to keep the battery from vibrating within the sleeve.
- U19 • The lid must act as both an environmental shield when empty and an integrated mechanical feature during the docking sequence.
- U20 • The layout places light DC ports on top and heavy AC cords at the bottom to prevent cord tangling
- U21 • Features must be accessible without an external application.
- U22 • Must be able to drain batteries in parallel or separately.
- U23 • Details of the PAYG financing and the battery statistics are available in an app or digital dashboard.
- U24 • The interface remains highly visible in direct sunlight.
- U25 • Clear, distinct auditory feedback to confirm secure battery locking and unlocking.
- U26 • Active thermal management systems must not exceed 65 dB at a distance of 1 meter to comply with residential noise ordinances.
- U27 • The inverter module separates the internal electronics into three distinct boards within a die-cast aluminium housing that acts as a heatsink and channels active airflow.

7.2.2 Validation within this project

The Requirements have all been numbered per category. The next chapter, Concept Development, breaks down the development process for the functional modules of the product concept. For each module, the *relevant requirements (black)* are mentioned at the start of the paragraph.

7.3 Final Concept in its Context

7.3.1 Contextual Adaptability

The concept's adaptability is a necessary component to accommodate the diverse user contexts of the Global South.

For instance, in places like Bali, where small generators are rare and the grid is widely available but prone to intermittent blackouts, the system defaults to a clean, stationary setup. It sits flush against a wall inside a house or Warung, protecting the expensive asset from theft and rain and serving as a silent buffer for business continuity.

In more erratic shadow grid contexts like Nigeria, the use of BUGS is more extensive to support livelihoods outside the house. 100% reliance on independent power is required for SMEs. Here, the inverter and dock are used with a rugged roll cage so it can be transported via light vehicles across rough terrain and road dust without cracking the housing.

Both configurations allow the user to transition from the Dirty/Open ICE logic to the Clean/Open swappable EV standard. Matching the frictionless informal refuelling habits with the upcoming battery infrastructure

Rendering workflow for Figures 7.4 - 7.9: Solidworks (model) → Keyshot (basic render) → Gemini 3.1 Pro (prompts) → Vizcom (realistic render) → Photoshop (adding in display)

7.3.2 The Rendered Contexts

- *Figure 7.4 [one dock with roll cage]:* An Indian woman on a bustling Mumbai market street. During a sudden monsoon shower, she escorts the unit to a dry spot under her stall. This render illustrates that the concept is designed for sudden weather changes and does not break down during rainfall.
- *Figure 7.5 [one dock without roll cage]:* A stationary setup inside a small retail kiosk in Lagos, Nigeria. The shop owner arrives on his scooter and uses that same battery to power his kiosk. An extension cord connects a payment terminal to a cellular signal booster for wireless payments. This render illustrates the local energy *empowerment of SMEs*
- *Figure 7.6 [two docks without roll cage]:* A stationary, high-power system placed in a community health clinic in rural India. An extension cord powers the clinic's medical devices and a full-size medical vaccine refrigerator. This render illustrates professional use cases in which power outages must be prevented at all costs.
- *Figure 7.7 [one dock with roll cage]:* A worker in Nairobi, Kenya, wearing a yellow high-visibility vest, is interacting with the system on a street curb. This render illustrates the rugged portability and handling ergonomics of a traditional petrol generator.
- *Figure 7.8 [two docks with roll cage]:* Showcases the system sitting on a greasy, high-abuse workshop floor next to a heavy air compressor in Delhi, India. The roll cage and casters allow a mechanic to easily wheel the heavy power hub around a tight, cluttered workspace. This render illustrates high-power professional environments that require mobility.

Figure 7.4
An Indian Woman on a Bustling Mumbai Market Street.

Stationary Use Cases

Figure 7.5
A Small Retail Kiosk in Lagos, Nigeria

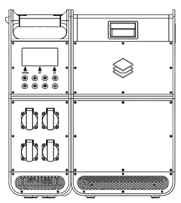
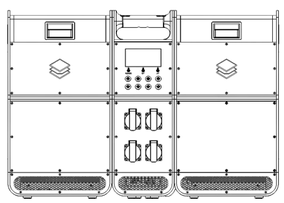


Figure 7.6
A Community Health Clinic in Rural India



Mobile Use Cases

Figure 7.7
A Roadside Setup in Nairobi, Kenya

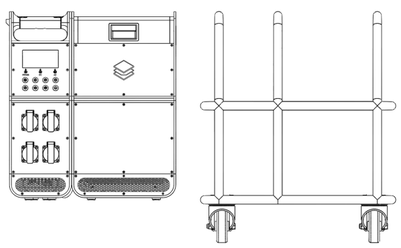
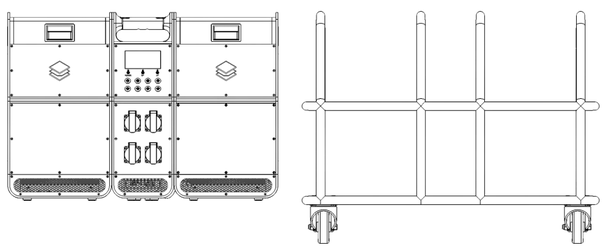


Figure 7.8
A Rickshaw Workshop in Delhi, India



7.4 A Structural Junction

Node Bawa

The term Node refers to a central point in a network, as illustrated in Figure 6.7. In biology, the term also refers to the *structural junction* where the leaf and stem join on a plant. The leaf is a metaphor for solar panels, and the stem is the grid or electricity use in general.

Chapter 1 described that the price of solar energy has plummeted and that the Global South is leapfrogging at a massive scale, adopting cheap PAYG solar kits. In a *futuristic Solarpunk world*. Cities would essentially increasingly copy the basic structure of plants, with leaves generating the energy to support livelihoods. At the junction points, buffering products like Node Bawa and battery-swapping stations are located.

By viewing the hardware as a structural junction, we see it as a living link connecting decentralised energy capture (the leaf/solar) directly to daily human livelihoods (the stem/grid). But the product is not just an abstract concept for a mere futuristic world, it translates this vision in a deployable physical product.

Figure 7.10 shows the concept in a residential setting in Lagos, Nigeria. It shows that the hardware does not demand a pristine, centralised infrastructure to function, but plugs into the existing, messy realities of the Global South.

This Chapter's purpose was to establish the system's visual and contextual identity, providing a clear, macro-level picture of how the form factor feels, looks, and moves in the field.

The modular adaptability allows Node Bawa to navigate diverse environments visually and conceptually, but making it work requires a concrete technical backbone. To understand how these modules actually lock together, handle thermal loads, and distribute power safely, Chapter 8 breaks down the system's precise technical architecture, internal layouts, and mechanical specifications.

Figure 7.9
The Concept Charging Through Solar Panels in a Residential Courtyard in Lago, Nigeria

Concept Development

8

Phase 2: Concept Development

8.0 Introduction

With an understanding of the different modules of Node Bawa, how they fit together, and how they can be applied in different use cases across the Global South, this Chapter moves on to the development process to arrive at the final concept. **RO8.1** is *to design the product architecture, aesthetic identity, and mechanical connection features of the split-module system*. The concept has been split into four main *functional clusters*, each comprising distinct sub-design challenges. Each of these clusters was developed in parallel processes and will be discussed in separate *concept development timelines*. The goal of the functional clusters corresponds to **RO8.2**: *to develop the physical embodiment, structural housing, and internal layout arrangements for the modules*. Paragraph 8.1 provides an overview of the Chapter hierarchy, including the four functional clusters.

Research Objectives

RO3.1	To design the product architecture, aesthetic identity, and mechanical connection features of the split-module system.
RO3.2	To develop the physical embodiment, structural housing, and internal layout arrangements for the modules.

Research Questions

RQ3.1	Which physical configuration and form factor best translate the hybrid requirements into a functional, split-module architecture?
RQ3.2	Which mechanical locking and alignment features enable secure, user-intuitive coupling between the modules?
RQ3.3	How are the modules structured to accommodate the internal components and battery placement interfaces?

8.1 Functional Clusters

8.1.6 Functional Clusters

Main Design: The first cluster is the most general; it focuses on the concept's outer shell. A question that comes to mind is: How did the configuration with the separate docking and inverter come to be? And why are they oriented side-to-side, and why is the battery loaded in a vertical orientation? Why is the roll cage not fully integrated into the concept? The concept's aesthetic design is also included in this part.

Modular Coupling Mechanism: After establishing the separation between the inverter and docking module, there needed to be a way to connect the two mechanically without tools, so the two modules would act as one unit. This functional cluster consists of the design of the locking handles and interlocking brackets.

Docking Module Embodiment: The docking design reaches a more technical level. It tackles the integration of active thermal management necessary to sustain a constant load. And to ensure that high power levels do not pose a danger in use cases such as those shown in Figure 7.4, it is important that water is redirected to avoid interfering with electronics and then exits the system. For mobile use cases, the docking module was designed to securely load and hold the battery in place on the roughest terrain.

Inverter Module Embodiment: This part consists of three parts. Firstly, the sizing and space allocation for the three PCBs in the module, along with the accompanying thermal management for those components. Secondly, the allocation and spacing of the input and output ports. The ports are considered part of the User Interface (UI). The UI for the display has also been developed to a TRL2/3 level.

A visual map with all the components of the final concept can be found in Appendix S.

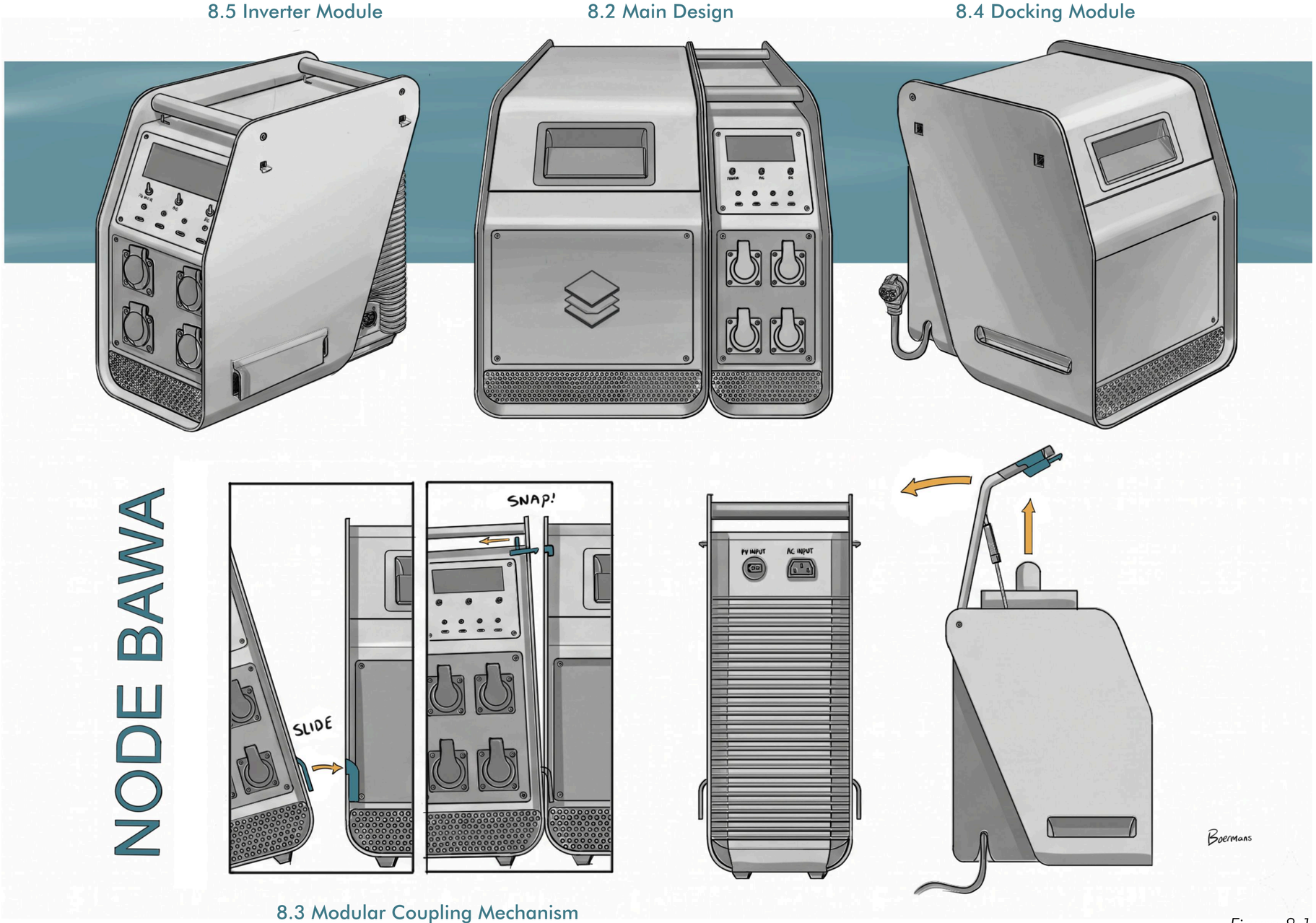
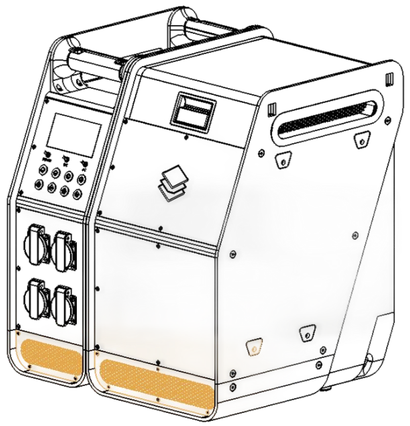


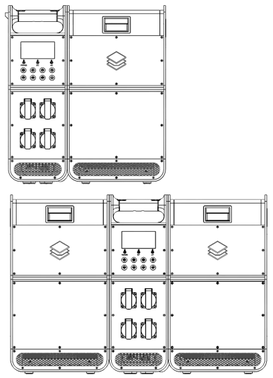
Figure 8.1
Final Concept Sketch

Table 8.1
Functional Clusters

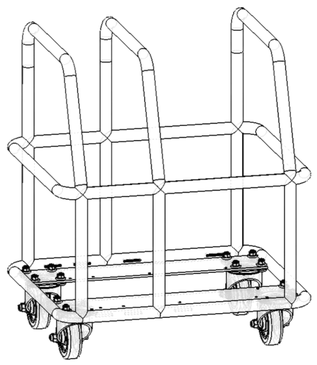
8.2 MAIN DESIGN



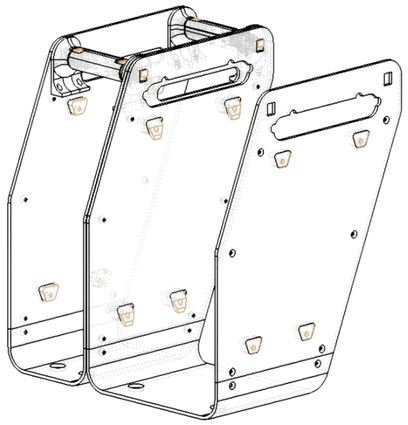
Component Architecture



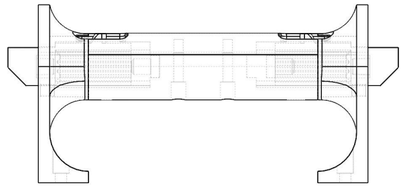
Roll Cage



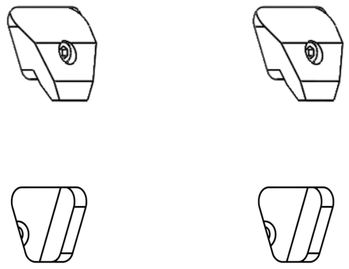
8.3 MODULAR COUPLING MECHANISM



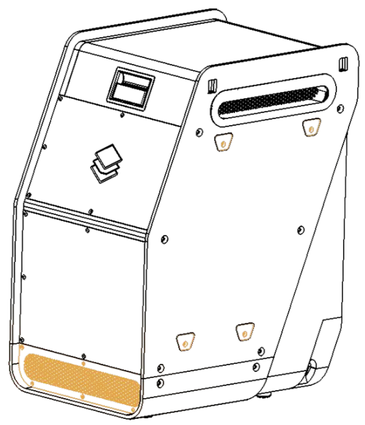
Locking Handles



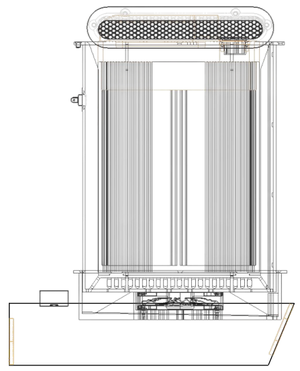
Interlocking Brackets



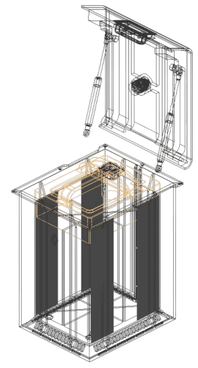
8.4 DOCKING MODULE EMBODIMENT



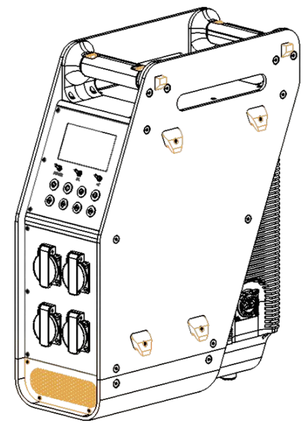
Thermal Management & Water Redirection



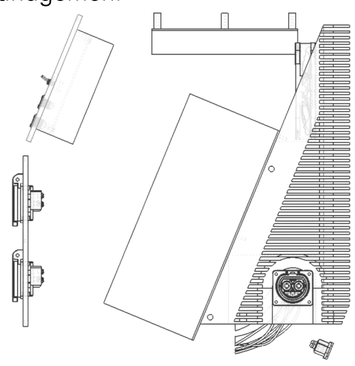
Docking & Clamping



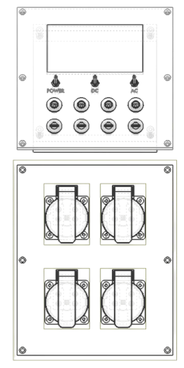
8.5 INVERTER MODULE EMBODIMENT



Electric Component Allocation & Thermal Management



Ports Allocation & UI



8.2 Main Design

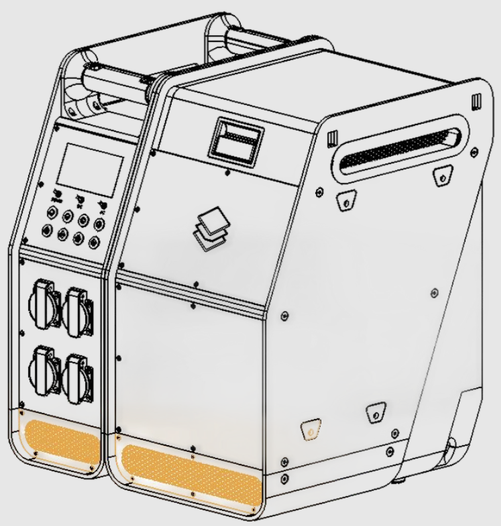
Introduction and Scope

This paragraph outlines the processes and choices that led up to the final design of the Node Bawa. The main design consists overarching design choices and the configuration layout of the spatial relationships between the inverter block and docking modules.

BUGS (Chapter 1.2) are usually designed for serviceability and ruggedness for rough physical handling. The focus here lies on translating those elements into the product concept.

Relevant Requirements

PERFORMANCE	REPAIRABILITY / OPENNESS	SAFETY	USE / ERGONOMICS
P3	R1	S4	U1
P5	R2		U10
	R3		U12
	R4		U13
	R6		U15



8.2.1 Topological Variants

Concept development kicked off with as much divergence as possible. With the knowledge that the concept must contain at least one swappable battery, space for an inverter and a UI, about 50 possible variants were generated. Variations include placing the battery docks vertically, horizontally, side by side, or stacked. The inverter and UI are facing sideways, to the front, at the bottom, etc. A main driving factor here is also the design of the roll cage. Various geometric interpretations of the roll cage provide direction for the body's main shape and aesthetics.

8.2.2 Form Development

Nine of the most interesting and viable topological variants were developed further into three-dimensional sketches. The sketches have been annotated to the accompanying sketches in Figure 8.2. This more spacious overview shows the viability of some of the shapes. At this point, two things became clear:

- For mobile applications, docking the battery vertically from the top makes it easier to engineer a vibration-proof docking module adaptable to different batteries.
- Turning the inverter and docking module into two separate modules (6 in Figure 8.2) allows flexibility in extending the system to meet specific user needs.

8.2.3 Topological Lo-Fi Prototypes

At this point, I realised that placing the batteries on top of the inverter is not the wisest choice, since the inverter's heat will warm the batteries. On the other hand, placing the inverter on top means that docking the batteries from the top is not possible. This leaves two main orientations: the UI facing left (in line with the docks) or the UI facing forward (parallel to the docks). To better understand the spatial implications of those two orientations, some *lo-fi prototypes* were printed (Figure 8.4). From these prototypes, it became clear that the parallel orientation is the most user-friendly topological variant, since it allows the system to stand flush against a wall whilst keeping the UI accessible.

Figure 8.2
Topological Variants

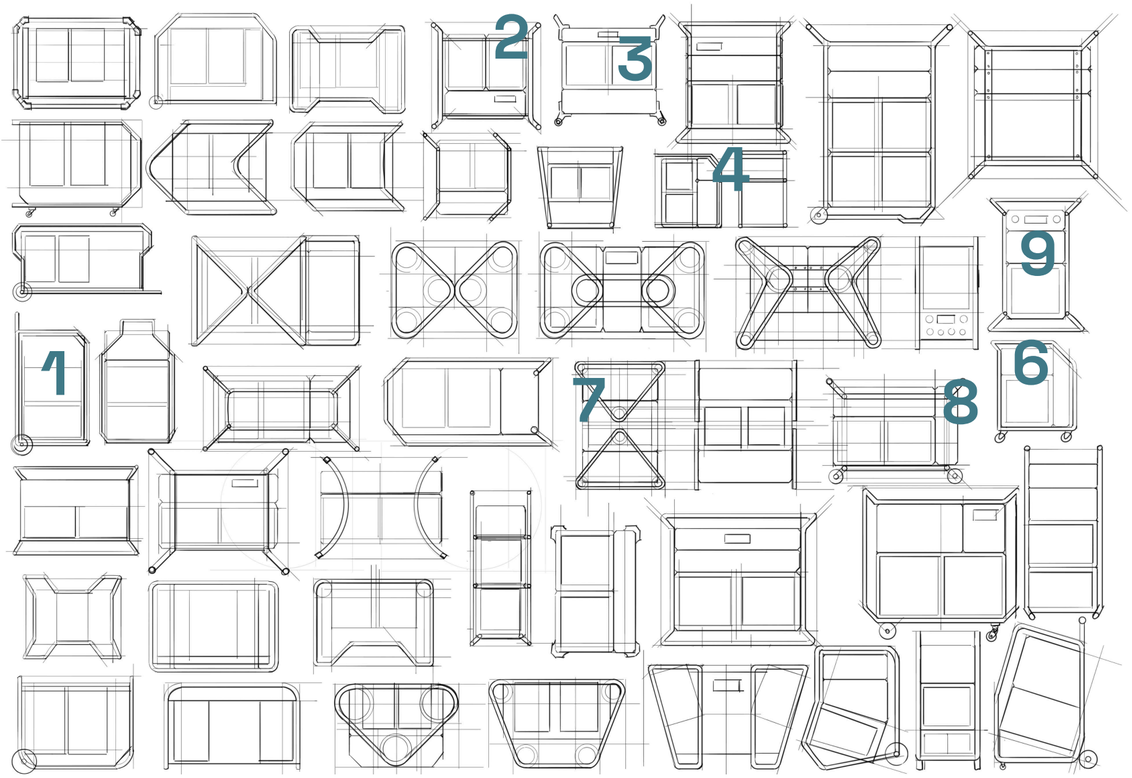
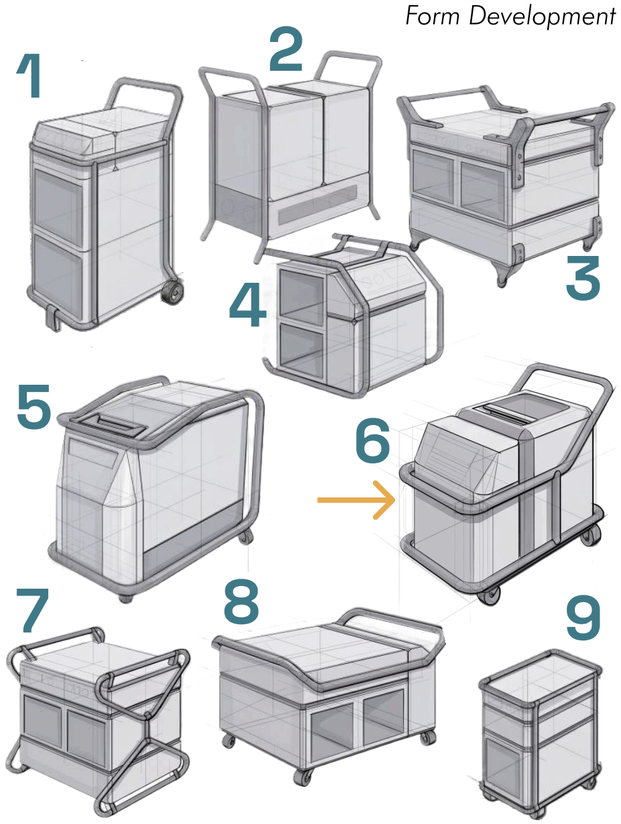


Figure 8.3
Form Development



8.2.4 Separation of the Roll Cage

After establishing that the inverter and docking should be oriented in parallel, it also became possible to attach a docking module to both sides of the inverter. This extendibility means that a user can gradually choose to add more docking modules to the system. This meant that the roll cage also needed to be extendable. But, as a roll cage is a roll cage and needs to protect the system, it was more viable to fully separate the roll cage and make it an optional modular extension as well. This also means the product's price can be lower for people who will use it in stationary setups that do not require robust protection.

8.2.5 Establishing Typological Aesthetic Direction for Final Concept

With a clear picture of topological distribution, comprising separate modules and roll cages that accommodate custom power needs and use cases, the only thing left was to integrate it all into an aesthetically consistent typological variant. Inspired by the modular products displayed in Figure 8.5, more concept sketches were generated. Only the inverter was sketched, since it has more factors that influence its shape (such as the screen, heat sink, and ports). The final aesthetic direction was chosen primarily because the top handles can be used in the modular coupling mechanism.

Figure 8.6
Formgiving Inspiration

Figure 8.4
Topological Lo-fi Prototypes

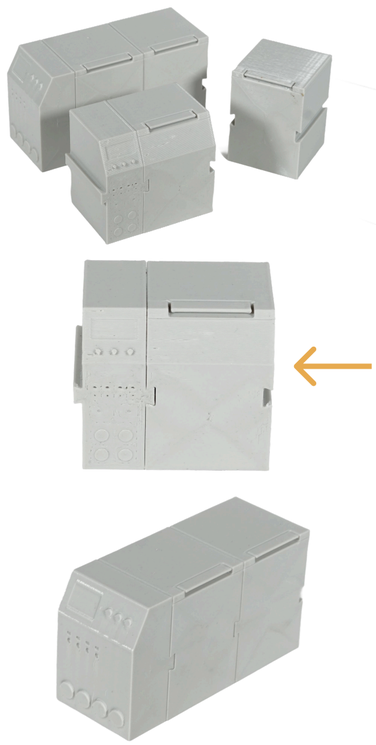


Figure 8.5
Separation of the Roll Cage

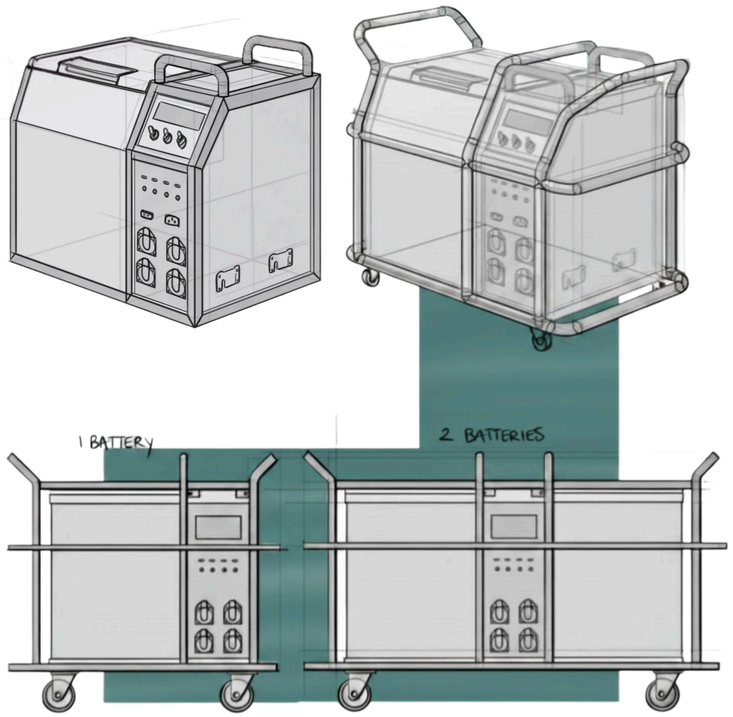
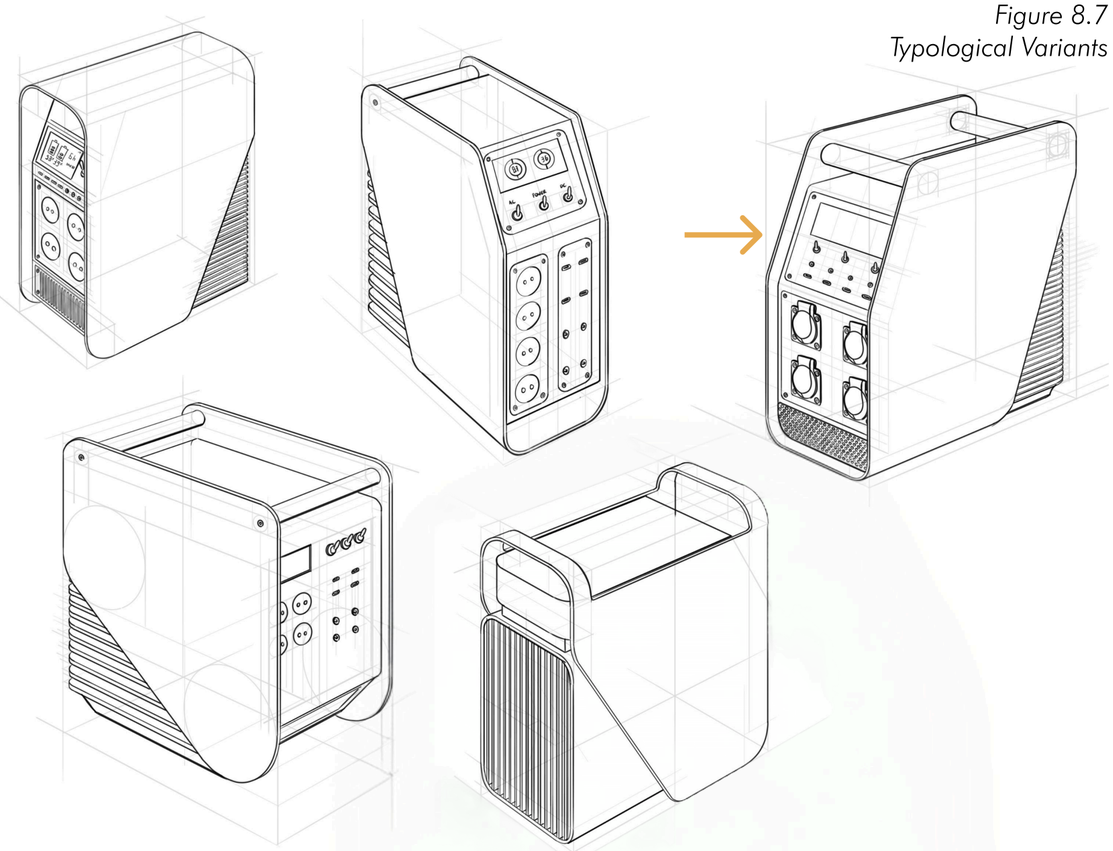


Figure 8.7
Typological Variants



8.2.6 Final Design

The final design is inspired by the use cases for the global south but due to time limitations not informed by the potential end-users.

Its thick aluminium side panels wrap around the bottom to create a rigid structure. The rigidity is necessary to protect the system and mechanically couple the two modules, as seen in the next paragraph. The panels protrude on the back and front of the product, protecting the plastic shell against impacts. The front of the product is angled so the user interface is visible from a standing perspective. All parts are easily removable and accessible using M3-M6 *Allen keys*.

Figure 8.8, 8.9, 8.10 & 8.11
Detail Renders in Studio Setting

8.3 Modular Coupling Mechanism

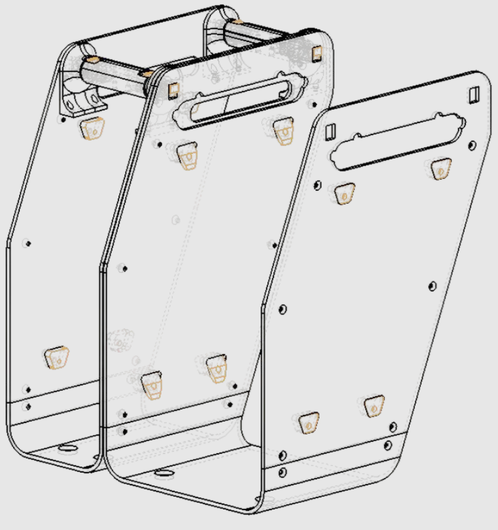
Introduction and Scope

This paragraph outlines the structural variants of the modular coupling mechanism and the design of the locking handles. The terrain of the described use cases in this report can be rough. The two modules should connect together to form a structurally complete whole.

Relevant Requirements

PERFORMANCE | REPAIRABILITY / OPENNESS | SAFETY | USE / ERGONOMICS

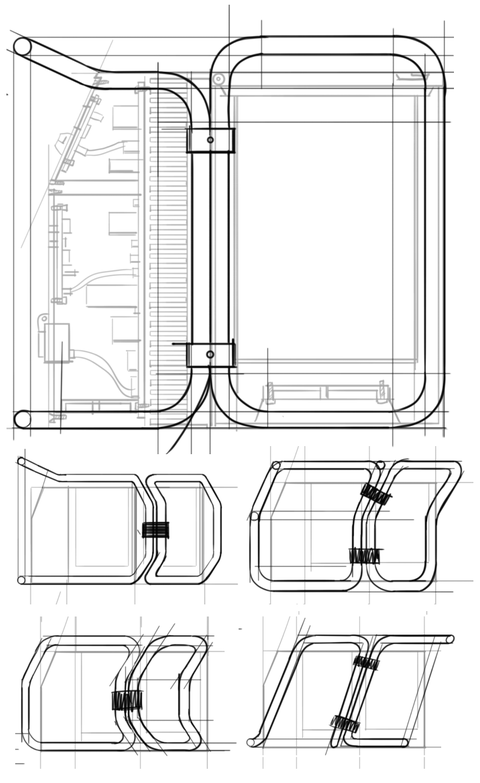
U14
U15
U16



8.3.1 Early Concepts

I started conceptualising the modular interconnections between the inverter and docking modules when it was decided to separate the two. At that point, the roll cage was still an integral part of the concept but separated from the modules. Early concepts, therefore, focused on connecting the modules at the roll cage level. Using brackets commonly seen on fences, two tubes from the roll cage can be connected securely. However, this meant using tools to connect and separate the modules.

Figure 8.12
Early Concept of Modular Coupling



8.3.2 Interlocking Brackets and Snap Latches

Another idea to connect the two modules was to use spring-loaded *snap latches* (often found in cabinets) and *interlocking brackets* (often found in modular couches). This proved very viable since the brackets are made to withstand high loads and abuse. The brackets would limit the degrees of freedom between the two modules along the X and Y axes. The snap latches would limit the degree of freedom along the Z-axis, thereby locking the two modules in place. I sourced some parts to get a better feel for how these would fit together (Figure 8.9).

Figure 8.13
Sourced Parts for Modular Coupling Mechanism

8.3.3 Integrating the Snap Latches into handles

Using interlocking brackets means that one of the two modules needs to be lifted and slid into the other module's brackets. The sourced snap latches are unlocked with one or two fingers. By trying out these parts, it became clear that there is no ergonomic way to lift one of the modules while also lifting the latches. For this reason, the choice was made to integrate the latches into the handles, engineering a sliding latch where your thumb naturally rests when lifting the module.

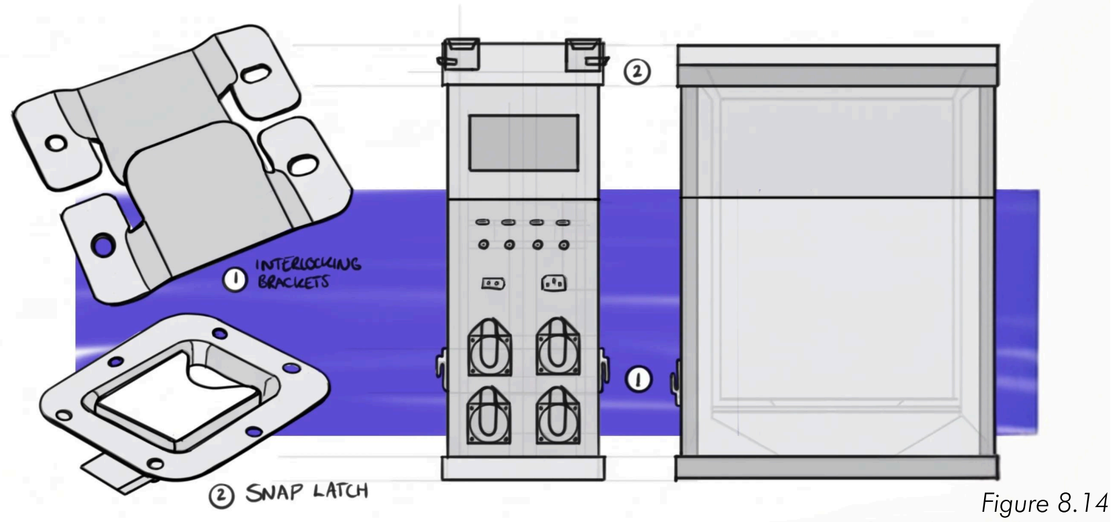


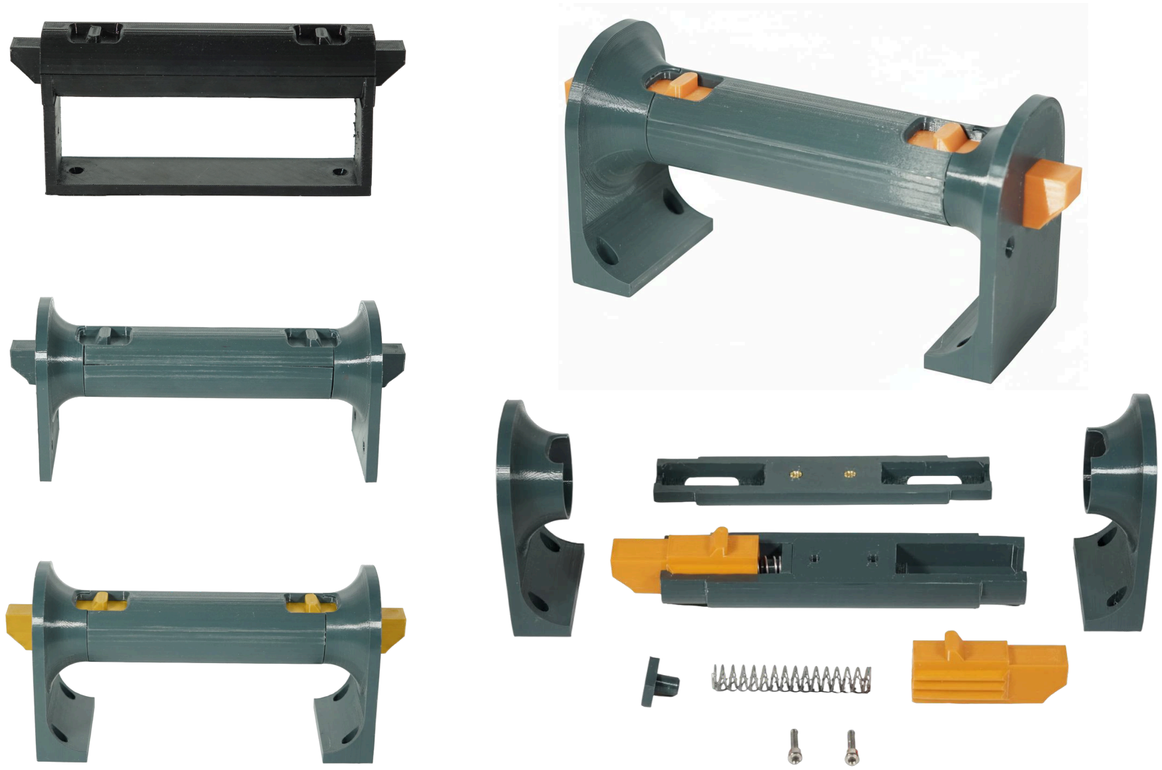
Figure 8.14
Integration of Brackets and Latches

8.3.4 Prototyping the Locking Handles

The final design of the locking handle has a grip length of 160mm, which provides ample space for the hand. The clearance under the handle is nearly 40mm, which allows even big hands wearing gloves to grip the handles without issue. A 35mm diameter works well for lifting the heavy module. The cross-section is slightly asymmetrical to prevent the hands from slipping when the thumbs are used to trigger the *spring-loaded plunger*. The plunger is designed to have as little friction as possible, and the spring is pre-tensioned at its maximum position to ensure the chamfered edge of the plunger snaps into place with an audible click.

Figure 8.15 shows the handle iterations. The first one is mounted to the inverter module using two bolts at the bottom. The implication is that the module's full load is carried by the horizontal layer lines of the 3D print. The second model solves this by separating the sides printed in different orientations. The sides are also filleted to distribute the load more evenly. The final prototype improves on this slightly more by reintroducing the mounting holes on the bottom. This way, the full load is carried not only by the bolts on the side that mount to the outer casing, but also by the main frame within the outer casing. The asymmetry of the handle has the added benefit that the handle cannot start rotating within the side parts.

Figure 8.15
Locking Handles Prototypes



8.3.5 Modular Coupling Mechanism Proof of Concept Prototype

The final design of the locking handles was integrated into a *Proof of Concept (PoC)* prototype, along with the off-the-shelf interlocking brackets. The brackets, when interlocked, leave a gap of 9mm between the two modules, which means the spring-loaded plunger needed to be slightly adapted. The prototype is dimensionally accurate laser cut plywood. The reason I did that was so that this model would accurately display the occupied dimensional space necessary for accurate validation.

This prototype was used in user tests, in which users were asked to connect the modules without further instructions. This user test is discussed in Chapter 9.

The modular interlocking brackets were designed for couches, where they are naturally hidden. They are not particularly aesthetically pleasing and add significant weight to the modules. The goal was to prove the concept of the interlocking brackets, but not to use these specific brackets in the final model. Therefore, they were redesigned and integrated into the design.

Figure 8.16
Proof of Concept Modular Coupling of Docking Module and Inverter

8.3.6 Prototyping the Modular Interlocking Brackets

With the interlocking brackets proven in user testing, they were redesigned to fit the design aesthetics and minimise the gap between the modules from 9mm to 1mm. Some prototypes were printed to test the basic principles. After some alterations to the tolerances and geometry, the final design resulted in a bracket that can be attached and removed depending on the side to which the module is attached. This way, the user can switch the brackets to suit your specific configuration and don't need them on all sides of the concept. Filler ‘plugs’ can be fastened instead to make the outer surface flush.

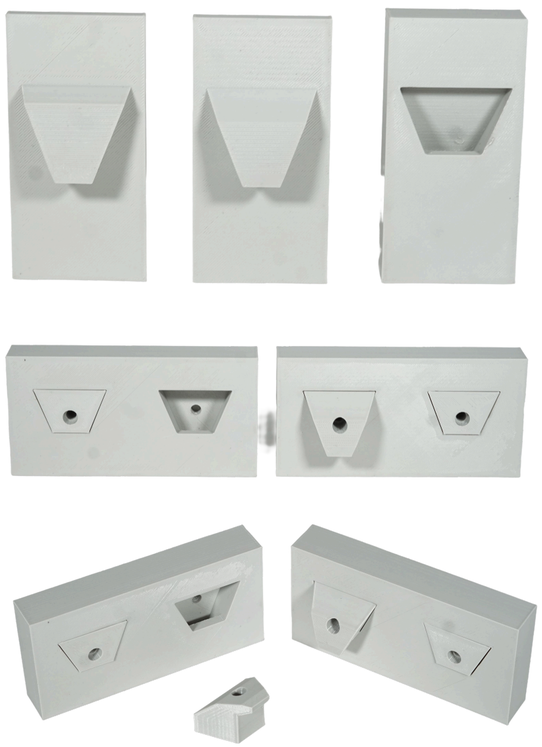


Figure 8.17
Modular Interlocking Brackets Prototypes

8.3.7 The Use-Cue Implementation

An insight from the artefact analysis in Chapter 4 (the blue fuel tank of the Tiger generator) and the user tests of the PoC model is to integrate *colour-coded use cues* into the model. Colouring the thumb sliders and interlocking brackets makes it clearer that this is where you interact with the product to perform an action.

The colour implementation was also extended to the air inlets and outlets of the docking and inverter modules. This is because the ventilation grilles should not be blocked. By giving them a bright colour, the user becomes aware that they exist and should be free (Figure 8.18).

Figure 8.18
Color-Coded Ventilation

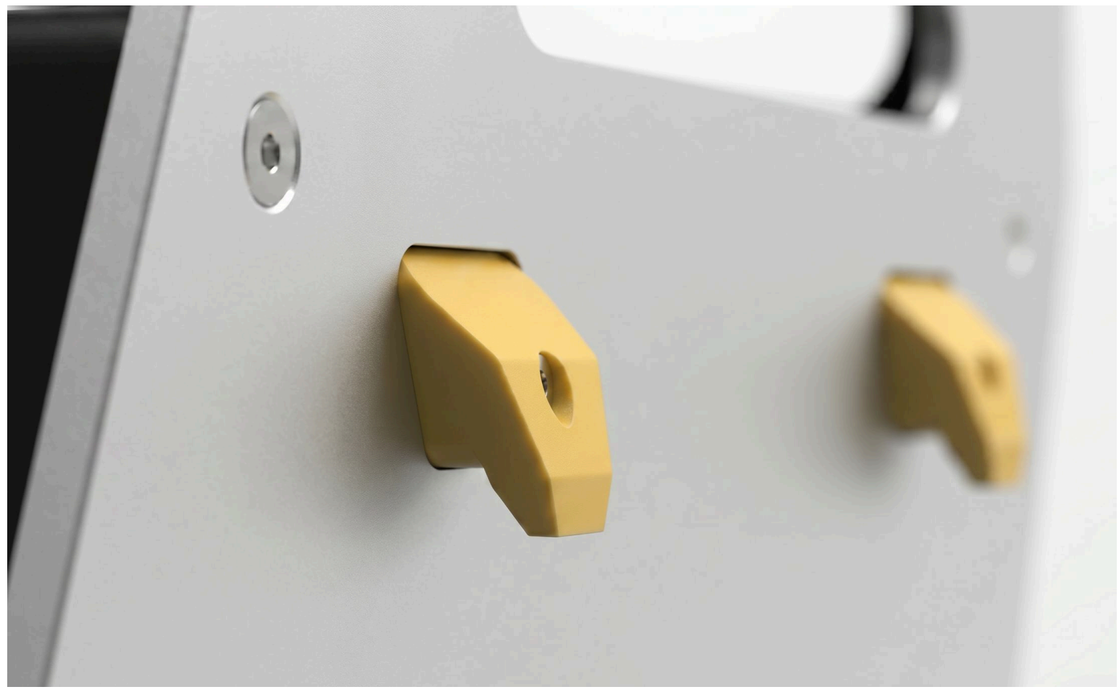


Figure 8.19 & 8.20
Color-Coded Parts for the Modular Coupling Mechanism

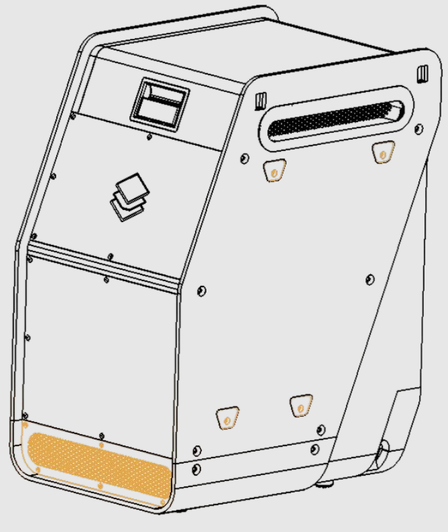
8.4 Docking Module Embodiment

Introduction and Scope

This paragraph defines the structural variants of the docking module, focusing specifically on the sleeve, clamping mechanism, and lid architecture. Paragraph 5.3 highlights how different manufacturers approach battery docking. While Gogoro uses smooth, orientation-agnostic docking with proprietary connectors, other manufacturers just use a swapping locker where the user plugs the battery in themselves. The docking module must reflect this battery-specific docking process.

Most Relevant Requirements

PERFORMANCE	REPAIRABILITY / OPENNESS	SAFETY	USE / ERGONOMICS
P1	R5	S2	U17
P2		S3	U18
P6		S4	U19



8.4.1 Early Concepts

The Tycorun battery can supply 2kW of continuous power with a peak load of about 4kW. Battery cells slowly heat up under electrical load due to internal resistance (efficiency depends on the load; see 3.1). In the mobility sector, they naturally ventilate through air inlets when driving. In a stationary setup like this, artificial ventilation is necessary. This can be achieved by introducing an air channel around the battery and a cooling fan underneath.

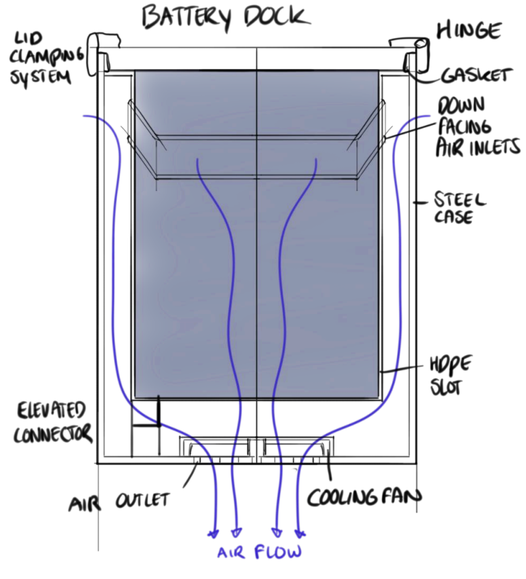


Figure 8.21
Early Ventilation Concept

8.4.2 Development of the Features

In the concept in Figure 8.22, the battery would be inserted into an *inner sleeve*. The air channel is created by using thick ribs as the battery's sliding slot. This inner sleeve has ventilation holes at the bottom. The sleeve is situated above a 12V brushless IP-rated fan. At the bottom, there is an outlet for accidental water to flow out.

The battery sits in the inner sleeve on top of dampening rubber pads. When closing the dock, the lid uses a pressure pad to hold the battery in place. Honda uses a sophisticated proprietary clamping lever system with rotating pressure pads. Because the docking here is not designed for bikes, the clamping system can be more minimal.

The Tycorun battery has a maximum discharge capacity of 80A. The spec sheet (Appendix O) also mentions that the top connector is rated for 80A. The brand most dominant in that market is *Chogori*. Their banga X100 100A cable (Appendix P) is a good choice for this application.

Branching off the main power line, a *buck converter* would be attached to step the voltage down to supply the 12V fan. A *mechanical thermal switch* (passive temperature sensor) set to a specific temperature, for instance, 40°C, would ensure the ventilator turns on only when the system draws active current. The battery indicator in Figure 8.22 was let out in the final model.

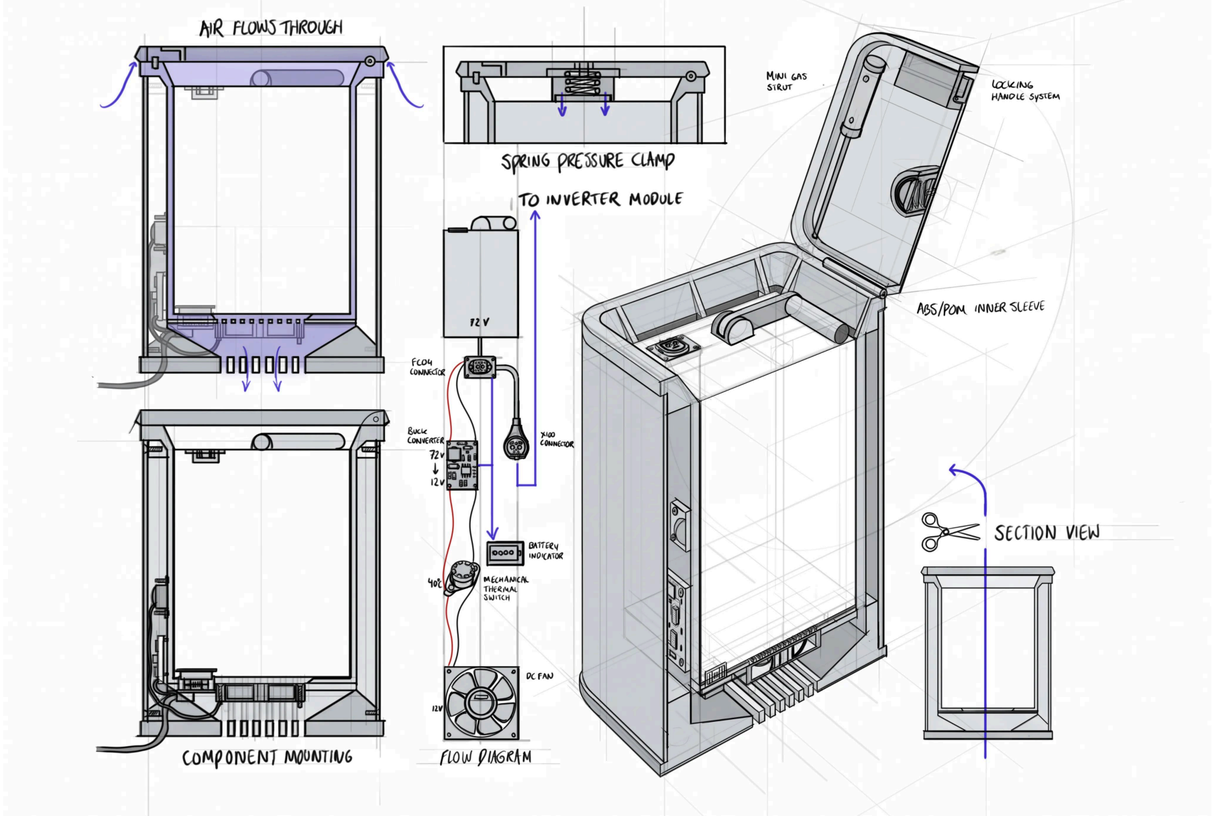


Figure 8.22
Development of the Docking Module thermal management, Battery Docking & Clamping

8.4.3 The Customizable Inner Sleeve

As mentioned in 7.1, one reason the Tycorun battery was chosen is that it is relatively large, measuring 159 × 230 × 375 mm, yet still within an acceptable range for user-friendliness. The inner sleeve was designed around these initial dimensions, but can be adjusted to have longer/shorter ribs to accommodate different battery brands/sizes. The inner sleeve can be a locally 3D printed part, for instance, and an open-source platform for local customisation. The first digital model was just to establish how to create the shape. The second version was already more sophisticated, introducing the water channels and ventilation holes.

The final sleeve (Figure 8.24) sinks about 30 mm into a *plenum base*, forming an enclosed chamber with a fan. There is about 20-50 mm of vertical space between the ventilation holes of the inner sleeve and the fan. The thick Chogori Banga cable sits between two smaller ribs, with holes for attaching tie-wraps to secure the cable in place. Most EV batteries have a connector like this one on the top, including the Tycorun battery. But the sleeve could be adapted to accommodate batteries with a panel-to-panel connector at the bottom.

8.4.4 The Cooling Channels

The docking module's side handles also conveniently serve as the system's top air inlet. This creates an overhang to prevent rain from entering the housing and allows the user to lift and manipulate the docking module. Around the battery, there is an air channel of about 20 mm wide. Heat rises, which makes you think that air should move upward. But because a battery heats quite evenly and controllably, this direction is not that important. In this case, the air moves upward because it is more important to ensure that the air is clean and that water does not have to fight the upward air circulation as it leaves the system.

8.4.5 The Water Channels

Parts of the Global South are notorious for their rainy seasons, with sudden, heavy downpours. Although in normal situations water cannot enter through the lid, it is important to account for situations where it can, since we are working with high currents and sensitive electronics. The air channels double as water channels. They were designed so that air primarily flows through the fan's ventilation holes, while water collects along the sides of the plenum base. Here, the water flows down an angled slope out of the holes in the back and through the back ventilation outlet of the main docking module. Because the air and water channels share the same spatial occupation, air needs to move in the same direction as the water.

Figure 8.23
First Digital models of the Inner Sleeve for Docking

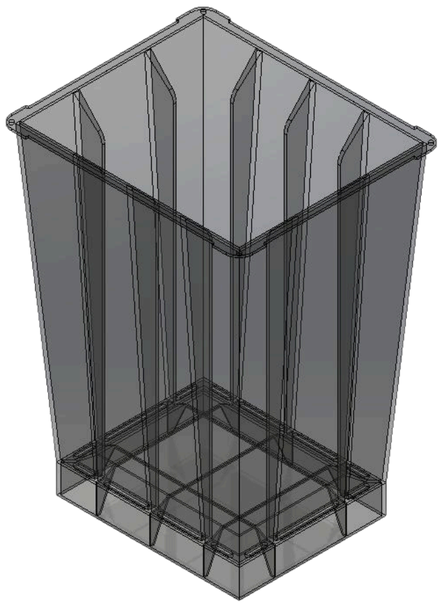


Figure 8.24
The Stack of Parts in the Docking system

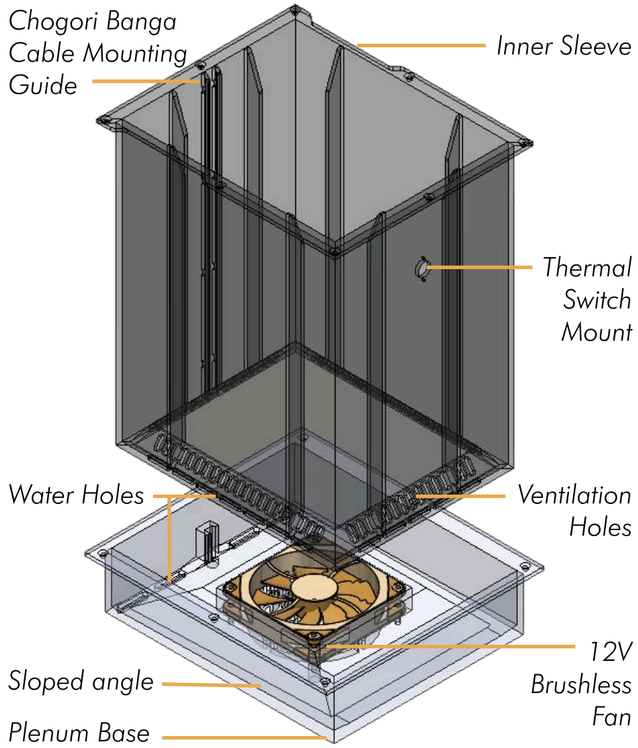


Figure 8.25
The Air Flow Through the Docking Module

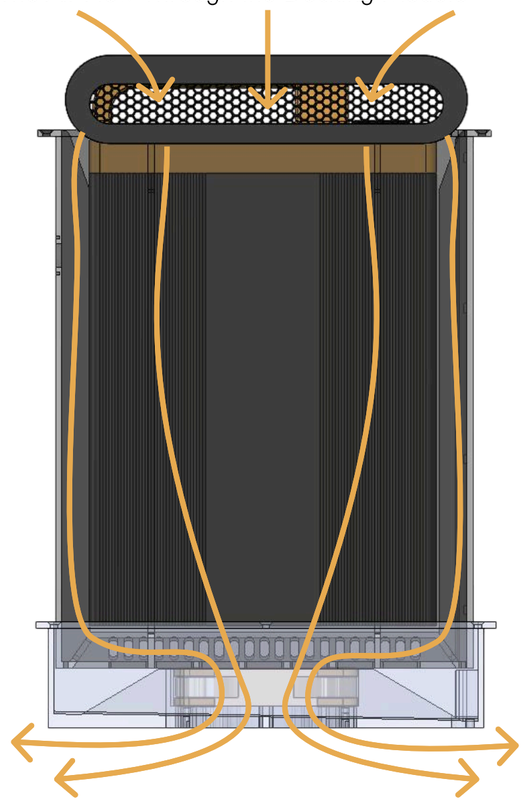
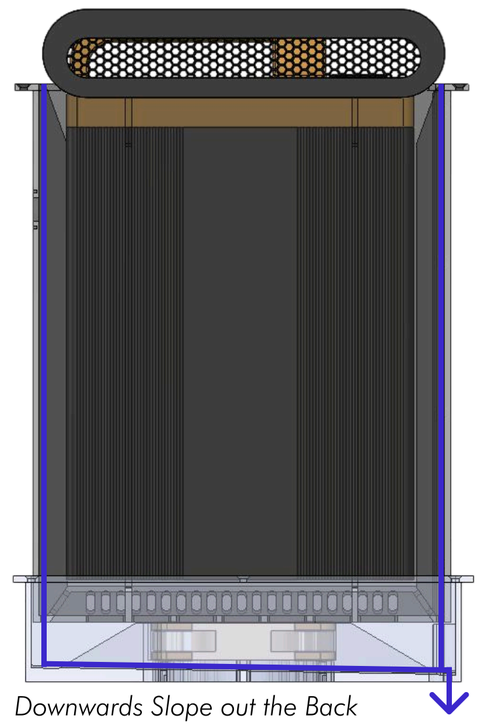


Figure 8.26
The Water Flow Through the Docking Module



OEM Parts Used in Docking Module Embodiment

12V Brushless Fan

40 °C. Mechanical Thermal Switch

Rubber Pads

DC Buck Converter

Chogori Banga X100 Cables

50N Gas Struts

Pressure Pads

Spring Loaded Handle

8.4.6 OEM Parts Used in Docking Module

All the OEM parts used in the Docking Module were sourced through *AliExpress* and are widely available standard components. The Chogori connector is only available through a B2B link with that company. But the connector in the system depends on choice of the battery. The Chogori in this case was selected to illustrate the connector type to be implemented in this system.

In reality, the module requires more electrical components to ensure safety, reliability, and proper system initialisation. For this reason, a lot of easily accessible space in the front of the docking module remains available

8.4.7 Gas-Strut Assisted Lid with Spring

Pressure Pad

The lid was designed with thick plastic ribs that ensure a rigid, solid top. The *gas struts* are mounted so that the lid stands perfectly vertical when opened. The inner sleeve has cutouts so it can be swapped from the top without getting in the way of the gas strut mounts. The spring-loaded pressure pad is a vibration-dampening pad for refrigerators. The length is now adjusted for the Tycorun battery, but the spring can be easily swapped out for different lengths to accommodate different batteries. The hinge consists of two 6mm rods with a spring behind them, so the lid can be fully removed through small pinholes in the sides.

Figure 8.27
Flow Diagram of Electronics in the Docking Module

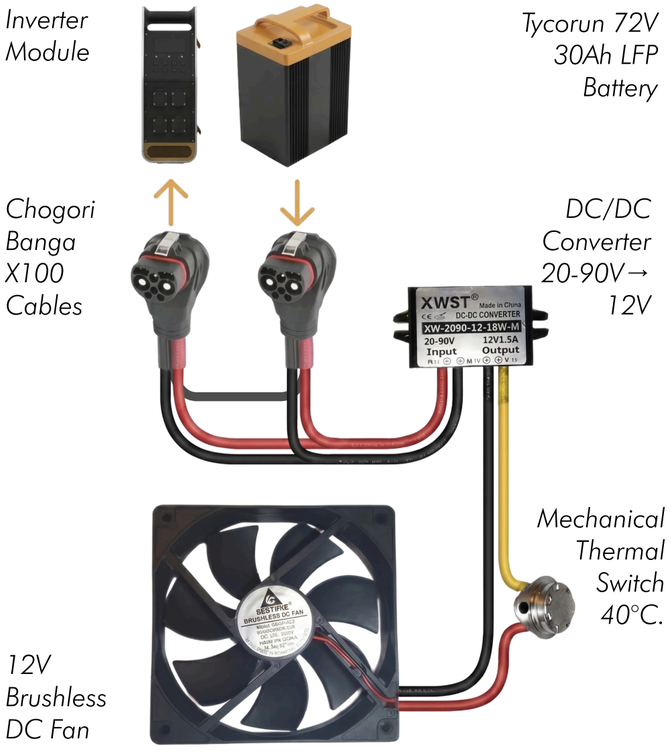


Figure 8.28
The Docking Module with Open Lid

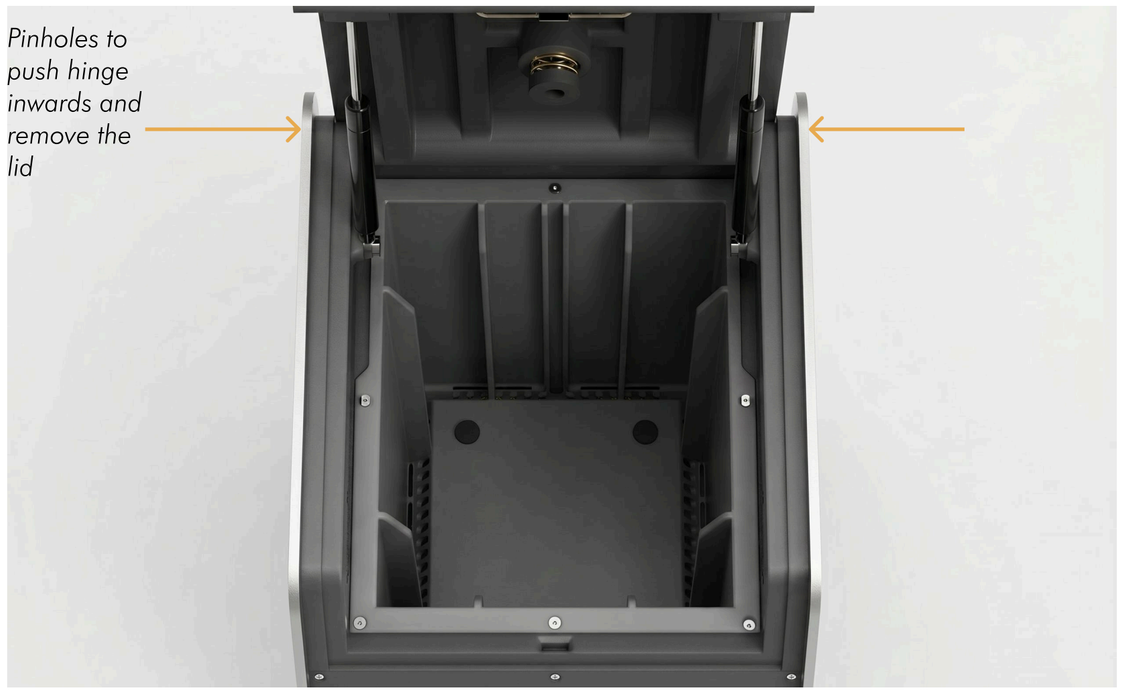


Figure 8.29 & 8.30
Different Angles of the Docking & Clamping Module

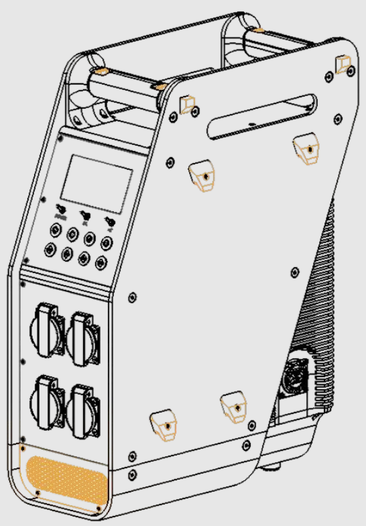
8.5 Inverter Module Embodiment

Introduction and Scope

This paragraph defines the structural variants of the inverter module, focusing specifically on component allocation and thermal management, port allocation, UI, and electronics wireframe. While the electrical power capacity and efficiency metrics are set by the List of Requirements in Chapter 6, the internal layout is driven by component-level troubleshooting. The precise functionality of the components doesn't need to be developed beyond TRL 2/3, since the inputs at that level can serve as design inputs for the Inverter manufacturer. The layout of the UI and the allocation of ports are determined by analysis of comparable products and sensitising booklets from user research.

Most Relevant Requirements

PERFORMANCE	REPAIRABILITY / OPENNESS	SAFETY	USE / ERGONOMICS
P4 P7		S1 S4	U2 U3 U4 U5 U6 U7 U8 U9 U11 U20

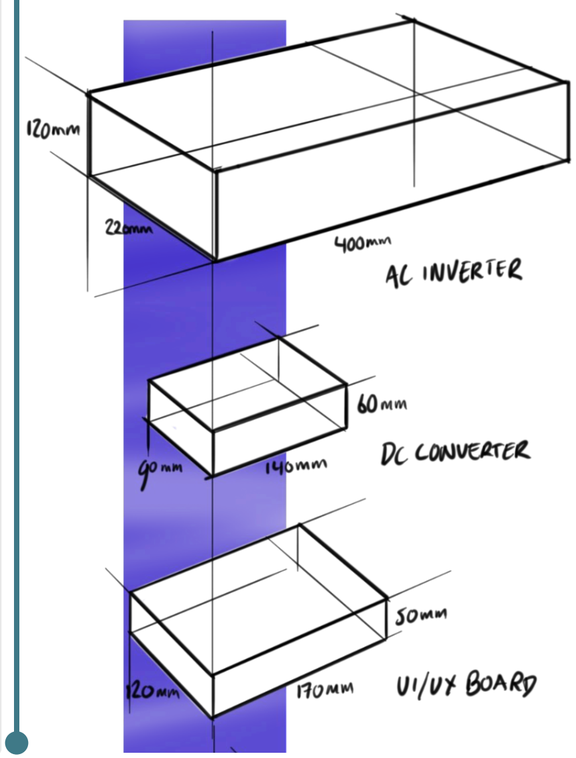


8.5.1 Space Allocation for PCBs

Input variables for the inverter stage were processed through generative estimation models to establish initial *spatial envelopes* for the primary PCBs. While exact component-level dimensions will be finalised during late-stage manufacturing design (DfM), this phase defines the volumetric boundaries of each functional block.

By analysing established power-density ratios, rough 3D footprints were allocated to prevent internal spatial conflicts. The DC-to-AC conversion stage, DC/DC converter, and the UI/UX board are treated as distinct physical chunks to optimise thermal isolation, airflow routing, and future serviceability.

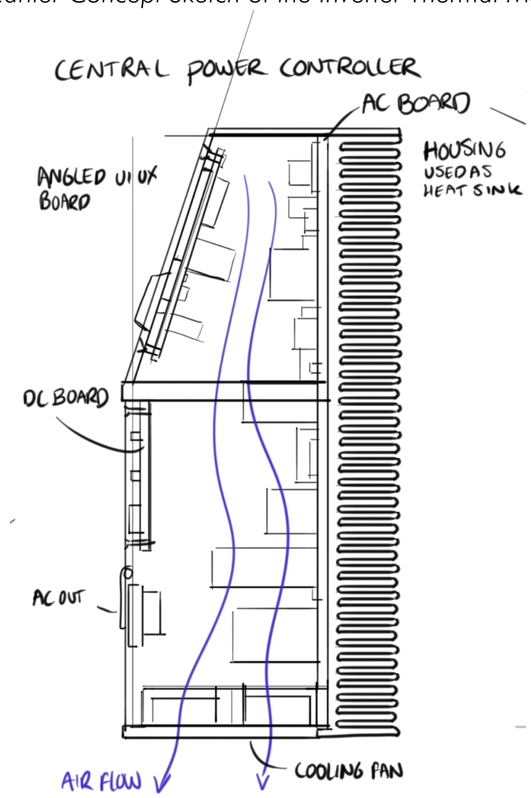
Figure 8.31
Estimated Spatital Envelopes of Inverter Components



8.5.2 Development of Thermal Management

Figure 8.32 displays the first concept of the airflow routing through the inverter. The main idea here is to mount the different PCBs on opposite sides and allow air to flow between them. Inspired by the visit to NeoVolt, the heatsink can be integrated into the housing rather than having separate heatsinks mounted on the individual boards. At a later stage in concept development, it can be ensured that components that generate the most heat, such as the *MOSFET transistors* on the AC converter, are mounted near the air inlet so they receive the coldest air.

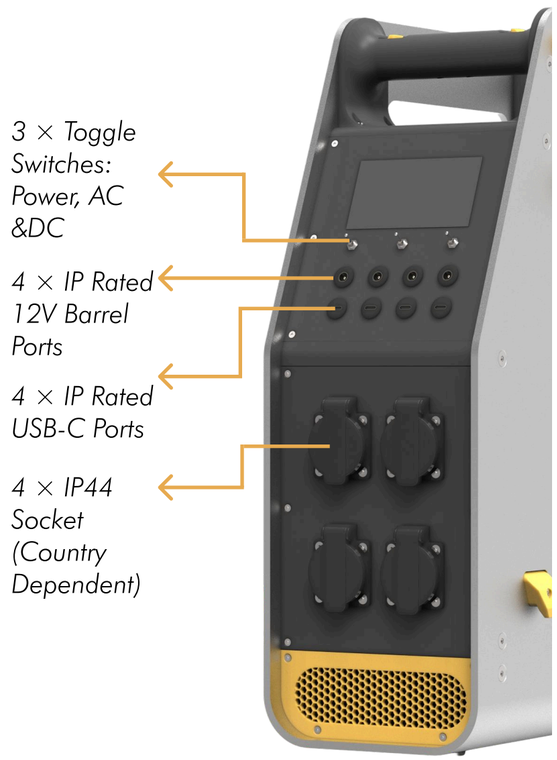
Figure 8.32
Earlier Concept Sketch of the Inverter Thermal Management



8.5.3 Placement of the Ports

The number of ports was determined by a combination of analysis of competing products and the sensitising booklets from the user research (appendix K). The placement of the ports needs to be intuitive and accessible, but no very specific layout is required beyond that. The DC ports are mounted on top because, for instance, when a phone is charging, the user can still use it while standing, or it can lie on top of a table or cabinet. On the other side, the AC sockets were placed at the bottom because AC cables are usually thicker and heavier and must not get in the way of the DC ports. The hierarchy is designed in a purely functional way, and will be validated in Chapter 9.

Figure 8.33
Placement of the Ports



8.5.4 UI Design

While the core focus of this project lies in the hardware architecture, visualising the User Interface at a low-fidelity level is essential for explaining the overall system coherently. As established in Chapter 3.2, the BMS is integrated into swappable batteries like the Tycorun. Standard Chogori or similar multi-pin connectors typically utilise two primary power pins, a grounding pin, and multiple signal lines. These signal lines serve to extract real-time *telemetry parameters* directly from the internal BMS.

For the user, the critical parameters requiring clear visual feedback are the *State of Charge (SoC)*, *State of Health (SoH)*, and internal cell temperatures.

To achieve this, the interface incorporates the following functional logic:

- The UI displays the individual SoC for each connected dock, along with an aggregated system SoC.
- By tracking real-time charging input power versus output load thresholds, the interface calculates and displays active time-to-full or time-to-empty metrics.
- To support a PAYG financing model, the interface explicitly notifies users when a micro-instalment payment is due.

Using these architectural input requirements, a generative mock-up of the user interface layout was produced to illustrate the system footprint.

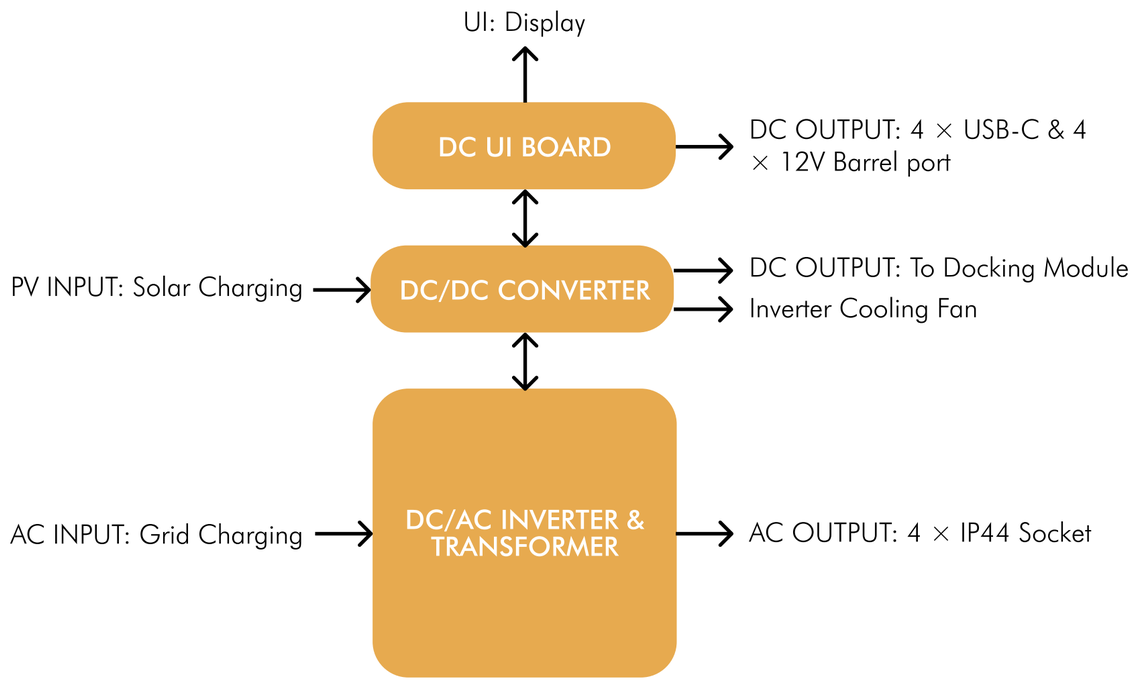
Figure 8.34
Mock-up UI Design of the Inverter Module (Gemini 3.1 Pro)

8.5.5 Wireframe of Central Power Controller

The wireframe from Figure 8.35 is based on Figure 3.1 from Chapter 3.1. While competing products like EcoFlow and Bluetti combine multiple components on 1 board, in this case, the choice was made to separate the functional components for future maintenance.

- The DC UI board draws power from the DC/DC converter board and houses the display, IoT and GSM components, toggle switches and the ports to which the DC outputs connect.
- The DC/DC converter houses the MPPT charge controller (for PV charging), the buck converter (low-voltage DC output) and the boost converter (battery charging). The inverter module cooling fan is also connected to this board. Finally, this board supplies a load to the DC/AC inverter/ transformer.
- The DC/AC inverter and transformer connect to the AC input for the charging current. This board also transforms the DC current from the DC/DC converter to supply the AC load for the sockets.

Figure 8.35
Lo-Fi Wireframe of the Cetral Power Controller



OEM Parts Used in Inverter Embodiment

12V Brushless Fan

IP44 Sockets

C14 AC Input

XT90 PV Input

IP USB-C ports

IP 12V Barrel ports

Chogori Banga X100 Ports

5" LCD Touch Screen

Toggle Switches

8.5.6 OEM Parts Used in Inverter Module

All the OEM parts used in the Docking Module were sourced through AliExpress and are widely available standard components. 4.3.3 showed that Bluetti soldered all the connectors straight onto the PCB, as is the norm in micro storage units. In this case, the ports are separately sourced IP-rated parts that plug into the board using a different connector. This choice fits the product's modular nature and allows the ports to be replaced with different ones, such as USB-A.

These components are not set in stone and can change in future development of the concept.

8.5.7 Final Inverter Design

The volumetric boundaries of each functional block displayed in Figure 8.31 were altered slightly to match the volumetric boundaries of the inverter module. Figure 8.36 displays the volumetric envelope of the components within the chassis. The DC/DC converter can be accessed through a plate on the top of the module. The DC UI board is also easily accessible through the front of the module. To access or replace the DC/AC inverter & transformer, one of the inverter module's side panels needs to be removed.

Figure 8.36 does not show the interconnections among the components and PCBs.

Figure 8.36
Placement of PCBs and Thermal Management of the Inverter Module

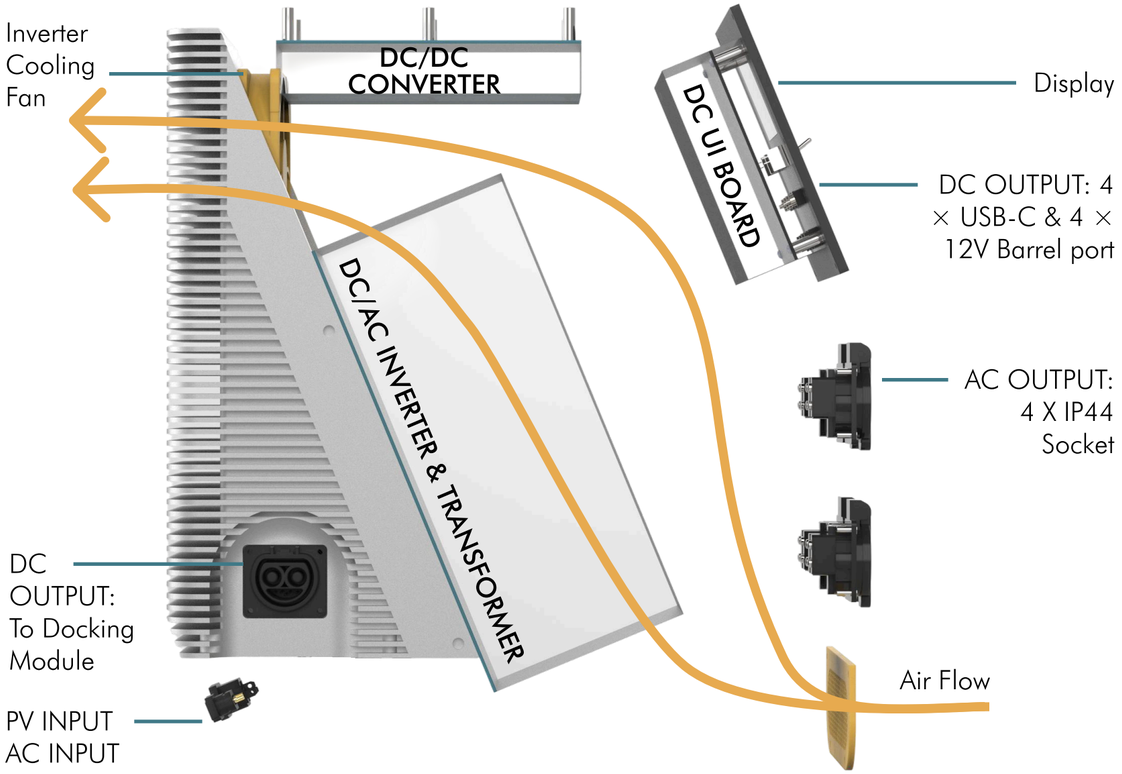


Figure 8.37 & 8.38
Final Design of Inverter Module

8.6 Chapter Conclusions

RQ8.1 What physical configuration and form factor best translate the hybrid requirements into a functional, split-module architecture?

The Chapter started with a distribution of functional clusters. The main body cluster focused on the overarching skeletal framework, the configuration layout of the spatial relationships between the inverter block and docking modules. Through initial form studies and 3D sketches, the idea of the separate modular interfaces was born. The final design is a mix between the honesty of a generator and the sleekness of modern micro storage units.

RQ8.2 Which mechanical locking and alignment features enable secure, user-intuitive coupling between the modules?

The second paragraph discussed the further development of the modularity and the design of the locking handles and brackets. The locking handles use a spring loaded plunger system that prevents the Degree of Freedom (DoF) along the Z-axis. The interlocking brackets prevent the DoF along the X and Y axes. The mechanical coupling mechanism has undergone iterative prototyping and user testing that resulted in meaningful improvements. The result is a system that works intuitively and ergonomically and looks very promising mechanically. Further testing is necessary to test the viability of this mechanism.

RQ8.3 How are the modules structured to accommodate the internal components and battery placement interfaces?

The concept development of the docking module focused specifically on the inner sleeve, clamping mechanism, and lid architecture. Another key feature is the integrated thermal management necessary in non-mobility applications.

The inverter module directed component allocation and cooling, port allocation and the UI. The result is a mock-up for the internal components that can be directly input to third-party partners to develop further.

There are more details that were not discussed in this Chapter. For instance, the ability to easily re-route the Chogori cable to change the dock orientation from the left to the right side of the inverter. Another example is the selection of OEM parts, such as gas struts. Unfortunately, not all design choices can be articulated whilst keeping the content concise and cohesive.

To integrate all the functional clusters beyond a digital prototype, an integrated (semi-) functional/geometric prototype will be built for part of the validation. It will not work electronically, since that could never be accomplished within the scope of this concept. The roll cage will also not be prototyped beyond the digital model. The prototype will use real OEM parts, but dummy versions of the UI, battery, and Chogori connectors.

Validation & Final Integrated Prototype

9

Phase 2: Concept Development

9.0 Introduction

The project formulation Chapter highlighted that the goal of the project was to develop a TRL3/4 product concept for a Clean/Open ESS. With TRL 3 as a lower limit for more technical subparts (electronics, UI, manufacturability) and TRL 4 for use-related subparts (affordances, user-friendliness, repairability). Through validating some of the functional clusters discussed in the previous chapters, the TRL can be lifted from a 2 up to 4. The TRL Validation Chart on the next page (Table 9.1) gives a complete overview of the concept development stage in the context of Technology Readiness Levels.

Not all functional clusters can be user-validated within the timeframe of this project. There are 3 main validations discussed in this Chapter. First, the PoC model of the modular coupling mechanism. The goal here is to find out how intuitive the physical alignment and latching interface of the split-module coupling mechanism really is, and what could be improved. Secondly, the viability of the cooling channels and ventilation is be validated through Solidworks Simulations. Since no advanced thermodynamics were used whilst designing the cooling channels and fan placing, this validation can help displaying the viability of the current system design and to see where the module needs to change to accommodate for the battery's heating properties.

Lastly, the integrated, functional/geometric prototype discussed in the last Chapter is to test multiple functional clusters at once. User testing is used to simulate the environment in a dummy set-up. The coupling of the modules, docking of the battery and using the ports to connect appliances, devices or solar panels are the most important user interactions. These are all included in user testing with the integrated prototype.

Research Objectives

RO3.1	To validate the physical performance of the coupling mechanism and the thermal system of the docking module.
RO3.2	To assess the functional feasibility of the hybrid product system within a simulated operational environment.

Research Questions

RQ3.1	How intuitive is the physical alignment and latching interface of the split-module coupling mechanism for independent users?
RQ3.2	How effectively does the integrated thermal management system of the docking module dissipate heat?
RQ3.3	To what degree does the integrated hybrid concept system satisfy the established performance baselines within a simulated operational environment?

TRL Validation Chart

= *validated in Chapter 9*

TRL 1 Basic Principles Observed

Purely conceptual stage. It can include user research, sketches, system maps, hypothesis and lo-fi prototyping.

TRL 2 Technology Concept Formulated

Defining the design intent and architectural boundaries. This is were the ideas turn into tangible concepts.

TRL 3 Experimental Proof of Concept

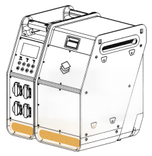
Physically validating individual features in isolation to see if they are functionally or physically viable.

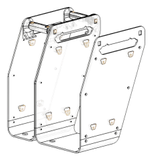
TRL 4 Component Validation in Laboratory Environment

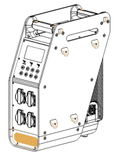
System integration in a low-fidelity, fully controlled setting. This is the first stage were different functional clusters get integrated.

TRL 5 Component Validation in Relevant Environment

Testing a high-fidelity system simulator in an environment that heavily mirrors real-world abuse. This is not in the scope of this thesis.







	Essential Requirements	RESEARCH PHASE			DEVELOPMENT PHASE
		Basic Principles	Concept Formulated	Proof of Concept	Laboratory Validation
		TRL 1	TRL 2	TRL 3	TRL 4
MAIN DESIGN Component Architecture	R1, R6, U1, U15	• Sketches • Lo-Fi Prototypes	• Concept Sketches • CAD Model	• Digital Renders	• Integrated Functional/ Geometric Prototype
MAIN DESIGN Roll Cage	U10, U12	• Sketches	• CAD Model	• Digital Renders	
MODULAR COUPLING MECHANISM	U14, U15, U16	• Sketches • Component Sourcing	• CAD Model • First Prototypes	9.1 • Proof of Concept Prototype	9.3 • Integrated Functional/ Geometric Prototype
DOCKING MODULE Thermal Management	P6, S4	• Sketches • Component Sourcing	• CAD Model	9.2 • SolidWorks Simulation	
DOCKING MODULE Water Redirection	S2, S3	• Sketches	• CAD Model	• Consolidated into TRL 4 (Empirical Testing Over Simulation)	• Integrated Functional/ Geometric Prototype
DOCKING MODULE Docking & Clamping	R5, U17, U18, U19	• Sketches • Component Sourcing	• CAD Model	• Consolidated into TRL 4 (Empirical Testing Over Simulation)	9.3 • Integrated Functional/ Geometric Prototype
INVERTER MODULE Component Allocation & Thermal Management	P7, R4, U27	• Sketches • Research • Component Sourcing	• CAD Model		
INVERTER MODULE Ports Allocation & UI	P4, S1, U7, U8, U9, U20	• Sketches • User Research • Component Sourcing	• CAD Model • AI Generated UI	9.3 • Integrated Functional/ Geometric Prototype	

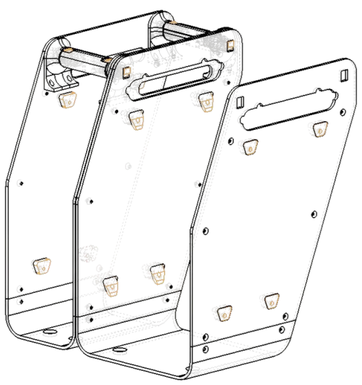
9.1 Modular Coupling Mechanism Proof of Concept Validation

RQ9.1: How intuitive is the physical alignment and latching interface of the split-module coupling mechanism for independent users?

9.1.1 Approach

To answer research question RQ9.1, a 1:1 model was made using 9mm plywood, off the shelf interlocking brackets and the locking handles in a plain white colour. The "Inverter" module was weighed down with bricks to simulate the heft of the inverter.

A total of six people were asked to participate to test the viability of this modular coupling mechanism. The two modules are placed side to side against a wall. The participants were given a very simple instruction: "The left module should be connected to the right module, forming one physical whole."



9.1.2 Results

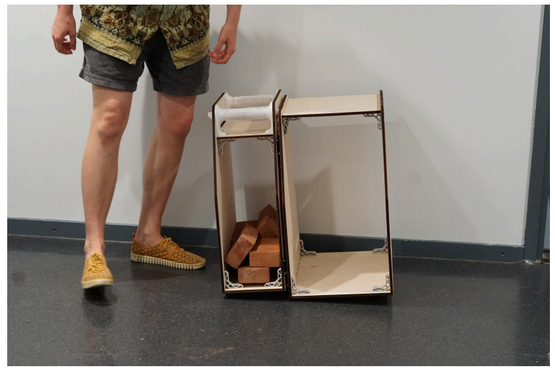
- All people instantly grabbed the two white handles to lift the inverter module. It was also very clear from the start that the interlocking brackets should fit together. But because the brackets need to be placed in a very specific position, each person had to look closely from the top through the gap between the two modules (Figure 9.6).
- Half of the people connected the modules in one try. They did not notice the thumb sliders at first (Figure 9.3), but noticed the latches were in the way of sliding the module into place.
- One person did not use the thumb sliders to attach the inverter module, which worked well, but needed some force.
- Three people needed a hint to look closely at the handles, when attaching the modules. For instance, in Figure 9.1, a person thought they had finished attaching the module, but the latches were not in the right place.
- All users found the handles to be ergonomically sound, and had a nice grip.

One thing that interfered with the setup was the lack of weight of the docking module. In reality, this module would weigh around 30Kg, so it would not move easily. But in this test, the docking module would slide on the floor, causing people to be confused and using their fingers to keep it in place when sliding the module into place.

Conclusions

- The tolerances on the final interlocking should be loose. The modules should find their right position by themselves without complex top-gazing.
- The thumb sliders should be more visible. In the final product, this is achieved by making this part a bright orange colour. This same principle was extended to the interlocking brackets. This was already described in the requirements but validated in this test.

Figure 9.1. 9.2, 9.3, 9.4, 9.5 & 9.6
Pictures From the User Testing With the Proof of Concept Prototype



9.2 Docking Module Thermal Management

RQ9.2: How effectively does the integrated thermal management system of the docking module dissipate heat?

9.2.1 Approach

To answer research question RQ9.2, two distinct scenarios are tested with Solidworks Simulation. The specifications of the Tycorun battery can be found in Appendix P. Using the theory from Chapter 3.2, the input variables can be calculated (Appendix R).

Scenario 1: Standard Operating Load

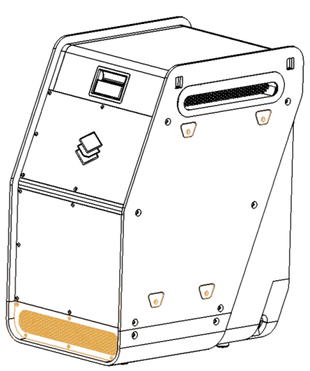
- 30A continuous
- 2.16kW output power
- 3% heat dissipation → 28W
- Environmental Boundary conditions: 40°C.

Scenario 2: Maximum Sustained Peak Load

- 60A peak
- 4.32kW output power
- 3% heat dissipation → 108W
- Environmental Boundary conditions: 40°C.

Chapter 8.3 shows a selected 40°C thermal switch. This would be the ambient temperature within the sleeve to trigger the fan. To compare the thermal load, one simulation is run without a fan. This is the control group to compare the impact of the fan and the cooling channels. If the fan can sustain a continuous peak load, it can handle all thermal loads.

The inner surface of the battery's aluminium casing serves as the heat source. The fan is a 120 × 120 × 25 preset comparable to the selected fan from Chapter 8.



9.2.2 Scenario 1 Results

Figures 9.7 and 9.8 show clear results. When the battery can heat up freely, it will can reach nearly 300°C. With LFP's thermal runaway temperature around 270°C, using this system without a fan would result in a catastrophic chemical fire. In reality, safety measures within the BMS would prevent this by shutting off the battery when it reaches a certain temperature. When the fan is turned on, the temperature is stabilised around 43°C. This is an acceptable temperature for continuous loads, because temperatures between 45°C and 55°C are the maximum continuous limit. Above 60°C, cell health is compromised. This shows that the fan is adequate for consistent load scenarios.

9.2.3 Scenario 2 Results

Figures 9.9 and 9.10 show results similar to those of the first scenario. Without a fan, temperatures of 750°C mean catastrophic failure. This is logical if the system already fails dramatically at 30A. With the fan, the final temperature stabilised around 52°C. For a peak load of 4kW, this is a good result. The fact that the thermal management system can handle the peak load as a continuous load means that the thermal management is more than sufficient.

9.2.4 Other Results

Figures 9.11 and 9.12 illustrate a flaw in the thermal management system. The air vectors show that air enters through the sides and flows down them as intended. Most of the air is blown out through the front of the dock, which is good, since that outlet is harder to physically block in user scenarios. But near the rear, air gets sucked back into the plenum base through the water outlet. This results in a circulation pattern that runs counter to the flow of water. This circulation could also cause the air to flow less quickly near the rear of the battery, resulting in uneven cooling. TRL 5 testing could show if the impact here is significant.

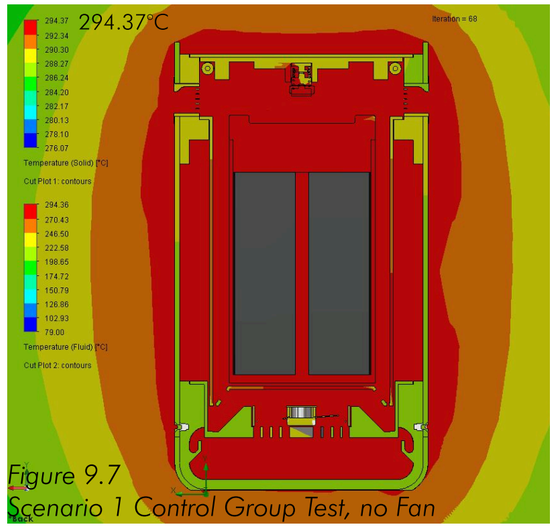


Figure 9.7
Scenario 1 Control Group Test, no Fan

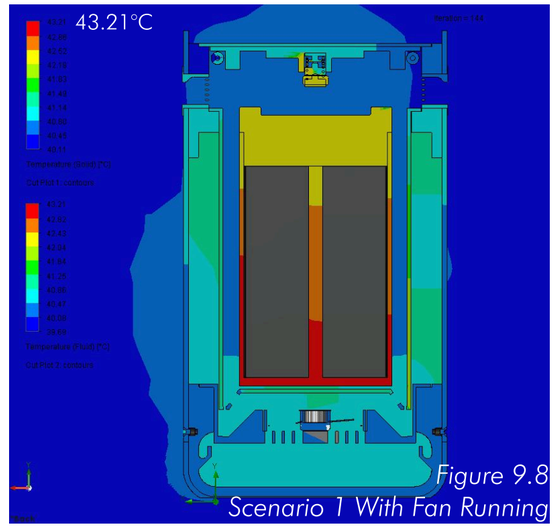


Figure 9.8
Scenario 1 With Fan Running

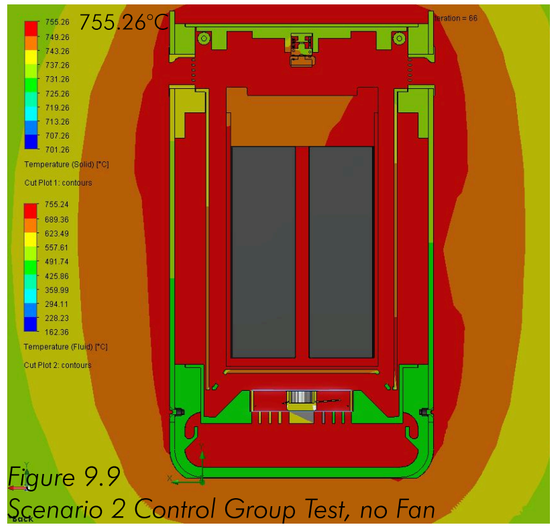


Figure 9.9
Scenario 2 Control Group Test, no Fan

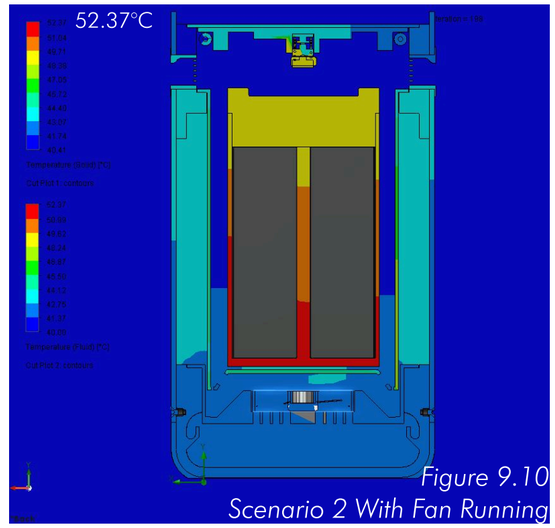


Figure 9.10
Scenario 2 With Fan Running

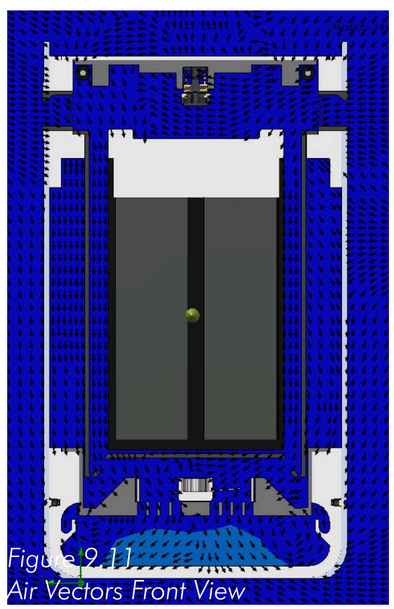


Figure 9.11
Air Vectors Front View

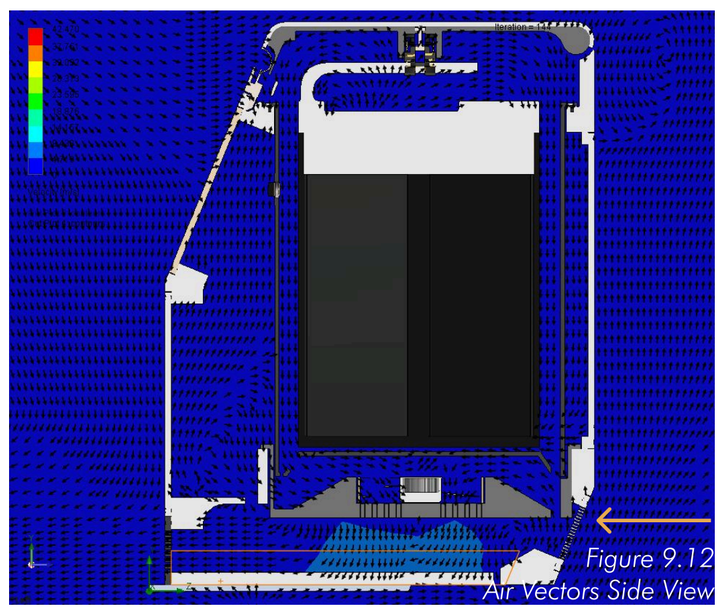


Figure 9.12
Air Vectors Side View

9.3 Integrated Functional/Geometric Prototype User Test

RQ9.3: To what degree does the integrated hybrid concept system satisfy the established performance baselines within a simulated operational environment?

9.3.1 The prototype

To answer RQ9.3, The integrated functional/ geometric prototype was built. It is functional in a mechanical sense. The docking and clamping of the battery are realized fully as modelled. Also, the inverter module can physically slide into and interlock with the docking station using the final handles and bracket designs. It connects “electrically” with dummy Chogori plugs. It is geometrical because it validates the footprint of the final design, as well as the tolerances, form and allocation/spacing of the ports.

Figure 9.13
Integrated Prototype Rear Ports

Figure 9.14
Integrated Prototype

Figure 9.15
Integrated Prototype

Figure 9.16
Integrated Prototype Battery Loading Dock

9.3.2 User Test Approach

The purpose of the user test is to evaluate the physical interaction and ergonomics of the Node Bawa system within a simulated operational environment. A sample size of 8 participants took part in the user testing.

The “simulated operational environment” consists out of the following components:

- Node Bawa Inverter + docking modules
- Tycorun 72V LFP Battery
- Object that represents a LEV
- Small PV panel (representing input option)
- Laptop + charger (representing AC appliance)
- Phone + charger (representing DC appliance)

The evaluation is structured around four core tasks. Following each task, participants rate their agreement with specific usability statements on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

The four primary tasks are designed to isolate and evaluate specific physical interactions with the system's external and internal interfaces. There is no user manual and there are no further instructions. The user is expected to figure out the tasks based on the use cues and physical attributes.

Task 1: Modular Assembly

- Participants physically connect the Inverter Module to the Docking Module to evaluate the ergonomics of the lifting handles, the intuitive use of the orange visual cues, and the alignment tolerances of the locking mechanism.

Task 2: Battery Docking:

- Using the dummy Tycorun 72V LFP battery and the object representing the LEV, participants simulate unloading a battery and loading it into the docking module to assess docking ergonomics and the internal cable connection.

Task 3: Solar Charging

- Participants connect the small PV panel to the corresponding input port to validate the clarity of the port accessibility and labelling.

Task 4: Appliance Powering

- Utilizing the laptop and phone chargers, users connect AC and DC appliances to the respective output ports and operate the physical toggle switches to test the overall visual hierarchy and logical layout of the ports.

The user test content can be found in Appendix R.

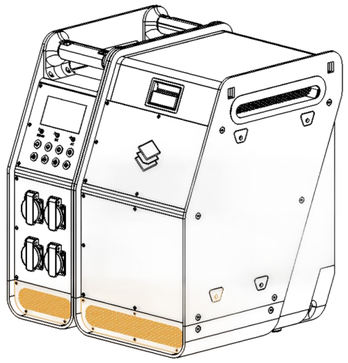


Figure 9.17
User Test Simulated Operational Environment

9.3.3 Task 1 results

Task 1 Modular Assembly: *Set up the system. Please connect the Inverter Module (the one the left) to the Docking Module (the one on the right). Connect them electrically (with the plug), and mechanically (using the grey handles).*

Electronical Connection:
Figure 9.25 shows that six out of eight users had little problem finding the right connection. One user tried to plug in the connector to the port on the other side of the inverter module (Figure 9.18).

Mechanical Connection:
Three of the eight participants gripped the inverter module with the panel grips on the side rather than the handles. (Figure 9.19). Still, they managed to connect the modules without too much hassle. The outlier in Figure 9.24 is a participant who used the wrong gripping location and failed to connect the modules correctly. Connecting the modules was confirmed by an audible 'click ', providing satisfying feedback and confirming the connection task.

Product Improvement Takeaways:

- In this instance, the electrical connection using the Chogori plug needs to happen prior to connecting the modules mechanically. A future iteration should place the ports on the rear of the inverter module, so the connection order does not matter.
- The orange use cues on the handle are not sufficient. A future iteration should include more visual cues, such as arrows or symbols, to make the user grip the correct handles.

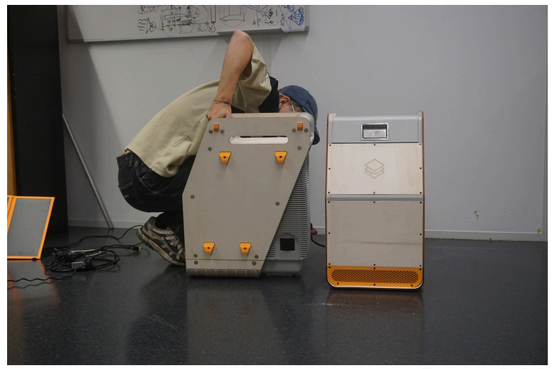


Figure 9.18
A User Struggling to Find the Right Chogori Port

Figure 9.19
A User Uses the 'Wrong' Handles for Connecting the Modules

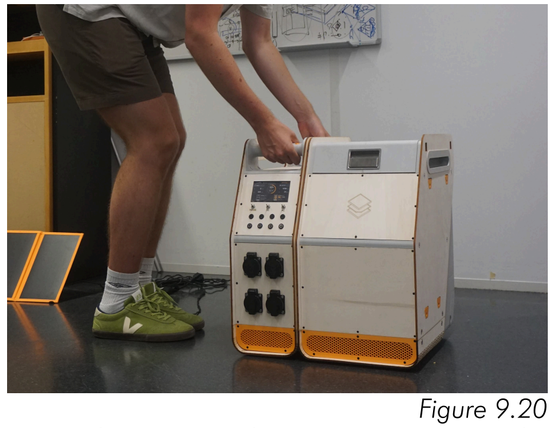


Figure 9.20
Other Users Had No Issues Connecting the Modules

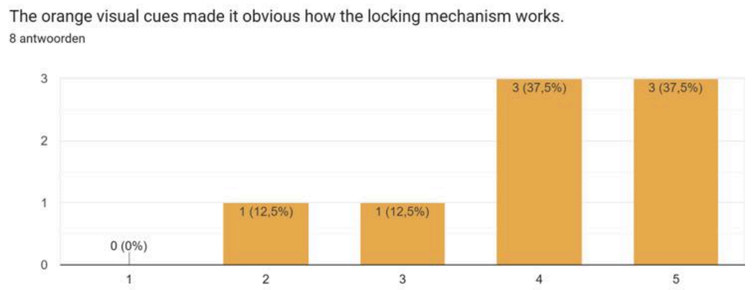


Figure 9.21

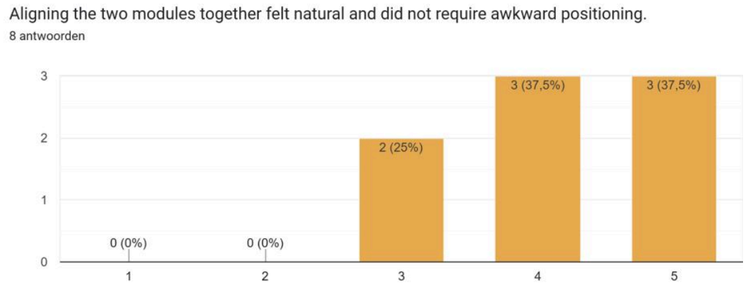


Figure 9.22

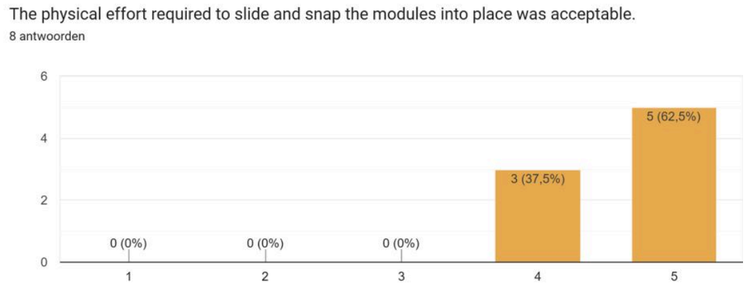


Figure 9.23

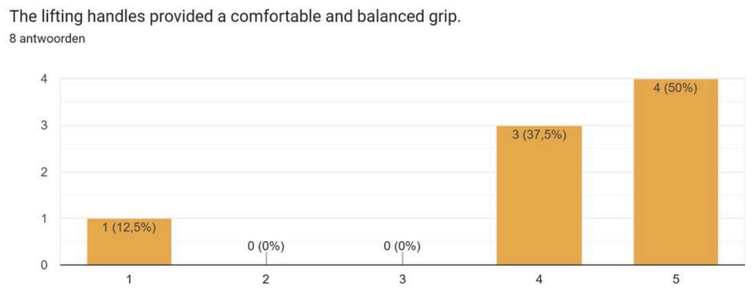


Figure 9.24

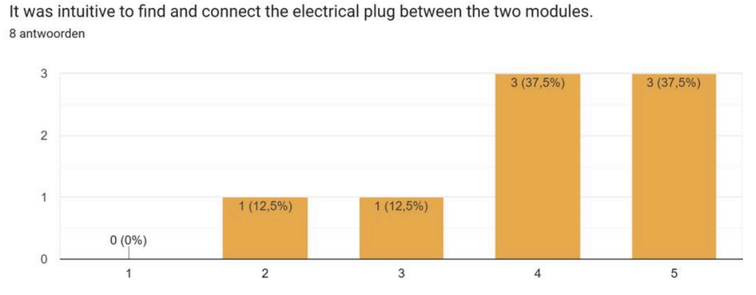


Figure 9.25

9.3.4 Task 2 results

Task 2 Battery Docking: You just arrived with your electric scooter. Please remove its battery, place it in the docking station, and connect the internal cable.

Figure 9.26
A User Inserts the Battery in a Correct Way

Finding the right place and orientation:
At first, about half of the participants were confused about where the battery had to go. Seven out of the eight participants inserted the battery in the right orientation (Figure 9.26). One participant had the battery orientation reversed (Figure 9.27). They still managed to connect the Chogori cable to the battery, but the cable being on the wrong side obstructed the lid when closing (Figure 9.31). All users felt confusion about how much force to apply to close the lid and needed a nudge. This is also because the participants felt they had to handle the prototype carefully. There was also one participant who felt the urge to hold the lid open to insert the battery.

Figure 9.27
A User Has Inserted the Battery in the Wrong Orientation

Connecting the cable:
Many participants experienced little to no issues connecting the cable and reported that the lid was not in the way when inserting the battery and connecting the cable.

Product Improvement Takeaways:

- The placement of the cable should be more towards the corner of the battery. Approaching it that way makes the cable shorter, which in turn makes it clearer that the Chogori port should be near the cable.
- The inside of the lid should include visual cues about the battery alignment.
- The outside of the lid should include visual cues to make it clear that it holds the battery.

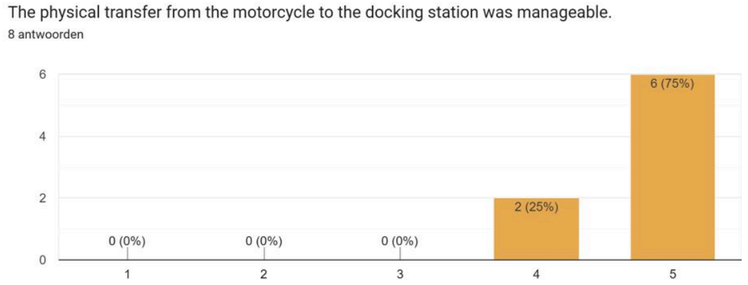


Figure 9.28

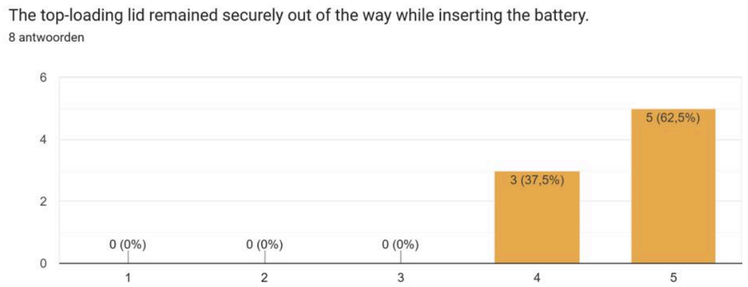


Figure 9.29

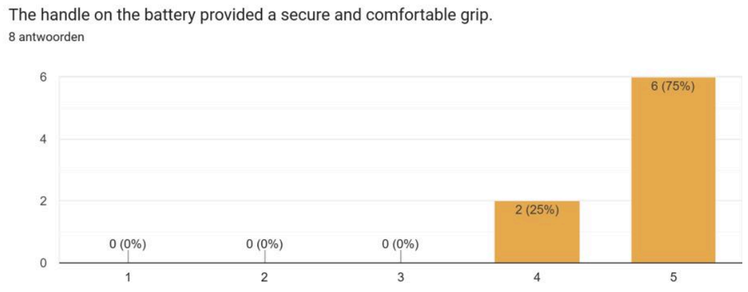


Figure 9.30

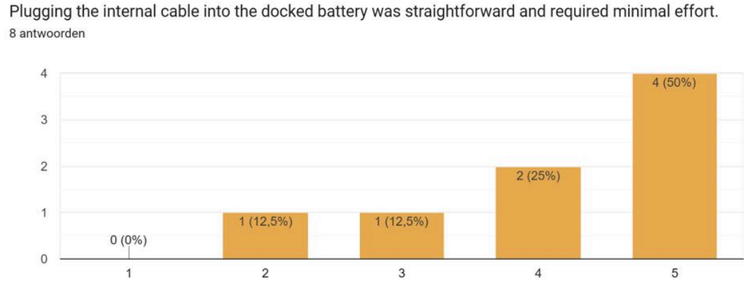


Figure 9.31

9.3.5 Task 3 results

Task 3 Solar Charging: Connect the solar panel cable to the appropriate port on the system to begin charging the battery.

Figure 9.32
A User Has Found the PV Input Port

Figure 9.33
A User is Searching for the PV Input Port

Finding the right port:
All participants were initially looking at the front of the inverter to connect the solar panel, and expressed confusion of the location of the port (Figure 9.33, 9.34 and 9.35). All needed around a minute to locate the port at the rear side of the inverter module. The labelling of the input ports was not clearly visible from the perspective of the user (Figure 9.36). It also does not help that the labelling is badly visible as a result of the manufacturing method (Figure 9.13).

Product Improvement Takeaways:

- In a real, stationary setting, the charging cables would stay connected to the input ports. So functionally, the port locations make sense, but the ports are difficult to locate without prior knowledge. Future iterations should include visual cues indicating the locations of the input ports on the rear of the inverter module.

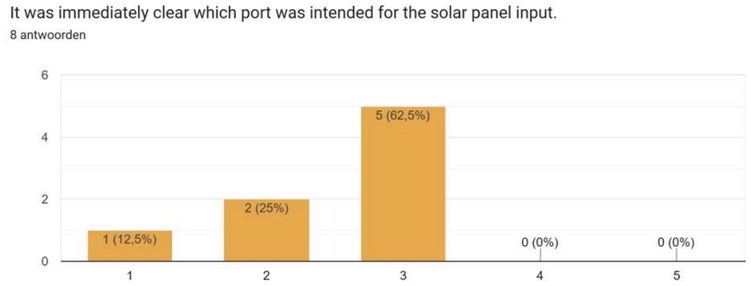


Figure 9.34

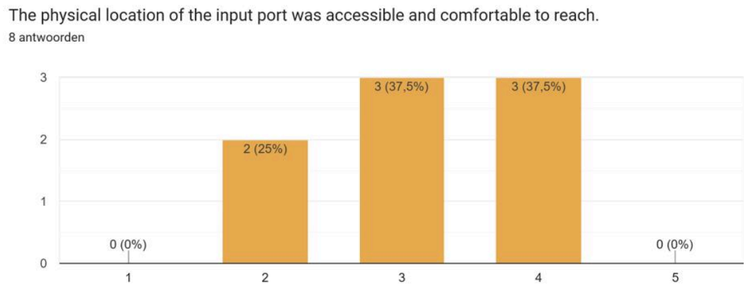
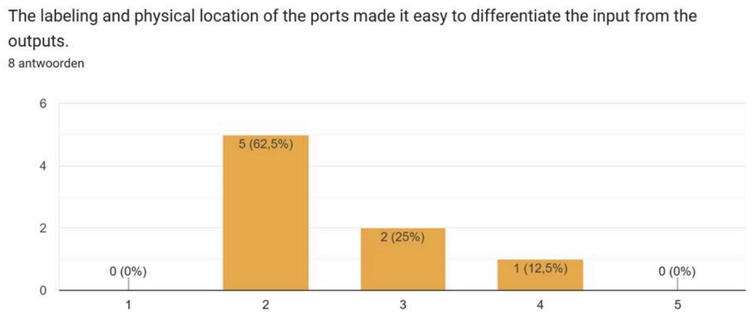


Figure 9.35



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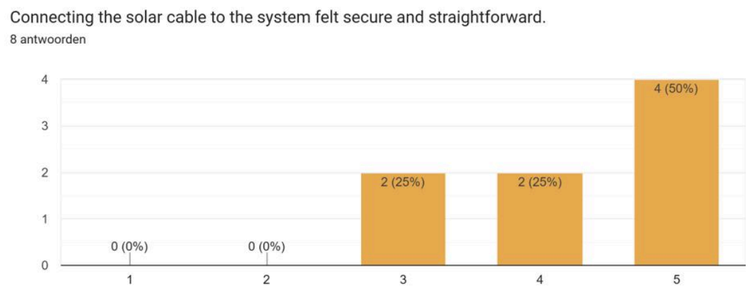

Figure 9.37

9.3.5 Task 3 results

Task 3 Appliance Powering: You have to charge the laptop and phone using the system. Connect them to the Node Bawa and turn on the power for the respective ports.

Finding the right ports:
The AC plug and USB-C cable are very familiar to the participants, and none experienced any difficulty finding the right port (Figure 9.38, 9.40 and 9.41).

Figure 9.38
A User Plugs in the USB-C Cable

Flipping the respective toggle switches:
The three toggle switches, labelled Power, DC and AC, caused some confusion among all the participants (Figure 9.42 and 9.43). The power switch was very straightforward, but none of the participants remembered whether the connected port was DC or AC, even though all of them are engineering students. One participant also interpreted the toggle switches as belonging to the two ports below them, rather than to the entire section of ports. One person just turned on all the switches to make sure everything was on. Other users shared that they would flick the switch to see if the device was charging or check the display for feedback.

Figure 9.39
A User is Confused Which Toggle Switches to Flip

Product Improvement Takeaways:

- Even though comparable micro storage products consistently use the DC and AC labelling, this terminology is not sufficient for the participants, let alone the target audience. In future iterations, the layout of the front panel should be redesigned so that it is clear which ports belong to which switch.

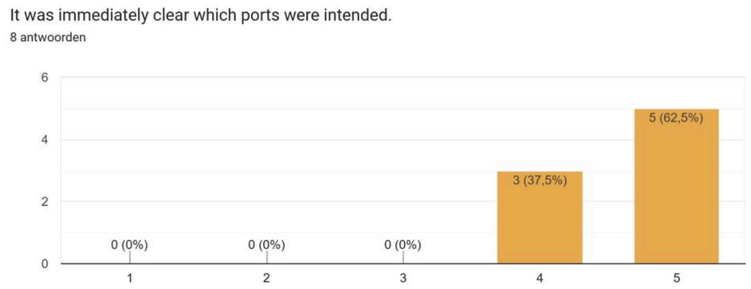

Figure 9.40

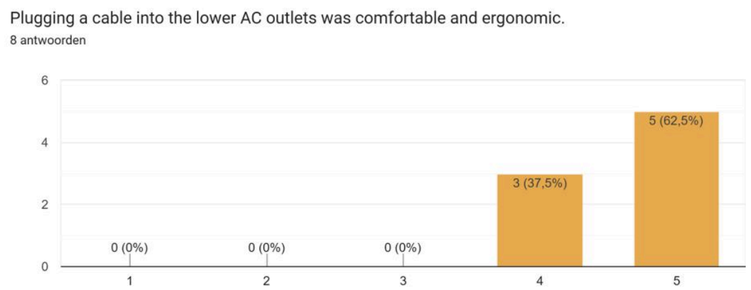

Figure 9.41

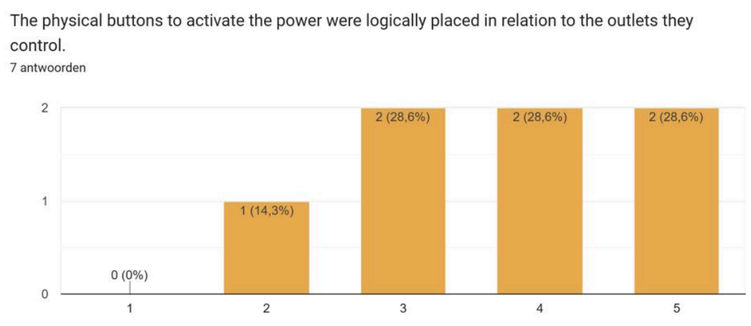

Figure 9.42

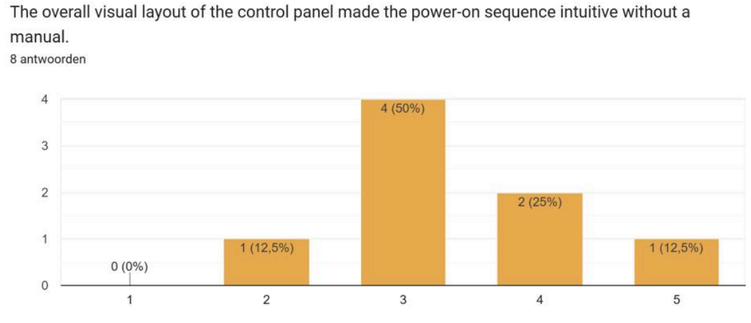

Figure 9.43

9.4 Chapter Conclusions

RQ9.1 How intuitive is the physical alignment and latching interface of the split-module coupling mechanism for independent users?

The modular interconnections were tested twice. Using the PoC model, it was confirmed that the latching interface is viable. There were two important insights from this validation. Firstly, the alignment tolerances were tight, requiring the user to gaze from the top to slide the brackets into their positions. Secondly, users did not initially see the thumb sliders that must be engaged for the locking procedure.

The integrated prototype improved on the PoC model by using colour-coded use cues for both the thumb sliders and the interlocking brackets. Also, the brackets were redesigned to improve sliding motion. The final coupling mechanism of the two modules was mechanically and ergonomically successful. The modules interlock beautifully, and the thumb sliders are not necessary to couple them (only for decoupling). Some users used the 'wrong' handles to interlock the modules, but they were still successful in their task. Nevertheless, additional visual cues should be implemented to guide the user to use the correct handles.

RQ9.2 How effectively does the integrated thermal management system of the docking module dissipate heat?

SolidWorks Simulation was used to validate the thermal management of the docking module. Simulating a continuous power (2.16kW) and peak power (4.32kW) scenario for steady-state operation. Both scenarios had promising results, with temperatures well within the safe temperature tolerances for LFP batteries. The fact that the system can handle peak loads for unlimited periods proves it can handle any load.

Even though the ventilation is sufficient, the simulation showed one flaw in the system. At the rear side of the docking module, air is circulated through the holes meant for water redirection. The rear air outlet is not actively engaged at all. In subsequent iterations, the rear air outlet could be fully removed, or the water and air channels could be redesigned to prevent air from circulating.

RQ9.3 To what degree does the integrated hybrid concept system satisfy the established performance baselines within a simulated operational environment?

The user tests with the integrated prototype consisted of four main tasks ranging from coupling the modules to connecting appliances. In the end, all eight participants successfully completed the tasks without any instructions or display feedback. There was some confusion in some of the tasks.

- The gripping handles were not used by three out of eight participants.
- The Chogori input on the inverter module was hard to find for at least one participant.
- It was not immediately clear that the docking module should house the battery and in which orientation it should be inserted.
- The input ports on the rear side of the inverter module were hard to find and required a minute of searching.
- Finding the right DC and AC outlets was easy, but the labelling on the toggle switches was unclear.

All confusion about the tasks was due to insufficient use of visual cues. Further development should include more visual cues and an improved hierarchy of the user interaction components.

Synthesis

10

10.0 Introduction

Chapter 1 sketched the energy context through literature research. Through analysis of the BUGS and their shadow grid, informal economies, MTF, OGS kits, and the introduction of black-box Energy Storage Systems, a clear gap was identified. Chapter 2 focused solely on project formulation, including the target audience, research objectives & questions, methodology, and project roadmap.

Chapters 3 to 6 embody the analysis phase. Chapter 3 laid the technical foundation for understanding energy storage systems and battery technology. Chapter 4 used comparative disassembly mapping to explain the Dirty & Open and Clean & Closed archetypes introduced in Chapter 1. Chapter 5 connected the parallel mobility industry and argued that informal refuelling economies are bound to be replaced by battery swapping ecosystems. Chapter 6 wrapped up the analysis with user research in Bali and introduced the hybrid opportunity of combining energy storage and battery-swapping ecosystems.

Chapters 7 to 9 embody the concept development phase. Chapter 7 introduced the final concept with the split-module architecture. Chapter 7 also includes an in-depth PoR and contextual renderings of the final product concept in its projected context. Chapter 8 breaks down the concept development across four functional clusters. Chapter 9 closes the concept development by validating some of the core functionalities using a PoC model, SolidWorks Simulation and an integrated prototype.

This final chapter zooms out to synthesise all the insights from the two phases into conclusions and recommendations. 10.1 will evaluate the final architecture against the original research objectives and the POR. 10.2 will critically reflect on the boundaries of the research, cultural ethnocentrism, and validation limits. 10.2 will also address the strategic, financial, and partnership realities required to bring open-source hardware to market. Finally, 10.3 will conclude the text body of this report with a note on AI usage across the project.

10.1 Conclusion: a Clean & Open System

10.1.1 The Design Challenge

The originally formulated assignment was to design a TRL 3-4 product concept for a modular micro storage system to demonstrate the feasibility of a Clean & Open energy architecture for Tier 3-4 productive users in the weak-grid contexts of the Global South.

Those productive users are now mostly dependent on fossil-fuelled BUGS, which are noisy and polluting, but highly serviceable. The clean alternatives are designed as black boxes, making them virtually unrepairable. This *serviceability gap* does not resonate with complex informal economies, where copycat products lack official repair centres and original products are maintained far beyond their expected lifespans and warranties.

Tightly interwoven is the mobility industry, where independent mobility shares characteristics with its energy-supplying counterparts. Owning a motorcycle is just as common as owning a bicycle in the Netherlands, and these share the same informal economies as the BUGS. As fossil-fuelled ICE motorcycles are slowly phased out in favour of LEVs, the informal refuelling industry will be replaced by battery-swapping stations and BaaS business models.

The result of this thesis is Node Bawa. Chapter 7 explained that the name refers to the structural junction where the leaf and stem join on a plant. As explained in Chapter 1, the plummeting costs of solar result in “leaves” spreading rapidly across the Global South. But in this metaphor, the leaves cannot grow into trees without proper “nodes” to the “stem” (grid/electricity use).

Node Bawa is not only repairable/open but also combines the emerging market for swappable LEV batteries with traditional ESS within the footprint of a traditional BUG.

10.1.2 Commercial Standardization

Whether your BUG runs on diesel or gasoline, you could get these fuels at every (informal) fuel station. Chapter 5 investigated the emerging battery-swapping industry and highlighted a paradoxical market, oversaturated with brands and battery types, each using different loading mechanisms and ports and compatible only with their own scooters. It is like having dozens of fuel types to choose from at a fuel station.

Honda and Gogoro are in a neck-and-neck race to reach a single standard across the industry but are doing so under the protection of a patent shield and epoxy-filled, black-boxed batteries. To truly empower local mechanics and informal economies, there is a need for an open-source, repairable battery.

But instead of designing yet another battery and ecosystem, Node Bawa opts for flexibility. The Global South cannot wait for a universal battery standard, and needs to adapt to current, local availability. For this open-source, modular “node” to succeed, Node Bawa needs to piggyback on the mass-manufacturing scale of commercial entities (such as the Tycorun ecosystem). The decentralised, Solarpunk vision requires commercial standardisation to work.

This flexibility also acts as a necessary buffer against an impending e-waste crisis. When a closed-ecosystem manufacturer goes bankrupt or changes its battery dimensions, thousands of perfectly healthy batteries are left behind. Node Bawa functions as an adaptable intermediary to ensure the core product survives these market shifts. Uncoupling the long-lasting inverter and docking station from the battery sleeve itself prevents premature obsolescence in a highly unpredictable industry.

10.1.3 Program of Requirements

To ensure Node Bawa successfully bridges the gap between high performance energy storage and local serviceability, the architecture was continuously evaluated against the four core categories of the Program of Requirements. Chapter 9 detailed the physical and theoretical validation of some of these requirements.

The final TRL 3/4 product concept is a starting point for developing the final product architecture, and the PoR is a relevant guiding tool for that development. But in this stage of the process it is not very relevant to directly validate all the requirements as if it is a finished product. There are some core requirements that remain consistent in further development. Some of these requirements are:

Performance:
Key Requirements: P3 (PV/AC charging), P4 (Independent AC/DC output control), P6 (Docking module active cooling), and P7 (Inverter module active cooling).

Requirement P6 was validated via SolidWorks thermal simulations (Chapter 9.2). The simulations proved that the integrated fan successfully stabilizes the battery temperature around 43°C and 52°C during standard and peak loads. P3 and P4 were functionally assessed during user testing of the integrated prototype (Tasks 3 and 4), verifying that users could successfully charge the system and power appliances.

Repairability/Openness:
Key Requirements: R1 (Exposed screws), R3 (Standardized fasteners), R5 (Docking adaptability), and R6 (Understandable physical architecture).

The open architecture is best visualized through disassembly maps (Appendix S). These maps show a horizontal and shallow distribution, similar to the disassembly map of the Tiger generator in Chapter 4. This guarantees an understandable physical architecture (R6) that is highly intuitive for technicians to navigate. By strictly utilizing exposed screws (R1) and standardized fasteners (R3) across the entire product, the whole system can be disassembled using only standard Allen keys. Along with its docking adaptability (R5), these disassembly maps serve as direct proof that Node Bawa is an open system.

Safety:
Key Requirements: S1 (IP-certified ports), S2 (Electronics separated from water entry points), S3 (Water redirection), and S4 (Unblockable ventilation).

Requirements S2 and S3 were functionally embedded into the docking module. (Chapter 8.4). The air channels were dual-purposed to act as water channels, utilizing a sloped plenum base to safely redirect accidental rainwater out the back. S4 was addressed by placing the air vents at the front of the device, and using color-coded grilles as a visual deterrent.

Use/Ergonomics:
Key Requirements: U1 (Generator footprint), U14 (Color-coded affordances), U15 (Modular architecture), U16 (Clearance for locking handles), and U17–U19 (Intuitive docking and lid interaction).

The final system has dimensions of 499 × 440 × 558mm, validating U1. Ergonomics and affordances underwent the most validation (Chapter 9.1 and 9.3). Task 1 of the user tests evaluated the grip and physical clearance of the handles (U16), while Task 2 assessed the physical transfer and lid interactions of the docking module (U17-U19). The effectiveness of the color-coded cues (U14) was also tested. while mostly successful for locking mechanisms, the tests revealed that other interactions also require visual cues in future iterations.

10.2 Discussion & Recommendations

10.2.1 Cultural Context & Validations

The target group of this thesis was the Global South, a collection of developing countries and low- and middle-income regions that share specific socio-economic and infrastructural challenges. Because this group spans roughly half the globe and encompasses innumerable cultures and societies, the term "Global South" inherently becomes an impossibly broad generalization.

As stated in Chapter 2.2, products, services, and other designed manifestations play a symbolic role in society. To understand that symbolic role, it was crucial to apply the concept of ethnorelativism. Figure 2.5 illustrates six distinct layers moving from ethnocentrism to integration. To avoid the pitfalls of cultural bias inherent in a university setting in the Global North, I traveled abroad to conduct research within the microcosm of Bali, Indonesia. Although achieving full "integration" was impossible during a short visit, conducting local research enabled at least "acceptance" or "adaptation" during the analysis phase. The final hybrid concept would not have been possible without this fieldwork; however, I cannot claim this project is entirely free of cultural bias. Particularly in the concept development phase, relying on local university facilities and networks to realize the final prototype introduced significant limitations:

- Aesthetic Validation: In section 8.2.5, the final aesthetic direction was established based on the visual language of other modular products and the requirements outlined in Chapter 7. Consequently, the final design aesthetic was not directly informed or validated by the target audience. There was no user validation involving individuals from the Global South during these latter stages of the design process.
- Usability Testing: The validations in sections 9.1 and 9.3 focused primarily on the ergonomics and usability of the product. However, these user tests were conducted using a convenience sample of fellow students. Relying on a homogeneous sample of participants outside the target demographic may introduce design biases or lead to skewed conclusions. While the validated ergonomic principles are largely universal, this reliance on convenience sampling remains a distinct methodological limitation.

This “convenience sampling” can be seen as a systemic symptom of early-stage development. To successfully reach TRL 4, the immediate priority was proving the core ergonomics and mechanical integrity of the concept architecture. Achieving this technical baseline required temporarily abstracting the user to isolate the hardware variables. However, moving this concept forward to TRL 5 requires a complete shift in environment. The prototype needs to be de-colonized by leaving the academic vacuum and reintegrating the cultural friction and unpolished realities of the Global South. The true test of the open architecture will only happen when it is handled by the technicians it was actually designed for.

10.2.1 Recommendations

Product-level recommendations discussed in Chapter 9 are primarily focused on user experience, including additional visual cues and affordances to strengthen the visual hierarchy. Implementing these micro-improvements keeps the product at TRL 3/4. To lift this prototype to TRL 5, more serious changes are necessary. At TRL 5, the product should be tested in a relevant context and be fully functional. The progression across Technology Readiness Levels is far from linear. To lift this TRL 3/4 prototype into a mass-manufactured product with established logistics requires substantial capital and time. Industry and engineering estimates suggest roughly 2.5 to 5 years and an investment between $500k and $2M to realize this project. These resources are currently not available to Biosphere Solar, and finding investment of this caliber proves very difficult for open-source hardware projects.

To overcome this financial barrier without abandoning the open-source vision, the project must lean on strategic partnerships to survive. The factory visits around Suzhou showed that the knowledge and hardware are already in place, and these companies need little additional input to turn the concept into a feasible product. Biosphere Solar has also recently partnered with GreenESS. They manufacture a stationary energy storage system using large, proprietary swappable batteries integrated into light electric vehicles (LEVs), along with smaller proprietary batteries for power tools and mobile use. While their product form factor does not resonate directly with Tier 3-4 users, it functions as a hybrid solution. Their current primary market is Australia, but they are open to supplying their product under Biosphere Solar’s brand to the Global South, with field tests in Bali set to start later this year.

However, if Biosphere wishes to keep its focus on impacting the shadow grid, a smaller, more portable version needs to be developed in parallel. By partnering with this company, Biosphere Solar can use validated hardware in combination with an in-house-designed open casing, as presented in this report.
Lastly, Biosphere needs to partner with established local battery swapping platforms, such as Tycorun. Introducing a new, proprietary battery such as the GreenESS battery also means rolling out their proprietary line of LEVs. To plug into the current transition from internal combustion engines to LEVs, partnering with an established major battery supplier is essential to present a relevant solution for the weak-grid contexts of the Global South.

10.3 A Note on AI Usage

10.3.1 AI as a Booster, not a Convenience tool

Throughout the process of this thesis, I've received feedback on the amount of work I had accomplished in a short time, even though I was working on a part-time basis. I've never used AI as a tool to replace my work so I can do less. I think I could have done half the work I put into this thesis and still delivered an acceptable result. I found that AI, when used as a companion, can boost productive engagement and help accomplish more in the same time span.

In hindsight, it is hard to break down exactly where AI has produced which results. But in this paragraph, I will try to clarify the added value.

10.4.2 AI Tools and Their Applications

Google Gemini 3.6 Flash and 3.1 Pro:
Gemini was the all-round AI sparring partner of choice. This is what it was used for:

- At the start, it was used to research topics to do the thesis on. I used it to identify the widespread use of generators and OGS kits in the Global South and establish the gap in the market.
- Structuring the report. I used Gemini in back-and-forth interactions to develop logical approaches to structuring the chapters and their contents based on the archetypes and research materials.
- Generating additional requirements for the POR.
- Generating the user validation form for the integrated prototype user tests.
- Technical questions, such as the components in the docking module, their electrical wiring, manufacturing tolerances, material choices, PCB spatial envelope estimations, ESS calculations for CC equivalents, mounting of gas struts, etc.
- Lingual matters, such as the glossary, and which keywords or concepts to write in cursive.

Nano Banana Pro:

- Integrated in Gemini and Figma. It was used to draw rough concept approaches, as well as UI design for the display, rendering sketches, removing backgrounds from images, and stretching and editing images.

NotebookLM:
This tool is powered by Gemini.

- Used for academic research. Identifying connections between reports or finding scientific basis for the statements that I envisioned in my narrative. It also helped me find more relevant academic sources when those were necessary. I would just ask something along the lines of "Is there anything about the 'closed' or 'black box' design of e-mobility batteries?"
- Used it to make the reference list in APA and to write the abstract.

OtterAI:

- I used Otter to transcribe and translate my interviews. Then it was used to summarise the insights. The summarised insights were copied into a new file and given to NotebookLM, which was then used to identify similarities and differences between the interviews.

Vizcom:

- This tool was used to make the realistic renderings. Although I did my own renders in Keyshot, I used Vizcom to place those renderings in relevant contexts of the Global South or make the studio renderings more realistic. The prompts for Vizcom were generated by Gemini.

Grammarly:

- An AI-based spelling and grammar tool was used to fix broken sentences or sentences that were hard to read. I did not use this tool to rewrite whole parts, just to improve the grammar.

References

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Visual References

Ahmed, A. (2025, March 24). Honda Activa E Review – Well-Rounded Electric Scooter Needs Strategy Swap. Car&Bike. https://www.carandbike.com/reviews/honda-activa-e-review-wellrounded-electric-scooter-needs-strategy-swap-3216471

Akkushop Schweiz. (n.d.). Akkushop-Schweiz. https://www.akkushop-schweiz.ch/bosch-powertube-625-wh-vertikal-e-bike-akku-3-6-volt-17-4ah-41-6cm-lang/

Alibaba.com: Manufacturers, Suppliers, Exporters & Importers from the world's largest online B2B marketplace. (n.d.). https://www.alibaba.com/search/page?scene=invalid_items_initiate_imgsrch&tab=all&SearchScene=imageTextSearch&productId=1600868741657&spm=a2700.details

Battery-swapping intelligent cabinet. (2026, April 20). www.winboard.cn. https://www.winboard.cn/products/battery-swapping-intelligent-cabinet

Becell Battery. (2025, September 23). GREAT Penghui 40135 20Ah LFP Battery - Becell Battery. https://www.becellbattery.com/shop/great-penghui-40135-20ah-lfp-battery/

CoLtd, H. C. T. (n.d.). Customizable electric motorcycle battery-swap cabinet for shared leasing and takeout lithium batteries fast swapping station. Hunan CTS Technology Co,.Ltd. https://www.ctsbattery.com/sale-53933806-customizable-electric-motorcycle-battery-swap-cabinet-for-shared-leasing-and-takeout-lithium-batteri.html

EcoFlow. (n.d.). EcoFlow Delta Series. EcoFlow.com. https://eu.ecoflow.com/products/delta-3-series-portable-power-station?variant=49573797495127

Elvidge, J., & Elvidge, J. (2020, September 21). New tech could make electric ADV bikes viable sooner than you think. ADV Pulse. https://www.advpulse.com/adv-news/electric-adventure-bike-new-technology/

Honda e:Swap. (2023, April 11). Honda e:Swap | Battery Sharing Service | Honda Power Pack Energy India [Video]. YouTube. https://www.youtube.com/watch?v=VcHjXZvEFGU

Hunan Chalong Fly Technology Co., Ltd. (n.d.). CLF 12V 30AH Solar Street Light Lithium Battery for solar garden light emergency light LiFePO4 2000cycles. https://www.lithium-batterypack.com/sale-36829346-cltf-public-charging-cabinet-battery-swap-module-ev-scooter-motorcycle-ebike-solar-battery-swapping-.html

Infinite Battery. (n.d.). Gouach Infinite Battery. https://infinite-battery.com/

Jumbo Shark. (n.d.). Grandado. https://gbr.grandado.com/products/jumbo-shark-ebike-hailong-case-batteries-housing-polly-max-load-80pcs-91pcs-18650-cells-battery-36v-48v-52v-electricbattery-box?variant=UHJvZHVjdFZhcmlhbnQ6MTQ0NjcyNzI1

Mars, A. (2026, 27 april). Technology readiness levels. Coanda Research & Development. https://coanda.ca/blog/trls/

Parikh, S. (2025, August 25). VinFast to install 150,000 battery-swapping stations in Vietnam - electrive.com. electrive.com. https://www.electrive.com/2025/08/25/vinfast-to-install-150000-battery-swapping-stations-in-vietnam/

Randall, C. (2024, March 6). LG Energy Solution launches scooter battery-swapping network with Kooroo - electrive.com. electrive.com. https://www.electrive.com/2024/03/06/lg-energy-solution-launches-scooter-battery-swapping-network-with-kooroo/

Redway, & Redway. (2024, November 25). How do 18650, 21700, and 26650 batteries compare? | Redway Tech. Redway Tech | Deep Cycle LiFePO4 Batteries Wholesale. https://www.redway-tech.com/how-do-18650-21700-and-26650-batteries-compare/

Schluep, M. (2023, May 25). African E-Waste experts trained in inclusive recycling. World Resources Forum. https://www.wrforum.org/projects/sri/ewaste-recycling-training-africa/

Tycorun battery-swap station. (2023, May 10). TYCORUN 5 ports swap station system for scooters ebike motorcycle batteries - TYCORUN. China Best Battery-swap Station System Solution Suppliers - TYCORUN. https://batteryswapstation.com/product/5-ports-swap-station/#listing-home

Williams, S. (2016b, November 17). The Gogoro SmartScooter: Clever tech behind the small-but-mighty EV | EV Performance. EV Performance. https://evperformance.co.uk/gogoro-smartscooter-clever-tech-behind-small-mighty-ev/

Yigetech. (n.d.-b). Let us delve deep into what makes the 4680 battery cell so special and its wide-reaching impact. Let Us Delve Deep Into What Makes the 4680 Battery Cell so Special and Its Wide-reaching Impact. https://www.neexgent.com/news_251.html

Literature References

Access to Energy Institute (A2EI) & Dalberg. (2019). Putting an End to Nigeria's Generator Crisis: The Path Forward. https://a2ei.org/resources/uploads/2019/06/A2EI_Dalberg_Putting_an_End_to_Nigeria's_Generator-Crisis_The_Path_Forward.pdf

Ali, Z. M., Calasan, M., Gandoman, F. H., Jurado, F., & Abdel Aleem, S. H. E. (2024). Data-driven reliability analysis of lithium-ion batteries based on experimental capacity fade under different temperature conditions. Ain Shams Engineering Journal, 15(1), 102442. https://doi.org/10.1016/j.asej.2023.102442

Ali, Z. M., Calasan, M., Gandoman, F. H., Jurado, F., & Abdel Aleem, S. H. E. (2024). Review of batteries reliability in electric vehicle and E-mobility applications. Ain Shams Engineering Journal, 15(1), 102442. https://doi.org/10.1016/j.asej.2023.102442.

Aqidawati, E. F., Sutopo, W., & Pujiyanto, E. (2020, August 10–14). Lesson learned in developing and implementing global business strategy to commercialize battery-swap technology: A comparative study. In Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management, Detroit, Michigan, USA.,

Baazouzi, S., Feistel, N., Wanner, J., Landwehr, I., Fill, A., & Birke, K. P. (2023). Design, properties, and manufacturing of cylindrical li-ion battery cells—A generic overview. Batteries, 9(6), 309. https://doi.org/10.3390/batteries9060309

Bali Fat Bike Cycling – Bali Eco – Tourism at its Best! We feature Fat Tire Electric-Bicycles. (n.d.). https://balifatbikecycling.com/

Bassey, C. (Ed.). (2025, September). Generators in Nigeria. Nigerianinfolink. https://nigerianinfolink.com/tips-managing-generator-fuel-consumption-nigeria/small-scale-online-digital-hustles/

Baurzhan, S., & Jenkins, G. P. (2016). Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? Renewable and Sustainable Energy Reviews, 60, 1405–1418.

BattaBox. (2012, January). Crazy Nigeria: A Generator Republic. . . (Real-Life Nollywood movie) [Video]. Youtube. https://www.youtube.com/watch?v=gBUWB8atYoY

CNBC International Live. (2024, June 3). An inside look into Gogoro's cutting-edge battery factory [Video]. YouTube. https://www.youtube.com/watch?v=BOTyG632lT8

The Battery Doctor. (2020, February 24). Bosch PowerTube 500 Wh - Complete Teardown [Video]. YouTube. https://www.youtube.com/watch?v=3HQfAxmuxQE

The Battery Doctor. (2025, July 31). Is the Gouach Infinite Battery really that good? [Video]. YouTube. https://www.youtube.com/watch?v=aiPpziWvY3c

Battery & screen - Spark. (2022, September 6). Spark. https://sparkenergy.io/product/battery-screen/

Bhatia, M., & Angelou, N. (2015). Beyond connections: Energy access redefined (Technical Report 008/15). Energy Sector Management Assistance Program (ESMAP).

Bhowmick, S., & Ghosh, N. (Eds.). (2022). Sustainable development in action: Examining Global North-South divergences. ORF and Global Policy Journal.

Cabanero, A., Nolting, L., & Praktiknjo, A. (2020). Mini grids for the sustainable electrification of rural areas in Sub-Saharan Africa: Assessing the potential of KeyMaker models. Energies, 13(23), 6350.

Van Boeijen, A., Daalhuizen, J., Zijlstra, J., & Van der Schoor, R. (2020). Delft design guide: Design strategies and methods (Revised 2nd ed.). BIS Publishers.

Van Boeijen, A., & Zijlstra, Y. (2020). Culture sensitive design: A guide to culture in practice. BIS Publishers.

Collett, K. A., Byamukama, M., Crozier, C., & McCulloch, M. (2020, February). Energy and transport in Africa and South Asia: State of knowledge paper. Energy and Economic Growth Applied Research Programme; Oxford Policy Management.

Chien, Y.-H., & Hsieh, I.-Y. L. (2025). Toward net-zero future: The potential of vehicle-to-grid (V2G) strategies for electric scooter battery-swap stations. Sustainable Cities and Society, 118, 106004. https://doi.org/10.1016/j.scs.2024.106004,

Cross, J. (2019). The solar good: Energy ethics in poor markets. Journal of the Royal Anthropological Institute, 25(S1), 47–66.

Cross, J., & Murray, D. (2018). The afterlives of solar power: Waste and repair off the grid in Kenya. Energy Research & Social Science, 44, 100–109. https://doi.org/10.1016/j.erss.2018.04.034

EcoFlow. (2025, September 26). EcoFlow DELTA 2 Power Station - EcoFlow.nl. EcoFlow.nl. https://www.ecoflow.nl/producten/power-stations/delta/delta-2/detail/1366/ecoflow-delta-2-power-station.html

EcoFlow. (2022, September 14). What's inside DELTA 2 | Portable power station teardown [Video]. YouTube. https://www.youtube.com/watch?v=OTUVaISLnrQ

Elektrisch vervoer - Light electric vehicles - Nederland. (n.d.). https://duurzamemobiliteit.databank.nl/mosaic/en-us/elektrisch-vervoer/light-electric-vehicles

de Fazio, F., Bakker, C., Flipsen, B., & Balkenende, R. (2021). The Disassembly Map: A new method to enhance design for product repairability. Journal of Cleaner Production, 320, 128552. https://doi.org/10.1016/j.jclepro.2021.128552.

French, eco-friendly lithium batteries | VoltR. (n.d.). https://www.voltr.tech/en

Gabbar, H. A., Othman, A. M., & Abdussami, M. R. (2021). Review of battery management systems (BMS) development and industrial standards. Technologies, 9(2), 28. https://doi.org/10.3390/technologies9020028

Gachaco, Inc.Gachaco will provide sharing service of standardized swappable batteries for electric motorcycle. - News Releases | Yamaha Motor Co., Ltd. (n.d.). Yamaha Motor Co., Ltd. https://global.yamaha-motor.com/news/2022/0330/corporate.html

Garroum, S. (2025, 4 november). Why Solarpunk is already happening in Africa. Climate Drift. https://climatedrift.substack.com/p/why-solarpunk-is-already-happening

GOGLA. (2024). Annual report 2024.

GOGLA. (n.d.). Methodology of the sales data collection.

Guillou, E., & Girard, B. (2023). Mini-grids at the interface: The deployment of mini-grids in urbanizing localities of the Global South. Journal of Urban Technology, 30(2), 151–170. https://doi.org/10.1080/10630732.2022.2087170

Gouach. (2025, April 22). Infinite Battery - Assembly Guide [Video]. YouTube. https://www.youtube.com/watch?v=8q-EEXqXcCA

Hirmer, S., & Guthrie, P. (2017). The benefits of energy appliances in the off-grid energy sector based on seven off-grid initiatives in rural Uganda. Renewable and Sustainable Energy Reviews, 79, 924–934.

Honda e:Swap. (2023b, April 11). Honda e:Swap | Battery Sharing Service | Honda Power Pack Energy India [Video]. YouTube. https://www.youtube.com/watch?v=VcHjXZvEFGU

Honda Introduces Initiatives for the Utilization of Honda Mobile Power Pack, portable and swappable batteries. (n.d.). https://hondanews.eu/be/nl/corporate/media/pressreleases/350819/honda-introduces-initiatives-for-the-utilization-of-honda-mobile-power-pack-portable-and-swappable-b

Honda Power Pod e: | Honda公式サイト. (n.d.). Honda公式ホームページ. https://www.honda.co.jp/battery/e1500/

Hoymiles. (n.d.). HiBattery 1920 AC. https://www.hoymiles.com/products/hibattery-1920-ac.html

Huahe Heavy Industries. (2025). Huahe 650W Home Used Portable Gasoline Generator 50Hz 63cc with 2-Stroke Engine. Alibaba. https://www.alibaba.com/product-detail/

Huahe-650W-Home-Used-Portable-Gasoline_1601380249679.html?spm=a2700.prosearch.normal_offer.d_image.288e67afDGBzIJ&priceId=3dabb43e8edb4deca0a9a4570e132923

Huang, F.-H. (2020). Understanding user acceptance of battery-swapping service of sustainable transport: An empirical study of a battery-swap station for electric scooters, Taiwan. International Journal of Sustainable Transportation, 14(4), 294–307. https://doi.org/10.1080/15568318.2018.1547464

Hwang, J.-Y., Myung, S.-T., & Sun, Y.-K. (2017). Sodium-ion batteries: present and future. Chemical Society Reviews, 46, 3529–3614. https://doi.org/10.1039/C6CS00776G.

Infinite Battery. (n.d.-b). Gouach Infinite Battery. https://infinite-battery.com/

International Electrotechnical Commission. (2005). IEC INTERNATIONAL STANDARD 60364-4-41: Low-voltage electrical installations (No. 60364-4–41). http://erlerdesign.com/download/ESD/old_iec60364-4-41_protection_shock_inst_buildings.pdf

International Finance Corporation (IFC). (2019). The dirty footprint of the broken grid: The impacts of fossil fuel back-up generators in developing countries. World Bank Group.

Kirpes, B., Danner, P., Basmadjian, R., de Meer, H., & Becker, C. (2019). E-Mobility Systems Architecture: A model-based framework for managing complexity and interoperability. Energy Informatics, 2, Article 15. https://doi.org/10.1186/s42162-019-0072-4

Krebs, S., & Weber, H. (Eds.). (2021). The persistence of technology: Histories of repair, reuse and disposal. transcript Verlag. https://doi.org/10.14361/9783839447413.

Li, W., Wang, J., Sun, C., Fan, X., Gong, L., Huang, J., Wu, J.-H., Yu, G., Chen, R., Li, J., & Duh, Y.-S. (2025). Comparison on thermal runaway and critical characteristics of cylindrical lithium-ion batteries: A review. ACS Chemical Health & Safety, 32(2), 133–156.

Life Where I'm From. (2023, September 24). Is Taiwan's battery-swap tech the future of EVs? [Video]. YouTube. https://www.youtube.com/watch?v=HpOQpwKeSnI

Lin, M.-D., Liu, P.-Y., Yang, M.-D., & Lin, Y.-H. (2021). Optimized allocation of scooter battery-swapping station under demand uncertainty. Sustainable Cities and Society, 71, 102963. https://doi.org/10.1016/j.scs.2021.102963.

Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. World Development, 28(12), 2083–2103.

Mobile Power Pack | Business and Innovation | Honda Global. (n.d.). Honda Global Corporate Website. https://global.honda/en/mobilepowerpack/world/

Motorized menace. (n.d.). The World of Chinese. https://www.theworldofchinese.com/2019/10/motorized-menace/#:~:text=Five%20years%20later%2C%20the%20rules,to%20ride%20in%20bike%20lanes.

Munro, P. G., Samarakoon, S., Hansen, U. E., Kearnes, M., Bruce, A., Cross, J., Walker, S., & Zalengera, C. (2022). Towards a repair research agenda for off-grid solar e-waste in the Global South. Nature Energy, 7(12), 1125–1132.

Practical Action. (2019). Poor people's energy outlook 2019: Enabling energy access from village to nation. Practical Action Publishing.

Quinn, J. B., Waldmann, T., Richter, K., Kasper, M., & Wohlfahrt-Mehrens, M. (2018). Energy density of cylindrical Li-ion cells: A comparison of commercial 18650 to the 21700 cells. Journal of The Electrochemical Society, 165(14), A3284–A3291. https://doi.org/10.1149/2.0281814jes

Prause, L., & Dietz, K. (2022). Just mobility futures: Challenges for e-mobility transitions from a global perspective. Futures, 141, 102987. https://doi.org/10.1016/j.futures.2022.102987

Rahmawatie, B., Sutopo, W., Fahma, F., Nizam, M., Purwanto, A., Louhenapessy, B. B., & Mulyono, A. B. (2017, October). Designing framework for standardization and testing requirements of battery management system for electric vehicle application. In 2017 4th International Conference on Electric Vehicular Technology (ICEVT) (pp. 17–22). IEEE. https://doi.org/10.1109/ICEVT.2017.8323526

Rateau, M., & Choplin, A. (2022). Electrifying urban Africa: Energy access, city-making and globalisation in Nigeria and Benin. Urban Studies, 59(1), 57–80.

Reynolds, O., & Paixão, S. (2024). Global off-grid solar market report: Annual sales & impact data (2024 Public Report). GOGLA.

Ritley, K. (2019, February). Cable clutter. https://ritley.com/first-impression-of-vietnam-what-cables-tell-you-about-culture/. https://ritley.com/first-impression-of-vietnam-what-cables-tell-you-about-culture/

Robert Bosch GmbH. (2025). Your eBike Battery Guide (No. 4054289016807). Retrieved March 31, 2026, from https://www.bosch-ebike.com/fileadmin/EBC/Service/Downloads/Akku_Guide/Akku_Guide/Bosch-eBike-Akkuguide-EN-GB.pdf

Robinson, K. S. (2020). The Ministry for the future.

Scott, A., Darko, E., Lemma, A., & Rud, J.-P. (2014). How does electricity insecurity affect businesses in low- and middle-income countries? (Report). Overseas Development Institute (ODI).

SUMEC FIRMAN SPG2500. (2026). IFESOLOX. https://ifesolox.com/products/sumec-firman-spg2500-100-copper-petrol-generator

Sun King | Lights, TVs & Appliances. (2025, October 13). Sun King. https://sunking.com/solar-home-systems-and-appliances/

Tiger TG950 Small Generator. (2020, May). GenGuide. https://genguide.com.ng/best-portable-small-generators-in-nigeria/

Thurber, M. (2024). Assessing energy technology leapfrogs (Issue Brief). Energy for Growth Hub.

The Upshift. (2026, January 9). This e-Bike battery rewrites all the rules [Video]. YouTube. https://www.youtube.com/watch?v=vfiH7PKu-XE

Utoh, I.-O., Ekpotu, W., & Obialor, M. (2024). Assessing the viability and impact of off grid systems for sustainable electrification of rural communities in Sub-Saharan Africa (SPE-221709-MS). Society of Petroleum Engineers.

Vishnumurthy, K. A., & Girish, K. H. (2021). A comprehensive review of battery technology for E-mobility. Journal of the Indian Chemical Society, 98, 100173. https://doi.org/10.1016/j.jics.2021.100173.

Waleed, K., & Mirza, F. M. (2022). Examining fuel choice patterns through household energy transition index: An alternative to traditional energy ladder and stacking models. Environment, Development and Sustainability, 25, 6449–6501.

Weinert, J., Ogden, J., Sperling, D., & Burke, A. (2008). The future of electric two-wheelers and electric vehicles in China. Energy Policy, 36(7), 2544–2555. https://doi.org/10.1016/j.enpol.2008.03.008

Wikipedia contributors. (2026, February 13). EcoFlow. Wikipedia. https://en.wikipedia.org/wiki/EcoFlow

Zebra, E. I. C., van der Windt, H. J., Nhumaio, G., & Faaij, A. P. C. (2021). A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. Renewable and Sustainable Energy Reviews, 144, 111036.

Zhang, Y., Wang, C.-Y., & Tang, X. (2011). Cycling degradation of an automotive LiFePO4 lithium-ion battery. Journal of Power Sources, 196(3), 1513–1520. https://doi.org/10.1016/j.jpowsour.2010.08.070

Appendix

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A. CERN-OHL-S-v2 License

CERN Open Hardware Licence Version 2 - Strongly Reciprocal

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8.6 This Licence shall not be enforceable except by a Licensor acting as such, and third party beneficiary rights are specifically excluded.

B. Generator Statistics & Pollutants

B1. Generator Statistics

1. The entire fleet has an estimated replacement value of 70 billion dollars, with an annual investment of 7 billion dollars.
2. 75% of the sites where generators are deployed are actually ‘grid-connected.’ However, as described in paragraph 1, people cannot rely on the grid to meet their energy needs.
3. About 98% of the generators are small Bugs (<60kW).
4. In sub-Saharan Africa, generators provide 9% of total electricity consumed. In western Africa, this figure jumps to over 40% of annual electricity consumption.
5. Bugs consume 55 Litres of fuel annually (38 billion Litres of diesel and 17 billion Litres of gasoline). In SSA, 20% of all liquid fuel (gasoline and diesel) is burned specifically for electricity generation.
6. In the ten low- and middle-income countries with the largest fleets, there is one generator for every 165 people. In Nigeria, there is one generator for every 60 people.
7. Nigeria is the largest market for backup generators in the Global Southdue to a grid that provides only about 30 Watts per person.
8. Nigerian manufacturing firms are heavily dependent on self-generation, with 86% owning or sharing a generator.
9. In Nigeria, 47.5% of electricity used by firms comes from generators. The industrial sector reportedly spends as much as $17 billion annually on generator operations
10. Electricity from Bugs is significantly more expensive than grid power. Users spend $28-50 billion annually with a marginal cost of 0.30/kWh, compared to grid-based energy, which ranges from $0.10 to $0.30/kWh
11. Operation and maintenance (O&M) costs add 10% to 20% to the already high fuel service costs.
12. In Sub-Saharan Africa, Bugs account for most power sector emissions of nitrogen oxides (NOx) and fine particulate matter (PM2.5). Their PM2.5 emissions account for 35% of the region's transportation sector emissions.

(NotebookLM (2026) was used to formulate the list above from the sources referenced in this report)

B2. Generator Pollutants

1. **Particulate Matter (PM2.5):** refers to tiny particles with a diameter of 2.5 micrometres or less. It is considered the best indicator for health risk because these particles can penetrate deep into the lungs (IFC, 2019).
2. **Black Carbon (BC):** A component of PM2.5 formed by incomplete combustion, BC is a potent climate-forcing agent that absorbs solar radiation. Generators are a significant source of local BC emissions, especially in developing countries (IFC, 2019; Bhatia & Angelou, 2017).
3. **Organic Carbon (OC):** Another component of particulate matter that, along with BC, contributes to climate impacts by reflecting or absorbing radiation (IFC, 2019).
4. **Nitrogen Oxides (NOx):** These are primary byproducts of fossil fuel combustion. NOx is associated with respiratory illnesses and reacts with other chemicals in the air to form ground-level ozone and acid rain. In Sub-Saharan Africa, BUGS account for roughly 15% of total NOx emissions, equivalent to 35% of the transportation sector's emissions (IFC, 2019).
5. **Sulphur Dioxide (SO2):** Emitted from burning sulphur-containing fuels like diesel and kerosene, SO2 can exacerbate respiratory diseases and form secondary small particles that increase PM exposure. While minor at regional scales, SO2 is an important driver of local toxic exposure (IFC, 2019).
6. **Carbon Monoxide (CO):** CO is the leading cause of accidental poisonings globally. It poses an acute threat when small generators are used inside or too close to occupied buildings. It is also a precursor to ground-level ozone (IFC, 2019).
7. **Non-Methane Volatile Organic Compounds (NMVOCs):** This group includes hazardous chemicals like benzene, formaldehyde, and acetone. They evaporate easily and act as ozone precursors (IFC, 2019).
8. **Carbon Dioxide (CO2):** This is the most important contributor to global climate change. In Sub-Saharan Africa, the CO2 emitted by generators accounts for 20% of the region's total CO2 emissions from all vehicles* (IFC, 2019).
9. **Methane (CH4) and Nitrous Oxide:** These are also emitted during the combustion of fossil fuels in generators. Methane is specifically noted as a potential fugitive emission from associated energy systems (Zebra et al., 2021).
10. **Noise Pollution:** Although not a gas, excessive noise from generators contributes to the local burden of disease by increasing the risk of heart disease, cognitive impairment in children, and loss of sleep (IFC, 2019).
11. **Secondary Pollutants:** The combination of high NMVOC and NOx emissions makes generators a potent source for the formation of ground-level ozone (O3), which causes further respiratory damage (IFC, 2019).

(NotebookLM (2026) was used to formulate the list above from the sources referenced in this report)

**The IFC report often refers to generators as ‘vehicles’ because of their similar architecture.*

C. Second Order and Grassroots Effects

Solar Energy and access to (clean) energy in general generate profound second-order and grassroots effects that extend far beyond simple illumination, transforming education, health, safety, and the economic structure of rural communities.

1. **Extended Learning Hours:** Access to light allows students to study after sunset, leading to better academic performance and higher quality of education (Utoh et al., 2024).
2. **Improved Enrolment:** Better academic performance directly correlates with higher school enrolment and grade completion rates (Bhatia & Angelou, 2015).
3. **Digital Literacy:** Access to computers and the internet allows students to develop digital skills and narrowing the educational gap between rural and urban areas (Utoh et al., 2024).
4. **Teacher Retention:** Reliable energy in schools helps attract and retain qualified teachers in remote areas by improving their living conditions (Bhatia & Angelou, 2015).
5. **Respiratory Health:** Replacing toxic kerosene lamps helps prevent pneumonia, tuberculosis, and chronic obstructive pulmonary disease (COPD), particularly in women and children (Bhatia & Angelou, 2015).
6. **Accident Prevention:** Solar systems reduce the risk of fire-related accidents and deaths caused by spilled fuel from kerosene lamps or candles (Bhatia & Angelou, 2015).
7. **Nutritional Improvements:** The introduction of solar-powered refrigeration facilitates improved food conservation and enhanced nutrition for rural households (Bhatia & Angelou, 2015).
8. **Clinical Efficacy:** Electrified health centres can power medical equipment, store life-vaccines in refrigeration units, and enable safer nighttime procedures and emergency responses, such as midwives reaching mothers more safely (Utoh et al., 2024).
9. **Mobility and Security:** Street lighting improves road safety, deterring robbery and attacks (Bhatia & Angelou, 2015).
10. **Protection from Wildlife:** Portable solar lanterns are highly valued for providing protection from dangerous animals, such as snakes, when users walk outdoors after dark (Bhatia & Angelou, 2015).
11. **Social Interactions:** Lighting facilitates evening social events and festivals, creating vital opportunities for community socialization and collective decision-making (Bhatia & Angelou, 2015).
12. **Extended Business Hours:** Public lighting and home systems create a safer environment for nighttime commercial activities, allowing shops and markets to remain open longer (Bhatia & Angelou, 2015).
13. **Micro-Enterprise Growth:** Solar access enables the establishment of new businesses, such as mobile phone charging stations, hairdressing salons, and grocery shops (Utoh et al., 2024).
14. **Income Generation:** Studies suggest that rural electrification can increase household income by 9% to 30% by extending work hours and improving net income for home-based non-farm enterprises (Bhatia & Angelou, 2015).
15. **Agricultural Productivity:** Solar-powered irrigation systems allow farmers to transition from seasonal to year-round irrigation, potentially increasing crop yields by 3 to 5 times and dramatically boosting annual revenue (Garroum, 2025).
16. **Financial Inclusion:** Solar-powered mobile phone charging is a critical first step that enhances social connectivity and financial inclusion by providing a platform for mobile banking and governance (Bhatia & Angelou, 2015).
17. **Social Mobility:** The role of mini-grid operator or technician often creates social mobility trajectories for local personnel, who gain authority and economic standing within their villages (Guillou & Girard, 2023).
18. **Air conditioning:** Access to energy allows for air conditioning, which can be lifesaving during future heat waves caused by global warming (Robinson, 2020).

(NotebookLM (2026) was used to formulate the list above from the sources referenced in this report)

D1: Context Mapping, Sensitising Booklet

Your Daily Life

kehidupan sehari-hari Anda

Feel free to write in Indonesian if that is easier for you!

Silakan menulis dalam bahasa Indonesia jika itu lebih mudah bagi Anda!

There are no wrong or right answers, only YOUR answers.
Tidak ada jawaban yang salah atau benar, hanya jawaban ANDA.

This is me!
Ini aku!

Name
Nama

Age
Usia

Profession
profesi

Religion
Agama

Place of residence
tempat tinggal

This is me!

Circle what is right for you
Lingkari pilihan yang tepat untukmu.

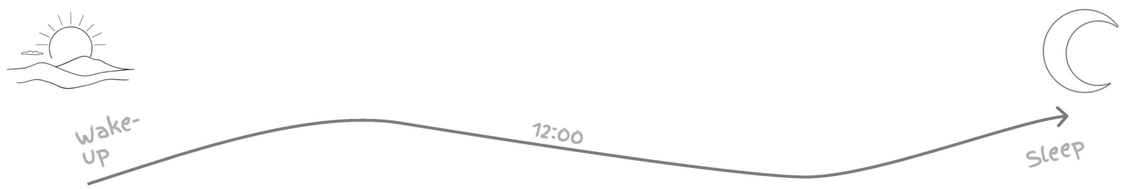
- I have a scooter | Saya punya skuter
- I have a bycicle | Saya punya sepeda
- I have a car | Saya punya mobil
- I have a generator | Saya punya generator
- I have solar panels | Saya punya panel surya
- I have a battery | Saya punya baterai

- I have other energy/transportation | Saya memiliki sumber energi/transportasi lain:

The education I've had
pendidikan yang telah saya dapatkan

What I do in free time
Apa yang saya lakukan di waktu luang saya

1 A day of my life
sehari dalam hidupku



Please show what you have been doing on a regular day in your life, from waking up until you go to sleep. Also show things that you think are normal. Did you take a scooter / bike somewhere? Grocery shopping? Went to work? Etc.

Tolong tunjukkan apa yang Anda lakukan pada hari biasa dalam hidup Anda, dari bangun tidur hingga tidur kembali. Tunjukkan juga hal-hal yang menurut Anda normal. Apakah Anda naik skuter/sepeda ke suatu tempat? Berbelanja kebutuhan sehari-hari? Pergi bekerja? Dan lain sebagainya.

1 A day of my life
sehari dalam hidupku

Please pick your most POSITIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen PALING POSITIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker yang tersedia dan jangan ragu untuk menggambar!

pengalaman paling positif saya hari ini adalah...

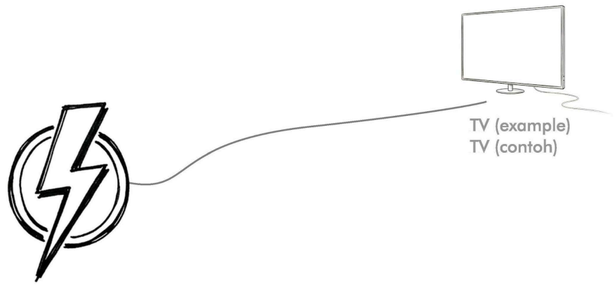
karena...

Please pick your most NEGATIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen TERNEGATIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker dan jangan ragu untuk menggambar!

pengalaman ternegatif saya hari ini adalah...

karena...

2 Where does my electricity go?
Ke mana aliran listrik saya?



Draw lines from the middle to all the devices you can think of, that you use or are in your house.

Gambarlah garis dari tengah ke semua perangkat yang Anda pikirkan, yang Anda gunakan atau yang ada di rumah Anda.

4 My Future
lingkungan saya

What do you want to do in the next 5 years from now? Write your friend about you plans and hopes. What is your ideal situation 5 years from now? How are you going to reach your goals? Do you need any extra education or training?

Apa yang ingin kamu lakukan dalam 5 tahun ke depan? Tuliskan rencana dan harapanmu kepada temanmu. Bagaimana situasi idealmu 5 tahun dari sekarang? Bagaimana kamu akan mencapai tujuanmu? Apakah kamu membutuhkan pendidikan atau pelatihan tambahan?

Kepada Yth. .....,

Dalam 5 tahun mendatang...

3 My Neighborhood
lingkungan saya

Please draw:
- **Your house**
- **Your families houses**
- **Your friends houses**
- **Your school**
- **Your grocery market**
- **Your work**
- **The routes you take to get there**

It does not have to be precise!

Silakan gambar:
- Rumahmu
- Rumah keluargamu
- Rumah teman-temanmu
- Sekolahmu
- Pasar swalayanmu
- Tempat kerjamu
- Rute yang kamu lalui untuk sampai ke sana
- Tidak perlu tepat!

Rumah

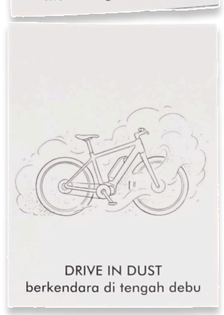
Thank You!
Terima kasih!

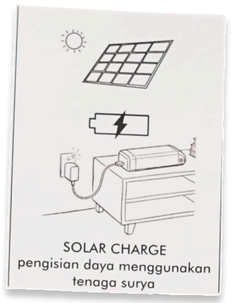
D2: Context Mapping, Preference Booklets

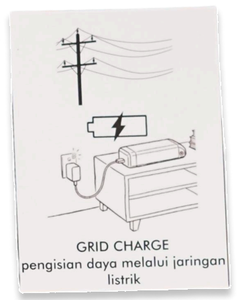
KEEP IN THE RAIN
tidak melindungi dari hujan

PROTECT FROM RAIN
melindungi dari hujan

DRIVE IN RAIN
berkendara di tengah hujan


DRIVE IN DUST
berkendara di tengah debu

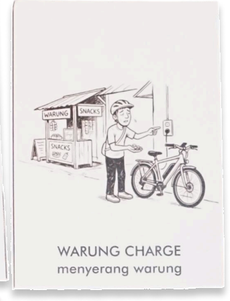

SOLAR CHARGE
pengisian daya menggunakan tenaga surya


GRID CHARGE
pengisian daya melalui jaringan listrik

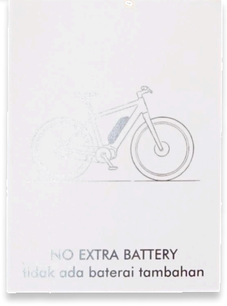
DRIVE IN RAIN
berkendara di tengah hujan

DRIVE IN SUN
berkendara di tengah terik matahari

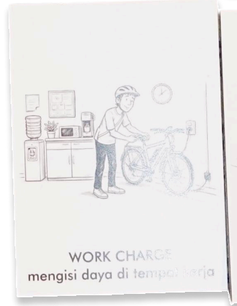
HOME CHARGE
mengisi daya di rumah



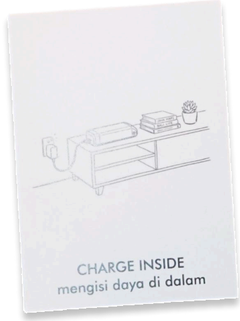
WARUNG CHARGE
menyerang warung

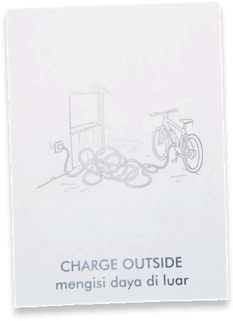

NO EXTRA BATTERY
tidak ada baterai tambahan

BRING EXTRA BATTERY
bawa baterai cadangan

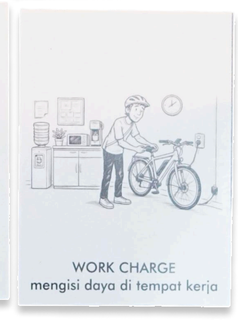

WORK CHARGE
mengisi daya di tempat kerja

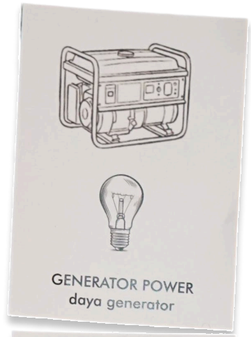
WARUNG CHARGE
menyerang warung

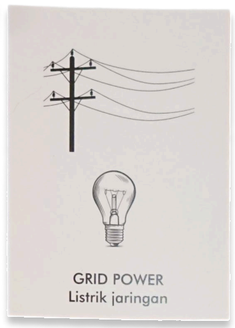

CHARGE INSIDE
mengisi daya di dalam


CHARGE OUTSIDE
mengisi daya di luar

HOME CHARGE
mengisi daya di rumah


WORK CHARGE
mengisi daya di tempat kerja


GENERATOR POWER
daya generator

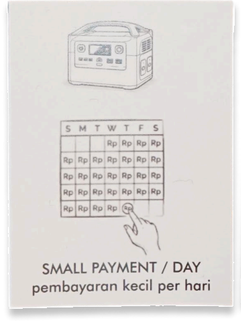

GRID POWER
Listrik jaringan

GENERATOR

BIG BATTERY
Baterai besar

2 000 000 Rp
NOISY GENERATOR
generator berisik

10 000 000 Rp
SILENT BATTERY
baterai senyap


SMALL PAYMENT / DAY
pembayaran kecil per hari

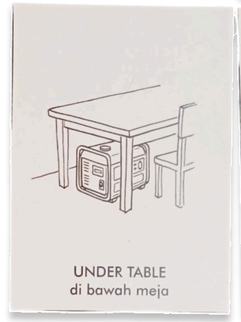
ONE BIG PAYMENT
satu pembayaran besar

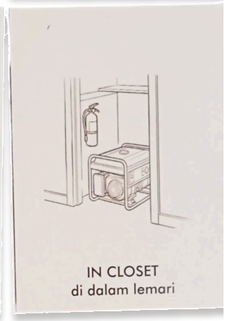
100 000 Rp 5 years

1 000 000 Rp 25 years

KEEP INSIDE
tetap di dalam

KEEP OUTSIDE
tetap di luar


UNDER TABLE
di bawah meja

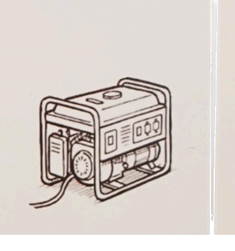

IN CLOSET
di dalam lemari

LIVING ROOM
ruang tamu

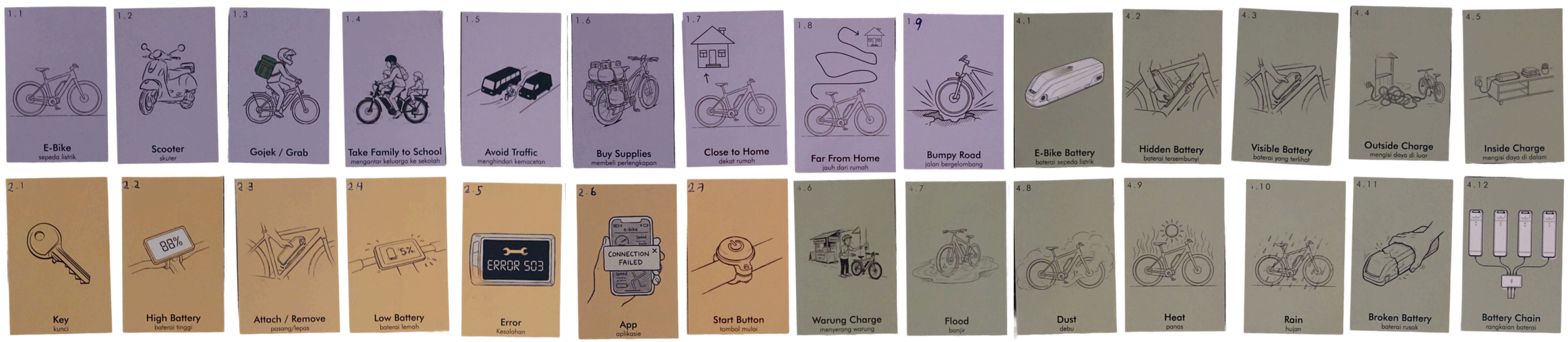
IN CLOSET
di dalam lemari

KEEP IN THE RAIN
tidak melindungi dari hujan

PROTECT FROM RAIN
melindungi dari hujan



D3: Context Mapping, Topic Cards



E: E-Bike batteries Market Examples

Here, the three models represent different grades of repairability in E-mobility.

3.3.3 E-bike Market Example: BOSCH

The *Bosch PowerTube* is an example of an e-bike battery that is a very popular choice for many e-bike manufacturers. It is only compatible with other Bosch hardware and costs between 300 and 500 euros for a replacement.

The Battery Doctor (2020), a Danish e-bike battery mechanic, performs a disassembly. The two caps are secured in place with eight safety-torx screws and thick rubber and foam sealing materials. The whole inner stack is very hard to remove from the aluminium extruded casing. Inside, the 18650 battery cells are stacked in tight vertical clusters, surrounded by cramped wires to string them all together. The BMS is printed on a *flexible PCB*, which is virtually un-repairable. The Battery Doctor (2020) says that there is a zero per cent chance they will take these in for repair.

Looking online, not a single company can take these in to revise the battery for a price that is lower than or equal to the price of a new battery. The time and effort required do not justify the optimised proprietary design of the Bosch PowerTube. When your PowerTube breaks or does not hold much charge, you replace it.

This is also what Bosch says themselves in their 2025 Battery Guide (Robert Bosch GmbH, 2025): all batteries lose capacity over time and e-bike batteries are also wearing parts. For safety reasons, you should not repair or refresh faulty, old, or worn-out batteries, but have them recycled appropriately. They support this by arguing that the certifications required for transport expire if the manufacturer or an authorised company does not carry out repairs. They encourage the user to recycle the battery in a proper way. This means that thousands of batteries with perfectly functioning components get scrapped every year.

But it is very likely that people throw away their batteries when the bike's action radius is no longer attractive enough to keep using them. Although the cells no longer have sufficient capacity to power an e-bike, they might still be *upcycled* for other purposes (The Upshift, 2026). There are already companies that focus on repurposing cells, such as *VoltR*. But Bosch does not have a system in place to collect and repurpose old batteries.

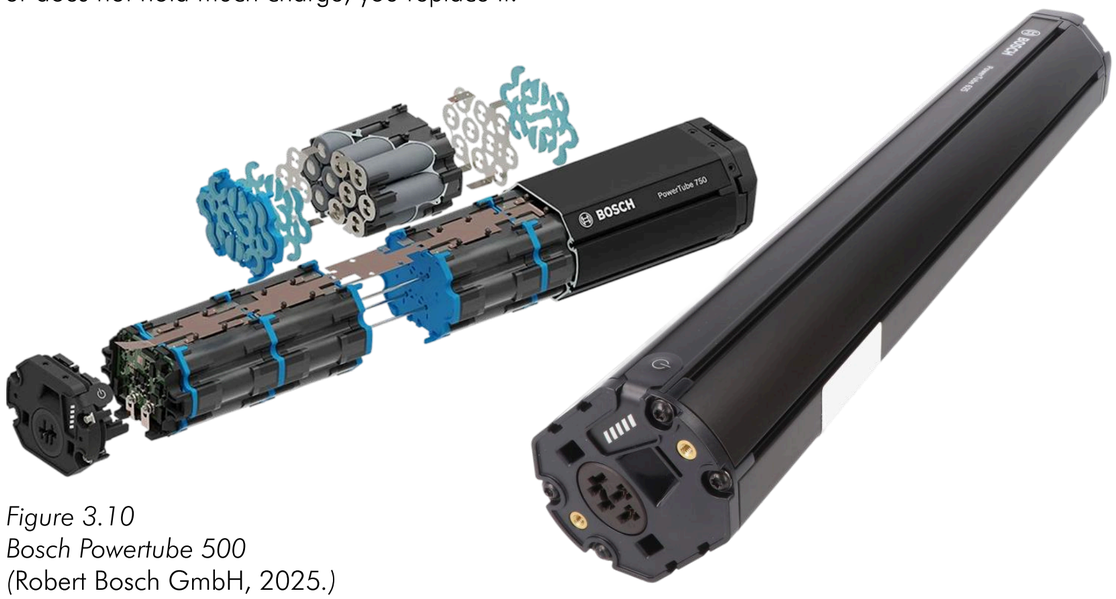


Figure 3.10
Bosch Powertube 500
(Robert Bosch GmbH, 2025.)

3.3.4 E-bike Market Example: HAILONG

The *Hailong battery* is widely used by many e-bike manufacturers as a cheap, ready to assemble battery case. In the Netherlands, you see re-branded versions everywhere on cheap e-bikes and fatbikes. To consumers, it is sold cheaply on sites like AliExpress for less than 50 euros for the case, nickel strips, *cell holder*, BMS, and the mount (Aliexpress, n.d.). The only thing that is sold separately is the battery cells. To assemble the unit, you would need a spot-welder, since regular soldering can damage the battery cells.

Compared to non-repairable batteries, you definitely sacrifice on the *water resistance*. Also, since the batteries are your responsibility, you must wrap the cells in *fire-retardant tape*, which is usually used on pre-packaged batteries.

The great thing about this battery is that you can easily remove the case with a standard *Phillips screwdriver*, unlike the *safety-torx* often needed for Bosch or Shimano batteries. This means that it is relatively serviceable, but replacing the cells still takes some effort and experience.

Figure 3.11
Hailong
(Jumbo Shark n.d.)

3.3.5 E-bike Market Example: GOUACH

Infinite Battery

Gouach is a Bordeaux-based start-up that is just reaching a point of commercialisation. They raised 3.5 million dollars through public funding to develop and realise the battery (Infinite Battery, n.d.-b). The company's size, values, and place in the development of its product are very similar to those of Biosphere Solar, except that Gouach is not explicitly open-source. But they are very transparent about their technology, showing exploded views, assembly videos, and explanation videos. They are also open to collaborating with manufacturers to make customised batteries. They have already developed batteries that are compatible with Bosch, Shimano, Bafang, Yamaha, Brose, Decathlon, and Rad. For instance, they make a repairable version of the Bosch PowerTube discussed in 4.2.2, showing that even uncommon shapes can be designed to be serviceable.

Gouach stands out because the battery can be assembled and disassembled within minutes, using basic tools that are also provided. They advertise it as modular, fireproof, and connected. Whilst other companies use glue, fire-retardant tape, uncommon screws, and spot-welded cells, Gouach solves these problems in different, *clever ways*, without sacrificing the certification. They have made significant progress in testing the batteries for vibration, drop, and *thermal-runaway* performance (The Battery Doctor, 2025).

Modularity
The casing can be opened by removing 10 standard Phillips screws. In between the two halves, a rubber seal prevents water from entering the battery case. The most interesting part is how the cells are clamped between two PCB halves, each housing pins that press firmly into the battery's poles, without soldering them (Gouach, 2025). This forms one solid battery pack with a slot for the dedicated BMS that is included in the package. With just a couple of bolts, the halves can be split, and the batteries or BMS can be replaced inside.

Fireproof
As discussed in 4.1, LIBs pose the risk of thermal runaway, especially when punctured with a metal object. Manufacturers circumvent this by tightly wrapping the cells in fire-retardant tape or foil, making it nearly impossible to access separate cells for replacement. Gouach solves this by encasing the battery pack in an aluminium housing. The aluminium can withstand the heat of thermal runaway, but it is more dangerous than plastic if it allows pressure to build up inside. To tackle that, the battery has a small *one-way air vent* that allows smoke to escape when the battery fails (The Battery Doctor, 2025).

Connected
Through WiFi and Bluetooth, the batteries can communicate with an *open-source app* (The Battery Doctor, 2025). The app provides insights into the health of individual cells, as well as other relevant statistics. The connectivity also enables *fleet management through API*, providing massive insights into defective batteries for bike-sharing services or enabling simultaneous updates.

Spoofing
Earlier, it was mentioned that Bosch batteries can only be paired with Bosch motors and so forth. This is due to the infamous digital handshake between the systems, which locks out non-original battery replacements. Gouach has developed *spoofing software* that mimics proprietary software, allowing batteries to communicate with motors from those brands.

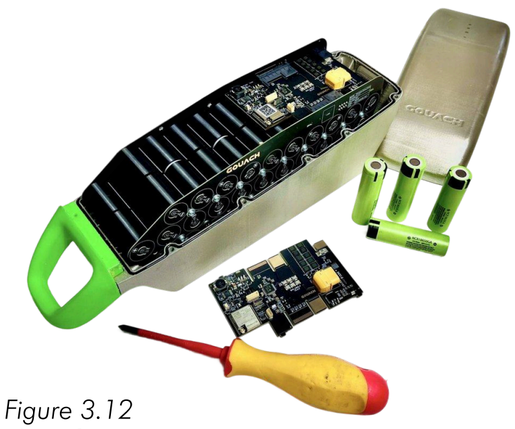


Figure 3.12
The Infinite Battery
(Infinite Battery n.d.)

Figure 3.13
The Infinite Battery
(Infinite Battery n.d.)

Figure 3.14
The Infinite Battery
(Infinite Battery n.d.)

F1: BTR Factory Visit Chuzhou

This Appendix contains a brief overview of the visit to 'BTR New Material Group' in Chuzhou, about a 2 hour ride with the high-speed train from Suzhou. For contextual info, refer to Chapter 5.

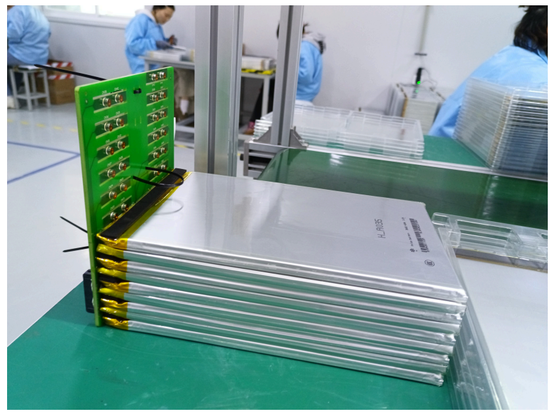
We (me and Siemen) were received by four employees of the company who gave us a presentation. After that, we got a tour through the production line of their *battery-swap packs*.

They do the whole design and production of battery-swapping services. That includes:

- Battery Packs (using LFP pouch cells)
- BMS
- Motherboards
- The Charging Cabinets
- Whole System Supply Chain
- System Operations

They collaborate with other companies, and have manufactured a battery-swapping service in Thailand, for which they also do the service and maintenance. They are starting a new project in July in Indonesia.

The battery packs can handle different Voltages for charging. They usually built them around 48 or 72V systems with 30Ah capacitiy



The LFP pouch cells, each battery pack contains a stack of these. Tabs go through slits on a PCB, stringing them together. They are more space efficient as compared to Cylindrical cells. They can replace individual cells, but the rest of the battery pack has a vertical hierarchy, meaning that everything has to be taken apart to get to the cells.

The cell assembly is placed in an epoxy case, which is then encased in sheet metal. They use standard MC2 connector for the BMS. The product is sturdy, but definitely not optimized for repair.

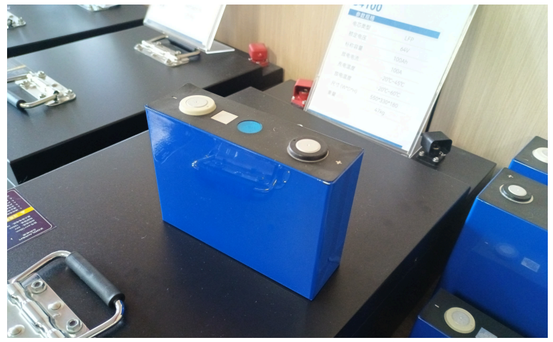
F2: Zoolnasm Office visit Suzhou

This Appendix contains a brief overview of the visit to 'Zoolnasm' in Suzhou. Zoolnasm mass-produces Sodium-ion batteries in pouch, prismatic and cylindrical formats of various sizes. They have collected over 200 patents in their brief existence. The application ranges from Light EVs to back-up home ESSs.

The materials they use are Natrium and Iron, two of the most common materials on earth. They won a national circular economy price with their sodium-ion technology. The anode material (iron) is a byproduct of steel production, and the natrium cathode material can be dissolved in water to fully separate and clean the layers.

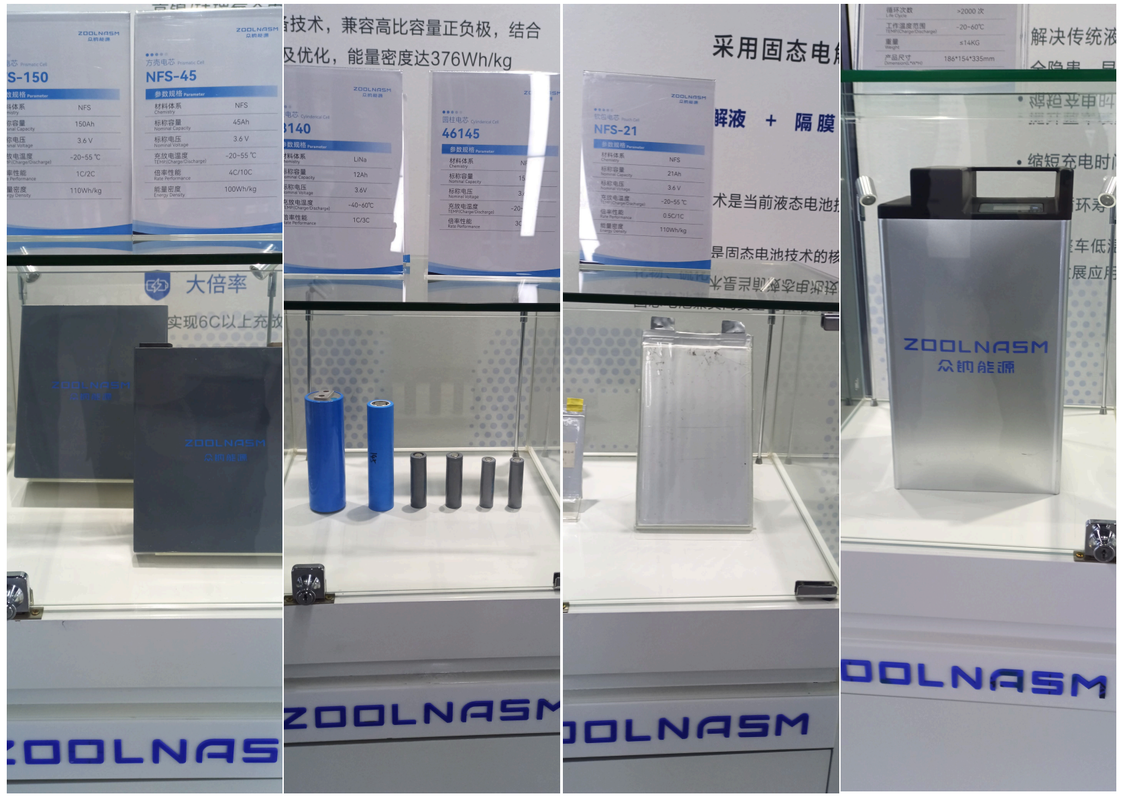
The advantages of Sodium batteries that they describe resonate with the research in Chapter 3:
Temperature range charging: -25 up to 55
Temperature range discharging: -40 up to 60
(This is also why they're targeting European countries)
They charge incredibly fast (15 minutes).
The temperature increase whilst charging is lower compared to Lithium, which is safer.
Lower heat waste = higher energy conversion rate. Cycle rate up to 5000-10000

The downside is that you sacrifice about half the energy density, which makes it less suitable for applications that are dependent on high energy density.



These are the prismatic cells. On the right you can see the other cell types: cylindrical, pouch and they also made a scooter battery. They also showed a video with all the tests the cells went through to get certified.

The raw materials in Sodium-ion batteries



F3: Weiheng/WHES

This Appendix contains a brief overview of the visit to 'Weiheng/WHES' in Wuxi, about an hours ride from Suzhou. With only 8 years of experience, they are now a huge player in large scale ESS systems and solar inverters.

On the smaller scale they make inverters and stackable storage solutions for homes. But they specialize in larger, industrial 'container' units that are used for EV chargers and Wind Turbine storage. They make everything inhouse except the prismatic LFP cells.

Although they could create a system that we are looking for, their focus is mainly larger scale. But the conversation/discussion was very fruitful because they gave various insights into the flow of current through such a system. For instance, they recommend keeping the PV charge controller/inverter, battery unit and EV chargers separate, and connecting them on the AC bus. I would have to research this a bit more to be able to judge if that is also the case for applications that are smaller than the cases that they are dealing with.

F4: NeoVolt

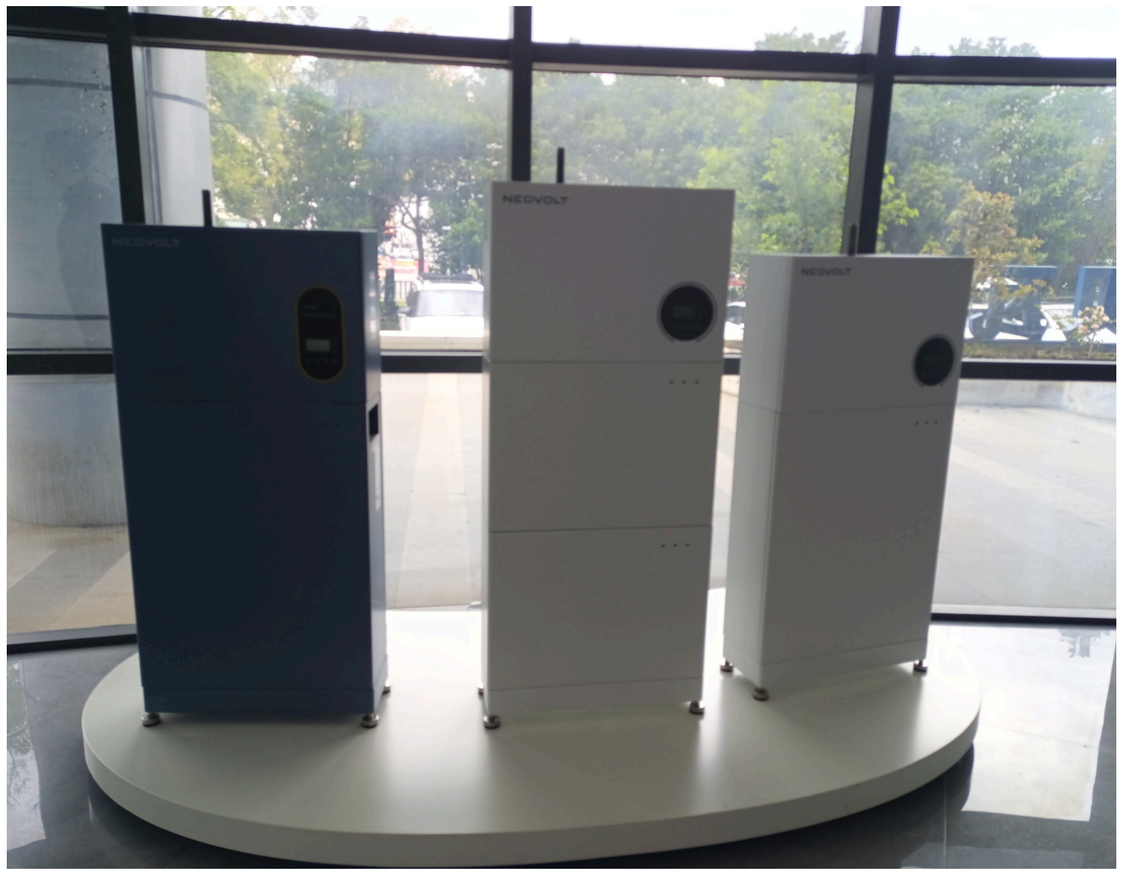
This Appendix contains a brief overview of the visit to 'Neovolt' in Suzhou. One of the largest players in the game, providing 2 out of the 5 largest ESS brands in over 80 countries. We got a comprehensive presentation as well as a tour around the factory production line. Unfortunately we could not take pictures of the assembly line or internal components.

They specialize in residential ESS with stackable modules. They make single and three phase modules, as well as Ev chargers. Their inverters are especially strong with 5 or 10kW capabilities. They're plug & play, and can be extended to 90kWh capacity. They developed an online monitoring platform through which they can diagnose faulty parts and determine if service is necessary. Through this dashboard they can also do remote updates if there is a software fault.

They said they distinguish from the market with several points:
10W threshold: In other ESS, there is a 50-100W threshold to get power from the ESS instead of the grid. For instance, if you charge your phone, the ESS will not detect the electricity and you will automatically use the grid power. In this case the threshold is very low.
Battery controller per battery: normally, the battery controller is separate from the separate battery modules. Here, they are integrated. This circumvents SOC calibration and the 'CASK' effect'. (when performance is limited by the weakest battery)

We were really surprised by some of the extra thought they put in. For instance, other manufacturers used giant heatsinks directly on the PCB. But with NeoVolt, the whole housing is die-cast aluminum with the fins integrated. This way, the whole housing is used as a big heat shrink, because why not? this is very efficient use of material. The whole construction is very solid and each component is separated. The whole unit is optimized for problem diagnose and replacement if necessary.

If you pay attention to the previous page, the WHES unit has an extra 'layer'. That is the battery control layer. Here it is integrated into the battery modules themselves.



G. Güde GSE951 / Tiger GT950 Specifications & Maintenance

Technical Data

Electric generator	GSE 950
Art. No	40626
Service connection	1 x 230 V ~ 50 Hz
Rated current	2,83 A / AC
Constant power	650 W / 760 VA
Rated power	750 W / 880 VA
Power class	G1
Power factor	0,85
Contents	63 ccm
Engine type	1-cylinder 2-stroke
Motor output	1,5 kW / 2 PS
Rated speed	3180 min^{-1}
tank capacity (Petrol)	1:50 / 4 l
Consumption at half load	0,5 l/h
Weight	17 kg
Dimensions L x B x H	380 x 310 x 370 mm
Degree of protection	IP 23 M

Noise and Vibration Information

Sound pressure level L_{PA}	70,83 dB (A)
Uncertainty K =	1,11 dB (A)
Measured sound power level L_{WA} [1)]	91,99 dB (A)
Guaranteed sound power levell L_{WA} [1)]	94 dB (A)

Wear ear protectors!

Measured according to [1)]2000/14/EG

Read and understand the operating instructions before using the appliance. Familiarise with the control elements and how to use the appliance properly. Abide by all the safety measures stated in the service manual. Act responsibly toward third parties.

The operator is responsible for accidents or risks to third parties.

In case of any doubts about connection and operation refer please to our customer center

Specified Conditions Of Use

This power unit has solely been designed for the operation of electrical equipment with a maximum power within the power unit performance data. Higher starting current of induction appliances must be considered.

The unit has been designed for operation of common effective and induction appliances such as light chains, electric hand tools (drills, electric chain saws, compressors).

⚠ When connected to a stationary device such as heating, electrical power, air conditioning equipment or for the supply of mobile homes, it is necessary to contact a professional electrician and heating manufacturer as far as connection and grounding is concerned.

Not observing general regulations in force and instructions from this manual does not make the manufacturer liable for damages.

Protective equipment „Protective separation with potential balancing" is provided and integrated by the producer.

Connection, installation and operation

Caution: Before using the product it is essential to check whether the appliance is suitable to be operated with the unit. Specifications of the appliance must always match the details and safety instructions of the unit.

Due to possible voltage fluctuation, we recommend not connecting any electronic equipment such as HiFi appliances or TV and PC as they could get damaged!

Do not connect the appliance before the unit is running at full speed. Disconnect the appliance before turning the unit off.

Never connect another appliance when there is one being operated. This would inevitably lead to fluctuations able to destroy electronically controlled equipment.

The electric energy consumption is the critical point of an induction appliance ehen starting. Electric energy consumption can be 3-5 times higher than the rated power that must necessarily be considered.

Always place the unit on a firm and flat surface! No turning or tilting or moving during operation.

Requirements for operating staff

Never let children work with the appliance. Never let adults work with the appliance unless they have been properly trained.

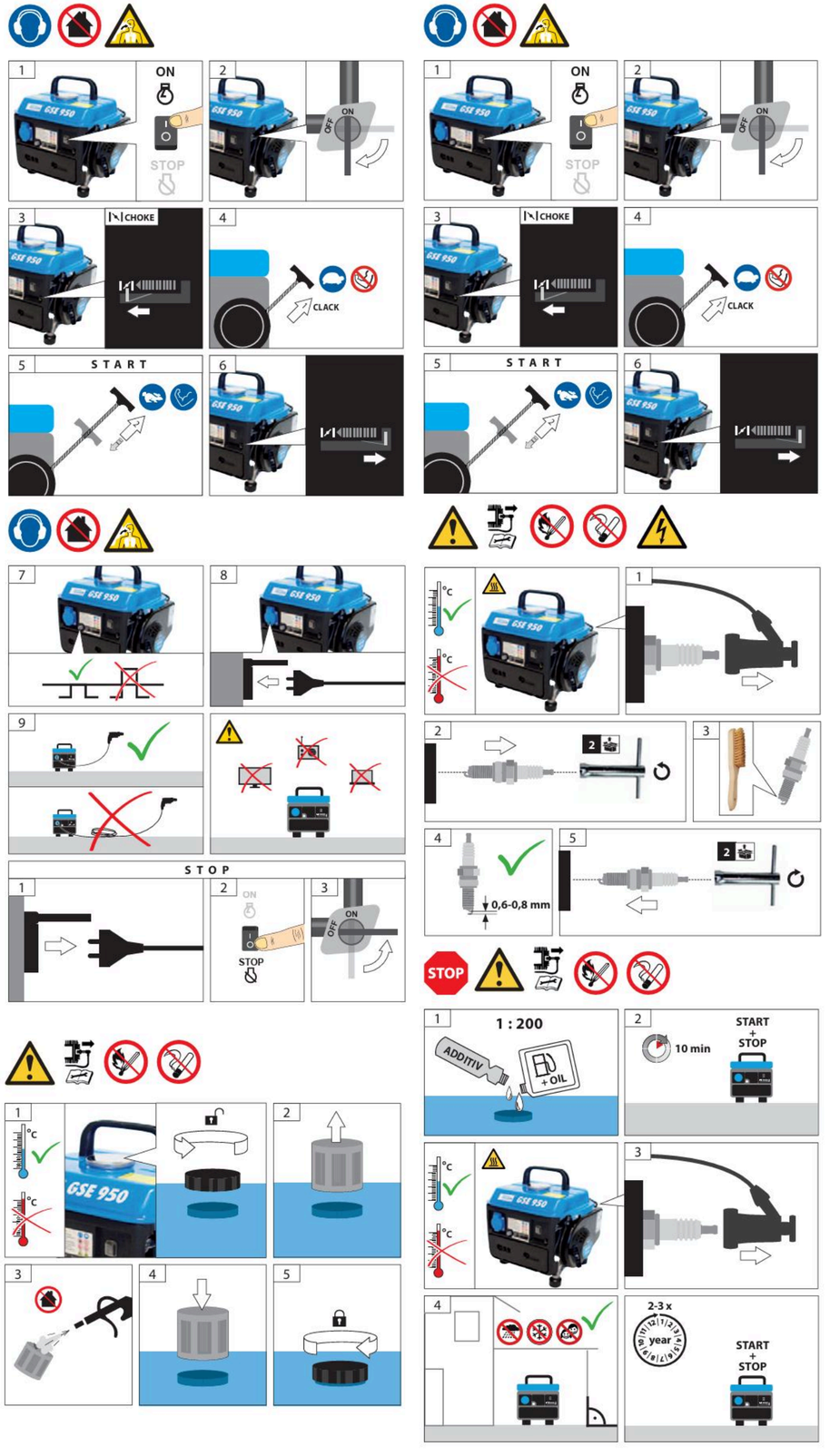
The operating staff must carefully read the Operating Instructions before using the appliance.

Qualification: Apart from the detailed instructions by a professional, no special qualification is necessary for appliance using.

Minimum age: Persons over 16 years of age can only work on the appliance. An exception includes youngsters trained in order to reach knowledge under supervision of the trainer during occupational education.

Local regulations may specify the minimum age of the user.

Training: Using the appliance only requires corresponding training by a professional or the Operating Instructions. No special training is necessary.



H. What is ‘Disassembly Mapping’?

This piece is a summary of *‘The Disassembly Map: A new method to enhance design for product repairability’* by de Fazio et al., 2021. Made using *NotebookLM* (NotebookLM, 2026).

Disassembly mapping is a visual design tool and architectural structural model used by designers and engineers to assess and enhance product repairability. It provides a standardized representation of a product's architecture, enabling systematic comparison of design solutions. The method is specifically intended to identify the most efficient routes toward "*target components*".

Core Visual Logic

The map represents product architecture using circles for components and arrows to indicate disassembly direction. It relies on three primary logic representations:

- **Sequential Dependency** (Vertical Axis): Communicates "*depth*" by showing when one component must be removed before the next. A deeper map generally indicates a longer disassembly time and greater difficulty. (Figure E.1)
- **Sequential Independence** (Horizontal Axis): Places components at the same level if they can be removed independently. (Figure E.2)
- **Multiple Dependency**: Uses an "&" symbol to show when reaching a component requires removing two or more independent parts first. (Figure E.3)
- **Cluster Blocks**: A single circle containing multiple part numbers represents components removed simultaneously, a key strategy for reducing disassembly time. (Figure E.4)

See more on the next page.

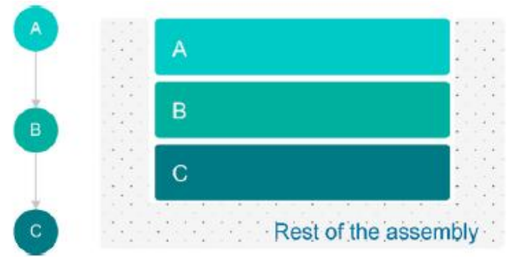


Figure E.1
Representation of sequence dependent disassembly.

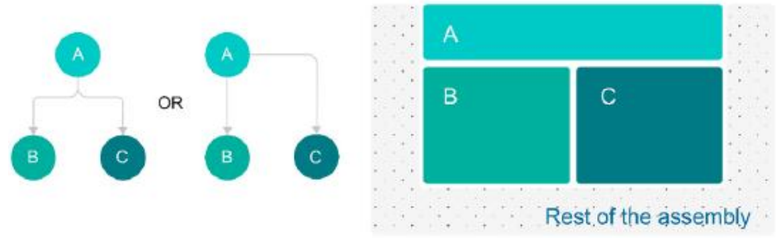


Figure E.2
Representation of sequence independent disassembly.

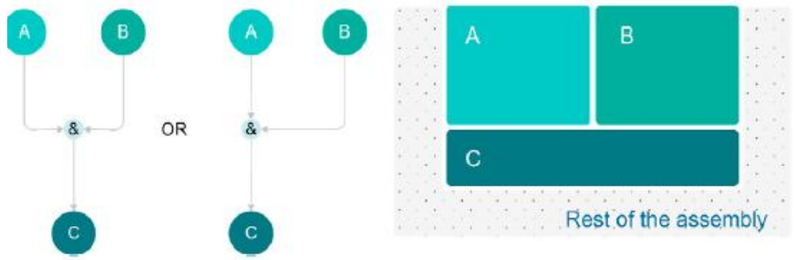


Figure E.3
Representation of multiple dependency.

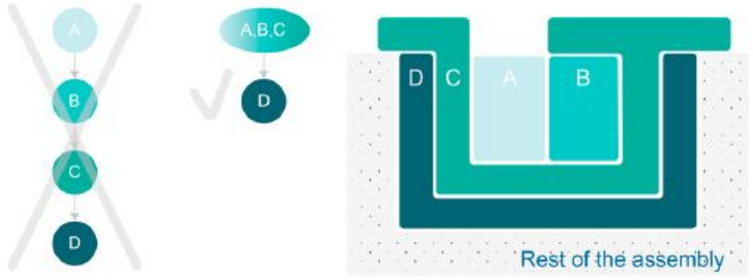


Figure E.4
Representation of cluster blocks.

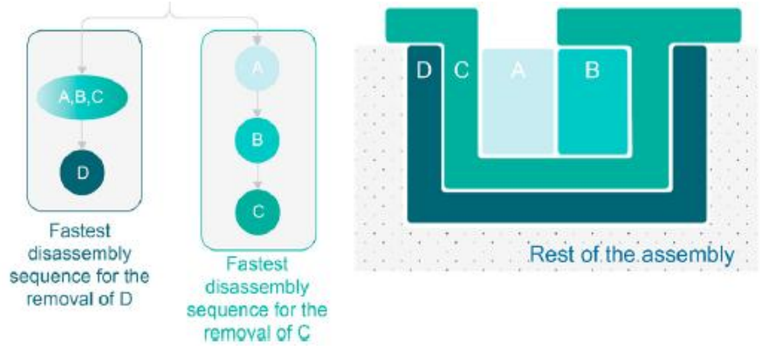


Figure E.5
Representation of two alternative disassembly paths for the optimal removal of two different components, involved in each other disassembly.

Action Blocks and Coding

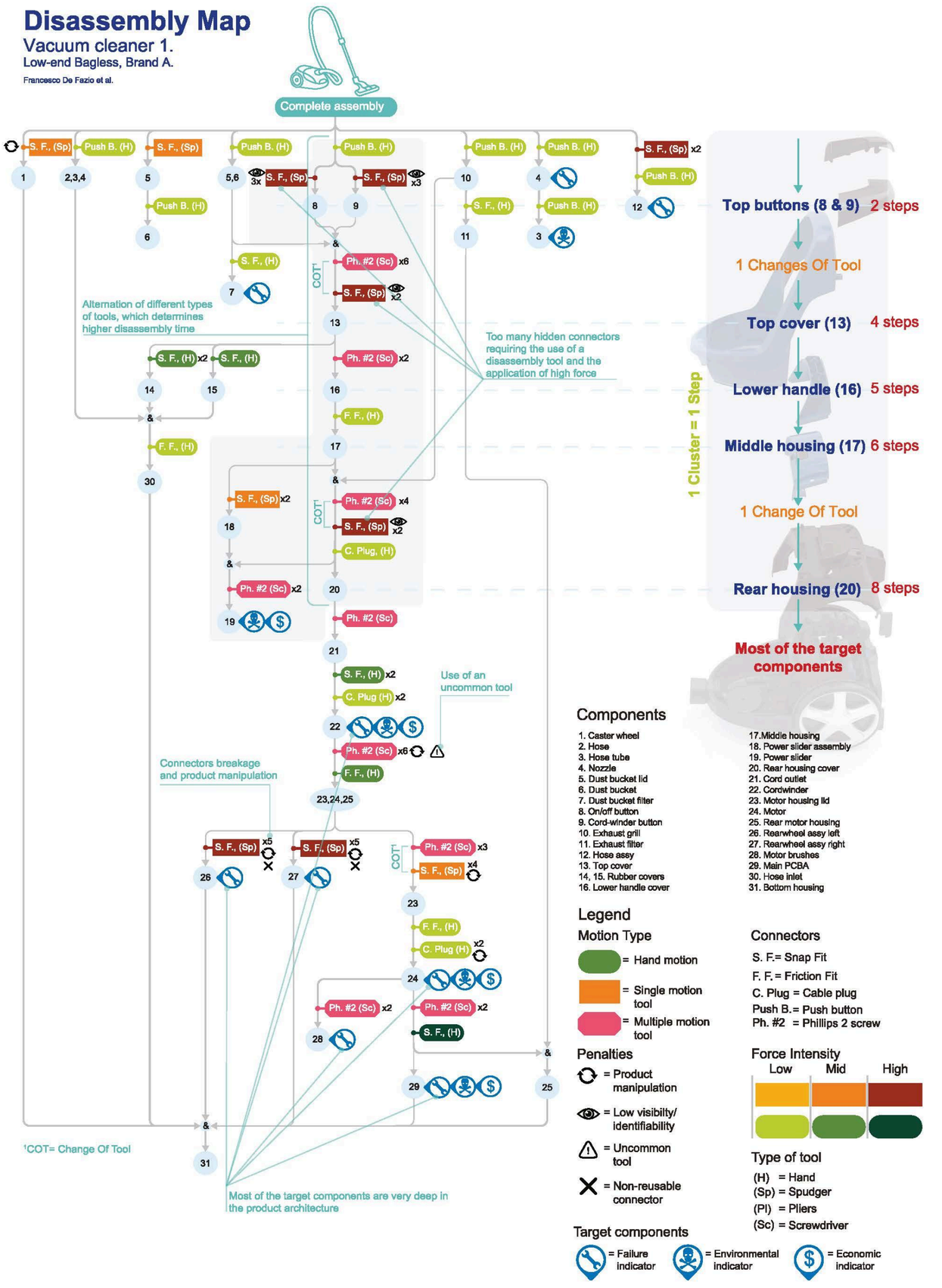
Between the component circles, the map uses "*action blocks*" to visually communicate the effort required for each disassembly step. These blocks are coded based on two systems: the Ease of Disassembly Metric (eDiM) and the Maynard Operation Sequence Technique (MOST). En example can be found on the next page.

- Motion Type (Shape/Color):
  a. Green rounded rectangle: Hand motion (e.g., snap fits, buttons).
  b. Orange rectangle: Single tool motion (e.g., spudgers, pliers).
  c. Pink hexagon: Multiple tool motions (e.g., turning a screwdriver), which typically represent the highest disassembly time.
- Force Intensity (Tone): The block's color indicates the intensity of force required, ranging from light fingertip force to use of both hands or the entire arm.

Penalties and Target Indicators

The map utilizes specific icons to highlight design features that should be avoided or prioritized:

- Disassembly Penalties: These mark features that increase difficulty, such as product manipulation (needing to flip the device), low visibility of connectors, the use of uncommon tools, or non-reusable connectors.
- Target Component Indicators: Icons identify parts that are functionally important/likely to fail (failure indicator), environmentally harmful (environmental indicator), or valuable for harvesting (economic indicator).



I: Interviews, Total Summary

1. The Hierarchy of Energy: Control, Comfort, and Cost

The choice between the national grid and independent power is not merely a matter of availability, but of personal autonomy and environmental value.

- Grid Distrust vs. Utility: While the grid is generally available, Interviewees 2, 3, and 5 view it as prone to blackouts, which is disastrous for business operations. Interviewee 2 specifically values generators because they ensure the impact of a power failure is localized to their own premises rather than an entire area. In contrast, Interviewee 4 finds generators a burden because they necessitate the constant task of purchasing and hauling gasoline.

- The Price of Silence: A significant finding is the willingness to pay a premium for batteries. Interviewee 3 explicitly stated they would spend more for a battery because it provides the "value" of silence and simplicity. Interviewee 4 echoed this, prioritizing "comfort" and a "not noisy" environment. Interviewee 5 even stated "no problem" regarding a higher price tag for a battery, viewing it as a superior tool for outdoor business events where a loud generator would be disruptive.

- Solar Aspirations: Solar power is viewed as the "green future," but the interviewees highlighted a massive adoption gap. Interviewee 2 noted that while solar is good for the environment, it is a "very big investment" with a 10-year ROI, making it impossible for "starter" businesses that need to cover basic operations first. Interviewee 5, an actual solar user, currently limits its use to lights because full-system costs remain prohibitive.

2. Financial Philosophy: Cash Flow vs. Interest Markups

The interviewees demonstrated a sophisticated, though split, logic regarding how to pay for expensive technology.

- The "Markup" Fear: Interviewees 2, 3, and 4 showed a deep-seated aversion to installment plans, correctly identifying that these models "markup" the price with high interest. Interviewee 3 even enforces a personal discipline of saving the full amount before purchasing to avoid the extra costs associated with small payments.

- Business Cash Flow Logic: Interviewee 5 provides a vital counter-perspective. As a business owner, they prefer daily installments. For them, the priority is not the total cost, but the "circulating cash flow," stating it is "okay if it's more expensive" as long as money continues to move through the business.

- The Token System as a Financial Tool: The prepaid electricity "token" (pulsa) system is universally liked because it mirrors this small-increment logic. Interviewee 2 explained that while monthly billing is cheaper, most Indonesians prefer tokens because a one-month bill feels "so expensive," whereas weekly tokens are affordable and allow users to "manage the electricity by ourselves".

3. The Cultural Infrastructure of the Motorbike

In Bali, the motorbike is not just transport; it is a primary tool for individual freedom and a standard rite of passage.

- The "One Man, One Bike" Standard: Interviewees 2 and 4 described a culture where children receive their first motorbikes as young as 12 to 14 years old to facilitate school attendance. This leads to households with as many bikes as there are people.

- Family Control vs. Space: Interviewee 5 offered a more communal model, preferring one bike shared by the whole family to save garage space and money. In this model, "one person holds the key" for safety and to maintain control over the children's mobility.

- Rejection of Shared Mobility: Every interviewee (1, 2, 3, 4, and 5) rejected bike-sharing or rental services. Their reasons are deeply practical: they want to be able to "choose the color," customize the engine, and ensure that a bike is available instantly without walking to a station.

4. Brand Trust, Maintenance, and "Bengkel" Culture

The success of any new technology in Bali depends on its ability to fit into the existing "informal" repair network.

- The "Bengkel" (Workshop) Advantage: Interviewee 1 and Interviewee 5 highlighted that while manufacturer warranties exist, they are often useless for businesses that need immediate repairs. Interviewee 5 would rather pay a local Bengkel for an instant fix than wait weeks for a free warranty repair.

- Established Brand "Pillars": Interviewee 1 argued that brands like Yamaha and Honda are successful because they have established networks where any mechanic has a "basic understanding of the machine".

- The BMW "Annoyance": To illustrate the failure of status-over-utility, Interviewee 1 cited their BMW car, calling it "the most annoying car to have" in Bali because the island lacks the infrastructure to support it, leading to months-long waits for parts. They believe electric vehicles from unknown startups will face a similar trust barrier unless "big dog" brands like Yamaha adopt the technology.

5. Environmental Realities and Safety Logic

Practical environmental factors significantly influence how technology is handled daily.

- Rain vs. Dust Dynamics: Interviewees 2, 3, and 4 surprisingly preferred driving in the rain over dust. Dust is viewed as an unhealthy "pollution" and a hazard that makes bikes "slip". Interviewee 3 even suggested that rain is beneficial as it "cleans" the bike.

- Fear of "Banjir" (Floods): Interviewee 5 provided a specific warning against electric vehicles during the rainy season. They expressed fear that an EV might be "submerged" during a flood, causing it to "die" or create an electrocution risk. They feel safer with gasoline bikes because "you just open the oil" to fix them after a flood.

- Security and Pests: Beyond human theft, Interviewee 3 noted a unique maintenance concern: generators and batteries must be kept in closed spaces to prevent "rats from biting the cable".

- The Upside of Corruption: Interviewee 1 provided a profound insight into the legal system, arguing that widespread "illegal" activity or corruption can be a "beautiful" precursor to innovation. By allowing informal systems (like artist visas or small-scale power use) to exist, the government eventually sees the economic benefit and creates a formal "legal portal" to tax and regulate it.

I: Interviews, 1

INTERVIEW 1

1. From generators to open, repairable battery systems
- In Nigeria, there's more electricity from generators than from the grid, leading to:
  - Noise, dangerous indoor use, fumes
  - But also a strong informal repair ecosystem (like with motorcycles).
- In the West and China, energy storage systems and portable batteries are:
  - Useful and growing (home batteries, van batteries, power stations).
  - But designed to be closed and non-repairable, forcing users to ship them back or discard them.
- Key point: Current battery systems lack openness and local repairability, which causes waste and dependence on manufacturers.

2. Battery-swapping and mobility business models
- In China:
  - Widespread battery-swap stations for electric scooters.
  - Early adoption, currently focused on businesses and fleets.
- In Indonesia/Bali:
  - A few swap stations at petrol stations and convenience stores.
  - Mainly used by ride-hailing and delivery drivers (GoJek, Grab), via company incentives.
- Discussion that:
  - Mobility may skip individual ownership in many places and stay as shared/fleet-based (like Zipcar, car/scooter sharing, rental vans for deliveries).
  - For many people, functionality and affordability (getting from A to B) are more important than owning a vehicle or caring about the brand.

3. Circularity vs "classic" sustainability
- The group distinguishes circularity from broad "sustainability":
  - Circularity: systems and products designed to be repaired, upgraded, reused, or remanufactured (not thrown away).
  - Example: Biosphere's modular, repairable solar panels vs traditional "use and discard" panels.
- Argument: If you design for circularity, you automatically improve sustainability (a "two for one").

4. Education and local repair ecosystems
- Strong emphasis on education and grassroots capacity:
  - In places like the Netherlands, education and forward-thinking culture help adoption of new technologies.
  - In Indonesia and similar contexts, huge populations are still "catching up" and working through trial and error.
- The importance of local mechanics ("Bengkel") and informal repair shops:
  - Mechanics know engines intimately and can fix almost any motorcycle, regardless of brand.
  - The goal is to create similarly widespread know-how for electric systems and batteries, with standardized, open designs.

5. Off-grid solar, leapfrogging, and social impact
- In rural Africa, small pay-as-you-go solar kits:
  - Provide basic electricity (lights, TV, phone charging).
  - Are often more efficient than extending the grid.
  - Have big social benefits: better education (studying at night), retention of teachers in rural schools.
- Point: Leapfrogging over traditional grid systems can both improve lives and support circular, distributed energy.

6. Legal, policy, and economic barriers
- Many obstacles are regulatory and political, not just technical:
  - In Spain: Solar wasn't attractive because rules required giving back a portion of generated power to the grid.
  - In Indonesia/Bali:
    - Very hard to legally set up solar or alternative systems without:
      - Dealing with government, local authorities, and monopolistic utilities.
      - Risking legal trouble if you circumvent official channels.
    - Example: A person building a super-efficient generator could face legal action from utilities.
- Repeated theme: Change must make financial and political sense for powerful stakeholders (governments, grid companies, fuel companies).

7. Design focus of the student project
- The student's specialization: "design for repairability and modularity", specifically:
  - Turning "vertical hierarchies" (components buried under many layers) into "horizontal hierarchies" (critical parts easy to access and replace).
  - Example:
    - Current scooter batteries: you must remove many parts to reach the cells.
    - Target design: a scooter battery pack where cells/modules can be removed and replaced directly.d and
- Honda, Yamaha, and others:
  - Developed a standardized swappable battery form factor, used by multiple brands.
  - But the packs themselves are still close
  - non-repairable.
  - Often, it's cheaper to shred the whole pack than repair modules, which is environmentally and socially problematic.

8. Brands, trust, and diffusion of new tech
- The group agrees that brand matters, especially for:
  - Trust in service and parts availability (e.g., Toyota vs BMW in Bali).
  - Comfort that spare parts and know-how exist locally.
- For a new repairable battery concept:
  - Partnering with or influencing big brands (Honda, Yamaha, BYD, Wuling) may spread impact much faster than starting a completely new brand.
- Mention of Apple, Airbnb examples:
  - Governments force cooperation by blocking products, grinding phones, or threatening platform bans until they get taxes, local production, or economic benefits.

9. Open source vs patents and realpolitik
- Tension between:
  - Big companies patenting everything (e.g., battery geometry, interfaces).
  - The desire to create open-source hardware that others can adopt and adapt.
- Problem: You cannot legally copy dimensionally compatible packs for Honda/Yamaha due to patents, even if your goal is repairability.
- Idea: Focus on generic Chinese platforms where you can integrate a more open, repairable design.
- Acknowledgment: Open source alone doesn't mesh easily with current legal/industrial structures; it has to be reconciled with:
  - National interests (local jobs, local factory, raw materials).
  - Taxes and government revenue models.

10. Waste, trash-to-energy, and local initiatives
- Bali's trash and landfill crisis:
  - Landfill closures without proper alternatives lead to burning trash and illegal dumping.
  - Interest in small modular trash-to-energy stations (e.g., 5 x 5 or 10 x 10 meter units) that villaaes or hotels could use.

Parallels with India:
  - Slums in Mumbai function as recycling engines, reprocessing plastic as a livelihood system.
- Examples in Bali:
  - Small companies cleaning rivers, turning plastic into furniture.
  - Others running composting and worm farms, selling plastic in bulk for new products.
- But again, local political economy and "mafias" often block system changes if they threaten existing revenues (e.g., local banjar controlling trash collection).

11. Politics, corruption, and adaptability
- Indonesia's system is seen as corrupt but adaptive:
  - Example: creation of artist/DJ visas after years of informal, corrupt arrangements; eventually formalized once the economic benefit was clear.
  - Example: iPhone import bans until Apple agreed to local content rules or compensation.
- Conclusion: Change is possible when it clearly benefits state revenues or elites, and may be easier in some African countries that are pushing renewables aggressively than in entrenched Southeast Asian systems.

I: Interviews, 2, 3 & 4

INTERVIEW 2

1. Energy Generation & Infrastructure
- Generators vs. Grid: Generators are favored for offering independent control and localized impact, though they pose noise and security issues. Because they are kept outside, frequent theft requires locked enclosures.
- Financial Constraints: High upfront costs prevent the widespread adoption of solar panels and premium generators among individuals and small businesses.
- Electricity Payments: Prepaid electricity tokens (pulsa) are the standard over monthly grid bills because smaller, weekly payments are easier to manage financially.

2. Transportation & Motorbikes
- Ubiquity of Ownership: Due to inadequate public transit, families typically purchase individual motorbikes for each member, sometimes starting as early as age 11.
- Purchasing Preferences: Buying is strongly preferred over renting for greater control, customization, and long-term affordability. Consumers heavily favor brand-new motorbikes over used ones to secure warranties and guarantee the vehicle's internal condition.
- Electric Vehicle (EV) Trends: Electric motorbikes and battery-swapping networks (like Gojek's partnership with Gogoro) are gaining traction and becoming a local trend.
- EV Charging Logistics: Users prefer charging e-bikes indoors to prevent theft and rely on grid power rather than expensive solar options. Preparedness is key, with riders opting to carry extra batteries if swap stations are unavailable on their route.

3. Environmental Handling
- Motorbikes are strictly covered when parked to protect the paint from sun and rain damage. However, when actively driving, rain is preferred over dry, dusty conditions due to the high risk of slipping and accidents in the dust.

INTERVIEW 3

1. Energy Generation & Storage Preferences
- Generators vs. Batteries: Generators are favored for business use to keep operations running during blackouts, despite being noisy, needing fuel, and requiring a dedicated enclosed space. Large batteries are preferred for daily personal use because they are silent, fuel-free, and can be safely kept indoors.
- Willingness to Pay: The interviewee is willing to pay a premium for a silent battery because of the added convenience and value it provides over a noisy generator.
- Storage & Security: Generators must be kept indoors to protect them from rain (which prevents operational issues) and kept locked away to prevent pests and theft, although large generators are considered hard to steal.

2. Financial & Purchasing Habits
- Payment Methods: One-time, upfront payments are strongly preferred over installments. Installment plans in Indonesia typically include a price markup (interest), which the interviewee actively avoids.
- Exceptions for Installments: The interviewee would only consider installment payments (such as for an expensive solar system) if there were absolutely no price markups compared to the upfront cost.
- Quality over Price: Expensive, durable products are preferred over cheap alternatives that break easily, as investing in long-lasting equipment saves money in the long run.
- Grid Electricity: The token system is preferred for grid power because it allows the user to easily monitor and manage their own electricity consumption.

2. Transportation & Motorbikes
- Owning vs. Sharing: Owning a scooter is preferred over utilizing a scooter-sharing service. Sharing services are viewed as unreliable because a bike might not be available at the station when urgently needed.
- Vehicle Purchasing: When buying an expensive scooter, the interviewee prefers buying a high-quality used one, but strictly only if it comes from a trusted source (like family or a close friend).
- Family Sharing: It is common to share bikes within the household depending on schedules (e.g., the interviewee's parents share one bike based on morning/evening shifts).

4. Electric Vehicles (EVs) & Charging Logistics
- Range Anxiety: Because charging stations are currently sparse (mostly near city supermarkets), the interviewee would carry an extra battery for safety
- Battery-swapping: Swapping batteries at local kiosks (Warungs) is considered the ideal and best option, provided the stations are widely available in all areas.
- Security: E-bike batteries must be removed and charged inside the house to prevent them from being stolen off the bike.

5. Environmental Handling
- Weather Preferences: While the bike is protected from the rain at home or the office, the interviewee doesn't mind leaving it in the rain when out.
- Driving Conditions: Driving in the rain is preferred over driving in a dust storm because the rain acts as a wash for the bike. However, driving on a hot, sunny day is ultimately preferred over the rain to avoid wearing an uncomfortable raincoat.

INTERVIEW 4

1. Energy Generation & Storage Preferences
- Grid power is preferred over generators because generators require the hassle and expense of buying gasoline.
- Large batteries are chosen over diesel generators because they are simple, completely silent, and comfortable, making them worth the higher price tag.
- Investing in high-quality, expensive batteries or generators that last a long time is favored over buying cheap units that break down quickly.
- Energy equipment needs to be kept locked up for safety to prevent theft, though large generators are usually secure due to their size, CCTV, and on-site guards.
- For energy solutions, the interviewee prefers small installment payments (similar to the electricity token system) rather than paying a large lump sum all at once.

2. Vehicle Ownership & Purchasing
- Owning a personal scooter is strongly preferred over rental or sharing services because the vehicle is always available when needed.
- When buying a scooter, a single upfront cash payment is preferred over installments to avoid the markup and higher overall costs associated with financing.
- The interviewee prefers buying an expensive, durable scooter (like a Yamaha) over a cheaper model (like a Honda Scoopy) for its longevity.
- Brand-new scooters are chosen over used ones —even if they cost twice as much—to ensure a guarantee, avoid hidden mechanical issues, and skip trips to the mechanic (Bengkel).
- Individual vehicle ownership is standard within the family, rather than sharing; the interviewee got their first motorbike around age 14.

3. Environmental & Driving Preferences
- Scooters are parked in covered areas, like garages, to protect them from the rain and prolong their life.
- Driving in the rain is chosen over driving in dusty conditions because heavy dust is considered unhealthy pollution.
- Ultimately, driving in the hot sun is preferred over driving in the rain simply because wearing a raincoat is seen as a hassle.

I: Interviews, 5

INTERVIEW 5

1. Power Generation & Storage
- Generators are considered a cheaper alternative to the grid, which is viewed as expensive and prone to blackouts.
- Batteries are favored over generators for business and outdoor events because they are silent, despite their higher cost.
- Generators are strictly kept outside to avoid indoor noise, but they are consistently locked and shielded from the rain for security and maintenance.

2. Financial & Purchasing Preferences
- Daily installment plans are highly preferred over lump-sum payments to maintain a healthy business cash flow.
- Expensive, long-lasting equipment (e.g., a 25-year lifespan) is favored over cheaper, short-lived alternatives.
- Purchasing a used electric scooter at half price is preferred over buying new, even with the inherent risk of having to pay out-of-pocket for repairs.

3. E-Bike Usage & Transportation
- Owning a personal e-bike is preferred over renting or using public sharing services.
- Families typically share a single motorbike to save garage space and minimize costs, with only one designated person holding the key for safety.
- E-bikes are charged indoors at home for comfort and convenience.
- Riders avoid carrying a spare battery while traveling because it is far too heavy.
- Sunny weather is the preferred riding condition to avoid the risks of electrocution and short circuits associated with rain and floods.
- If forced to choose between poor conditions, riding in the rain is chosen over heavy dust to protect personal health.

4. Technology & Future Outlook
- Mobile app integration for electric scooters is viewed as highly desirable and advanced technology.
- Charging via solar power is seen as the ideal green future, though it is currently only used for small-scale lighting due to high installation costs.
- Widespread solar and EV adoption in Indonesia is noted to be lagging behind countries like China due to a lack of public education, high costs, and government or grid company monopolies protecting their revenue streams.

5. Maintenance & Repairs
- Urgency dictates repair choices: business owners will pay a workshop (Bengkel) for an instant fix rather than wait weeks for a free warranty repair if the equipment is needed daily.
- Users prefer to handle simple fixes themselves but will take complex electrical issues to a professional repair shop.
- New replacements are purchased if the cost to repair an old battery is too close to the price of a new unit, or if the repair comes with no guarantee.

J. Patents Selected Overview

I. Physical Mating & Electrical Connectors

- Patent Number: US10505327B2 (also EP3180821B1)
  - Assignee: Gogoro Inc.
  - Description: Multidirection Electrical Connector.
  - Implication: This is the primary "Orientation-Agnostic" patent. It protects the circular, concentric metal tracks on the battery base that allow for 360° mating. It creates a legal wall against any competitor wanting to make an "any-way-up" battery.
- Patent Number: US10312492B2
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery Mounting Structure for Vehicle.
  - Implication: Protects the specific polarized 7-pin blade interface. By patenting the "Keyed" pin-to-socket alignment, Honda ensures that generic connectors cannot be used without risking mechanical or legal failure.
- Patent Number: US10468894B2
  - Assignee: Gogoro Inc.
  - Description: Magnetic and Secure Mating System.
  - Implication: Covers the use of magnetic alignment to ensure high-current terminals are perfectly seated. This prevents 3rd-party "loose fit" batteries from functioning safely in their docks.
- Patent Number: US11456502B2
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery Module Connector Assembly.
  - Implication: Specifically protects the internal high-current busbar configuration. This ensures that the way power is routed from the cells to the external pins remains a proprietary secret.

II. Mechanical Locking, Rails & Ergonomics

- Patent Number: US11155166B2
  - Assignee: Gogoro Inc.
  - Description: Locking Mechanism for Battery.
  - Implication: Protects the electronic latching bolt system. This "digital-to-mechanical" lock ensures the battery cannot be removed or inserted into an unauthorized vehicle or swap station without a software signal.
- Patent Number: USD820782S1
  - Assignee: Gogoro Inc.
  - Description: Battery Housing (Design Patent).
  - Implication: Protects the "pill-shaped" aesthetic and the specific recessed handle. This is an ornamental patent used to sue companies that produce batteries looking like a Gogoro unit.

Patent Number: USD921582S
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery Casing (Design Patent).
  - Implication: Protects the external footprint of the MPP e:. Any competitor making a battery with the same dimensions and corner radii for a "drop-in" fit violates this patent.
- Patent Number: USD966192S1
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery Handle.
  - Implication: Protects the "bridge" handle design. This handle is optimized for heavy extraction from utility bike slanted docks; copying its shape is a legal violation.
- Patent Number: US11332034B2
  - Assignee: Gogoro Inc.
  - Description: Insertion Detection System.
  - Implication: Protects the logic and sensors that verify a battery is "fully seated" before the circuit is closed. This prevents DIY "dumb" docks from activating a smart battery.

III. Structural Integrity & Internal Housing

- Patent Number: US11260749B2
  - Assignee: Honda Motor Co., Ltd.
  - Description: Tough Structure Housing for Mobile Power Pack.
  - Implication: Protects the honeycomb cell-cradling system. This internal architecture is designed for the 150cc utility Tier to survive high-frequency vibrations; it is a major barrier to building a "rugged" alternative.
- Patent Number: US11752854B2
  - Assignee: Honda Motor Co., Ltd.
  - Description: Vibration Shielding Interface.
  - Implication: Protects the specific damping material and "float" mechanism between the cell stack and the outer shell. This makes the battery nearly impossible to repair without specialized damping adhesives.
- Patent Number: US9381826B2
  - Assignee: Gogoro Inc.
  - Description: Battery Configuration for Electric Vehicle.
  - Implication: Covers the internal arrangement of cells and the distribution of "Boost" and "Main" power banks. It ensures the internal electrical hierarchy remains proprietary.
- Patent Number: US8517132B2
  - Assignee: Gogoro Inc.
  - Description: Base Surface Heat Exchange.
  - Implication: Protects the physical cooling "dimples" or ridges on the bottom of the battery. These align with specific station hardware to prevent overheating during fast swaps.

IV. Thermal Management & Fast-Charging

- Patent Number: US11073338
  - Assignee: Gogoro Inc.
  - Description: Liquid-Cooled Heat Dissipation Device.
  - Implication: Protects the thermal management systems within the GoStation and the vehicle. This ensures that only their batteries can safely accept high-speed charging within their infrastructure.
- Patent Number: US8901861
  - Assignee: Gogoro Inc.
  - Description: Thermal Management of Components in Vehicles.
  - Implication: A broad utility patent covering the software-throttling of battery output based on internal temperature sensors (thermistors).
- Patent Number: US6360835B1
  - Assignee: Honda Motor Co., Ltd.
  - Description: Thermal Management for Small Power Vehicles.
  - Implication: Protects early liquid-cooling paths and thermal exchange methods for swappable batteries, forming the legal foundation for their modern cooling tech.
- Patent Number: WO2017060038A1
  - Assignee: Industry Standard (Used by both).
  - Description: Thermally Conductive Potting for Battery Cells.
  - Implication: This "Process Patent" protects the use of epoxy-glues that encase cells. This is the ultimate "anti-repair" wall; once poured, the battery cannot be serviced.

V. Digital Logic & Software Handshakes

- Patent Number: US10720034B2
  - Assignee: Gogoro Inc.
  - Description: Authentication and Management of Energy Storage.
  - Implication: The "Digital DRM" patent. It protects the NFC/Bluetooth handshake required to "pair" a battery to a vehicle. Without this handshake, the battery is a "brick."
- Patent Number: US10110030B2
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery-to-Vehicle Communication.
  - Implication: Protects the specific CAN-bus PGN (Parameter Group Number) dictionary. This is the software "language" the battery speaks to the motor controller.

Patent Number: US8798852B1
  - Assignee: Gogoro Inc.
  - Description: Predictive State-of-Health (SoH).
  - Implication: Protects the algorithm that calculates when a battery should be "retired." It can be used to legally and digitally lock out batteries from the network even if they still hold charge.

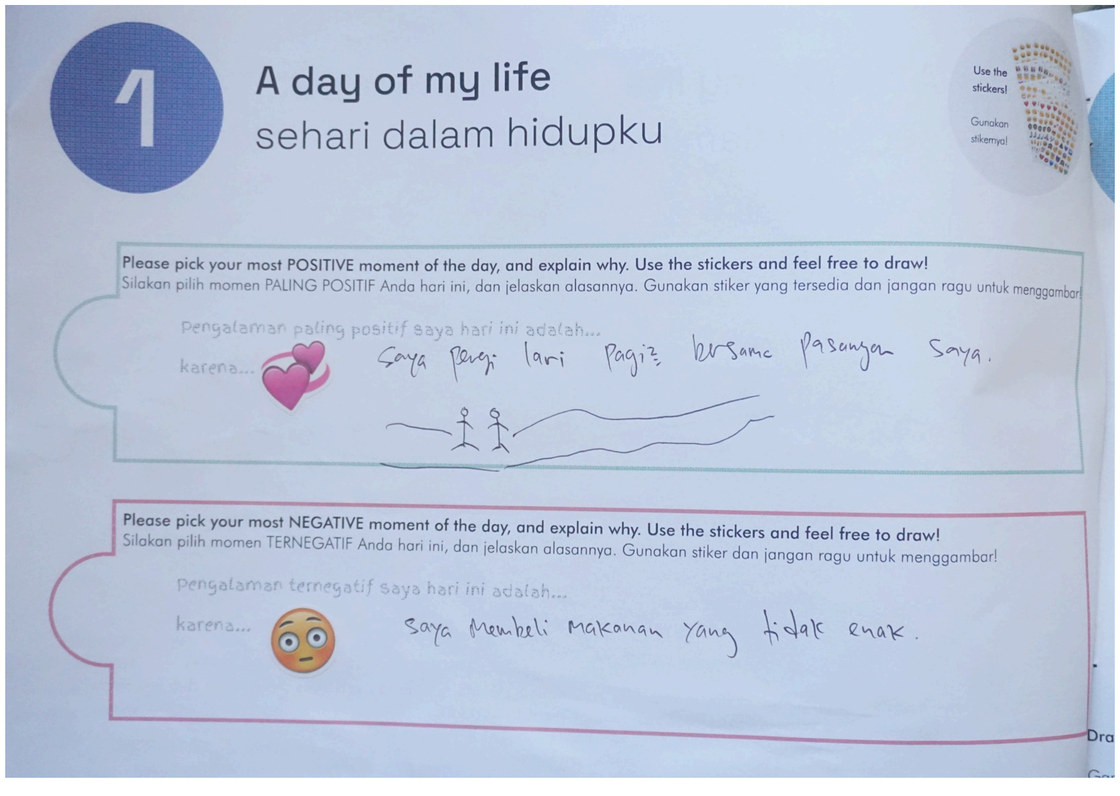
Patent Number: US9182244B2
  - Assignee: Gogoro Inc.
  - Description: Networked Energy Infrastructure.
  - Implication: Covers the cloud-connection requirement. The battery must "report home" to a central server via the station to remain active, a primary feature of the walled garden model.

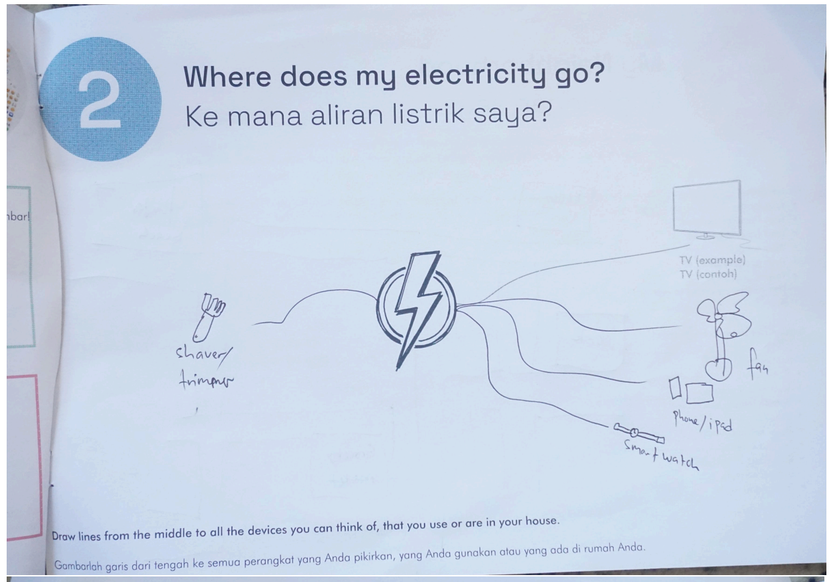
VI. Infrastructure & Station Utility

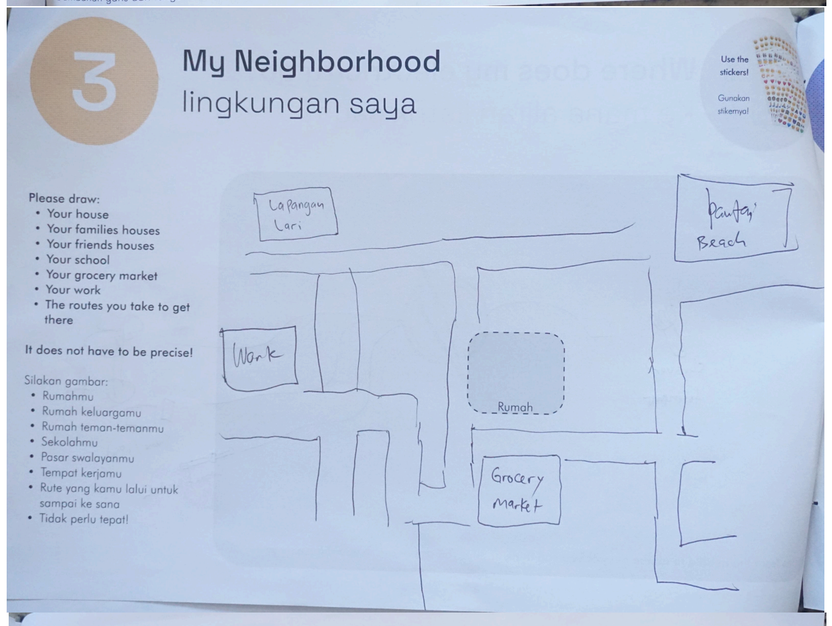
- Patent Number: US8560147B2
  - Assignee: Gogoro Inc.
  - Description: Swapping Station Infrastructure.
  - Implication: The foundational patent for the modular "cabinet" style station. It prevents others from building stations that share the same aesthetic or physical interaction logic.
- Patent Number: US5612606A
  - Assignee: Honda Motor Co., Ltd.
  - Description: Battery Exchange Station for Electric Vehicle.
  - Implication: Protects the mechanical robotics or "slide-in" charging ports used in high-volume exchange stations.
- Patent Number: US11130420B2
  - Assignee: Gogoro Inc.
  - Description: Station Load Balancing.
  - Implication: Covers the logic for using stations as a "Virtual Power Plant" (VPP). This creates a business-model moat that competitors cannot easily replicate.
- Patent Number: US20260103185 (Latest Filling)
  - Assignee: Honda Motor Co., Ltd.
  - Description: Control Device for Electric Vehicle Storage.
  - Implication: Protects the latest 2025-2026 iteration of the communication bridge between home stationary storage and the mobile power pack.

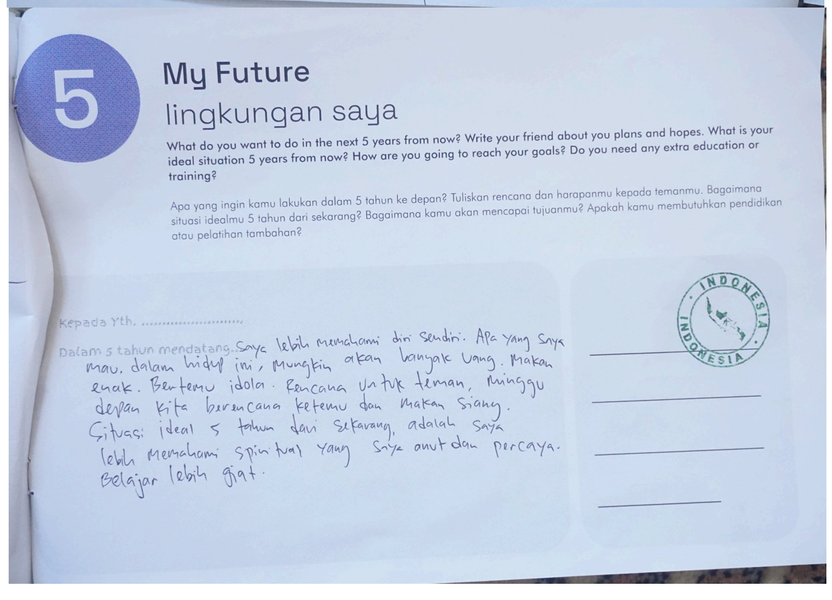
K. Sensitising Booklets, Returned

Unfortunately, some of the participants forgot to bring the sensitising booklets during the interview, and have not made the trip back home

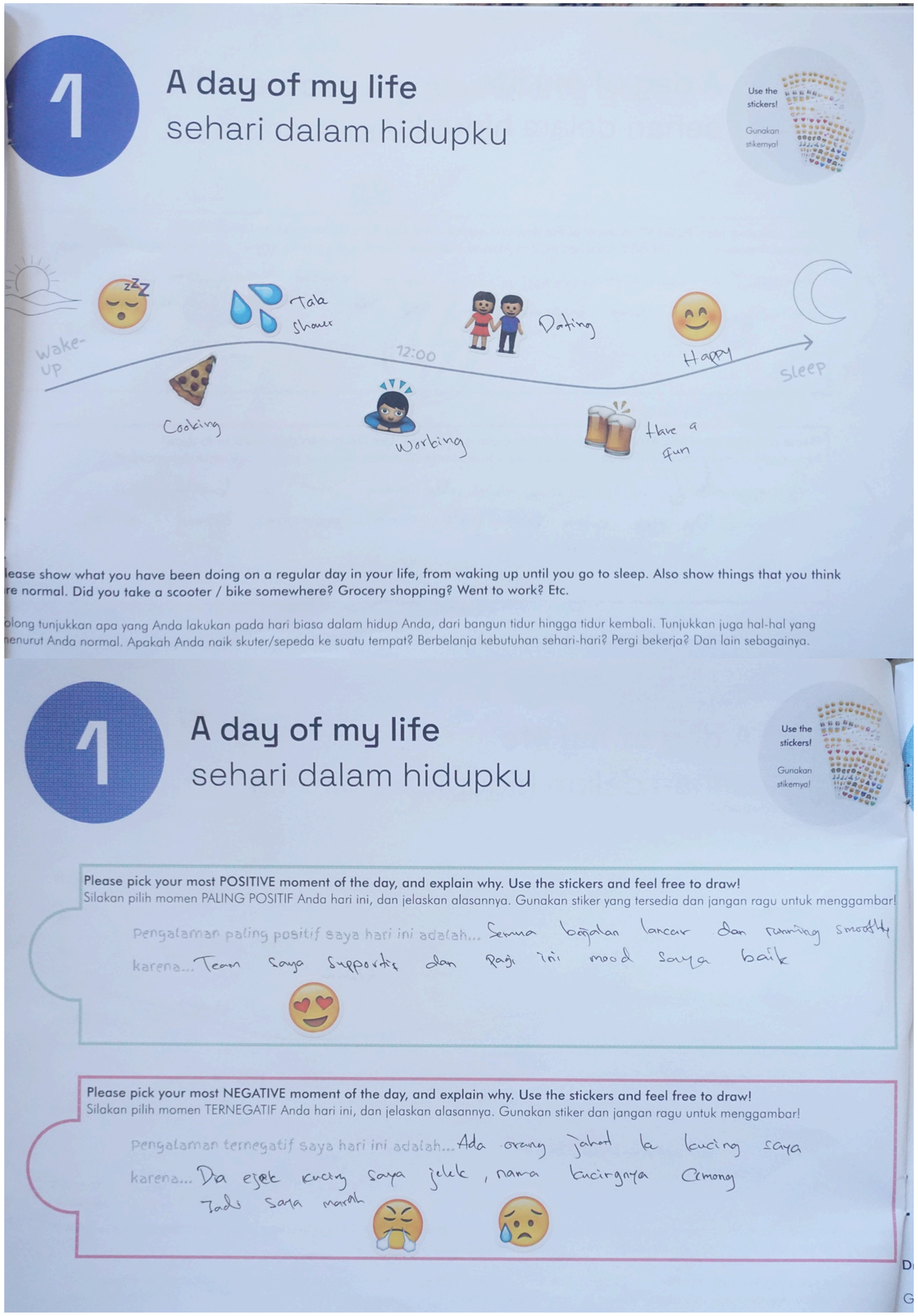








K. Sensitising Booklets, Returned



1

A day of my life
sehari dalam hidupku

Use the stickers!
Gunakan stikernya!

lease show what you have been doing on a regular day in your life, from waking up until you go to sleep. Also show things that you think re normal. Did you take a scooter / bike somewhere? Grocery shopping? Went to work? Etc.

olong tunjukkan apa yang Anda lakukan pada hari biasa dalam hidup Anda, dari bangun tidur hingga tidur kembali. Tunjukkan juga hal-hal yang enurut Anda normal. Apakah Anda naik skuter/sepeda ke suatu tempat? Berbelanja kebutuhan sehari-hari? Pergi bekerja? Dan lain sebagainya.

1

A day of my life
sehari dalam hidupku

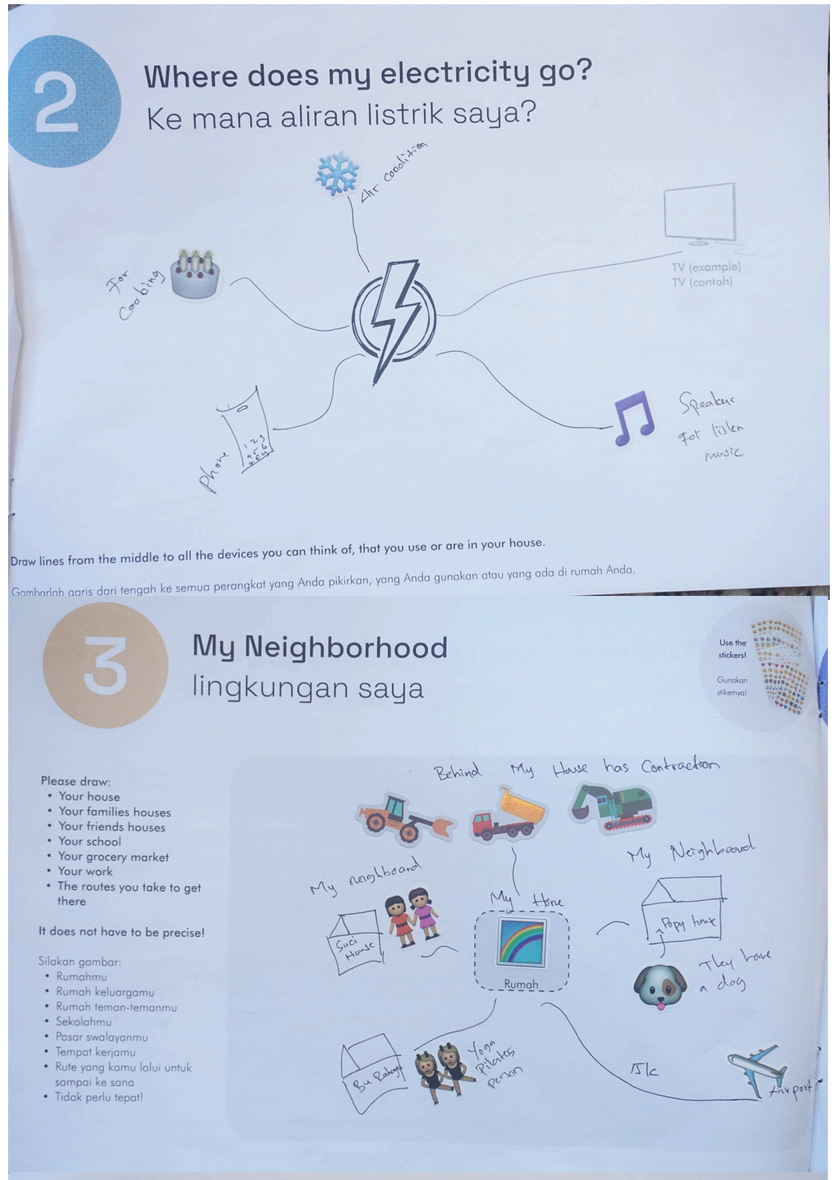
Use the stickers!
Gunakan stikernya!

Please pick your most POSITIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen PALING POSITIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker yang tersedia dan jangan ragu untuk menggambar!

Pengalaman paling positif saya hari ini adalah... Semua berjalan lancar dan running smoothly
karena... Team saya supportif dan pagi ini mood saya baik

Please pick your most NEGATIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen TERNEGATIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker dan jangan ragu untuk menggambar!

Pengalaman ternegatif saya hari ini adalah... Ada orang jahat ke kucing saya
karena... Dia ejek kucing saya jelek, nama kucingnya Cemong
Jadi saya marah



2

Where does my electricity go?
Ke mana aliran listrik saya?

Draw lines from the middle to all the devices you can think of, that you use or are in your house.

Gambarlah garis dari tengah ke semua perangkat yang Anda pikirkan, yang Anda gunakan atau yang ada di rumah Anda.

3

My Neighborhood
lingkungan saya

Use the stickers!
Gunakan stikernya!

Please draw:
- Your house
- Your families houses
- Your friends houses
- Your school
- Your grocery market
- Your work
- The routes you take to get there

It does not have to be precise!

Silakan gambar:
- Rumahmu
- Rumah keluargamu
- Rumah teman-temanmu
- Sekolahmu
- Pasar swalayanmu
- Tempat kerjamu
- Rute yang kamu lalui untuk sampai ke sana
- Tidak perlu tepat!

5

My Future
lingkungan saya

What do you want to do in the next 5 years from now? Write your friend about you plans and hopes. What is your ideal situation 5 years from now? How are you going to reach your goals? Do you need any extra education or training?

Apa yang ingin kamu lakukan dalam 5 tahun ke depan? Tuliskan rencana dan harapanmu kepada temanmu. Bagaimana situasi idealmu 5 tahun dari sekarang? Bagaimana kamu akan mencapai tujuanmu? Apakah kamu membutuhkan pendidikan atau pelatihan tambahan?

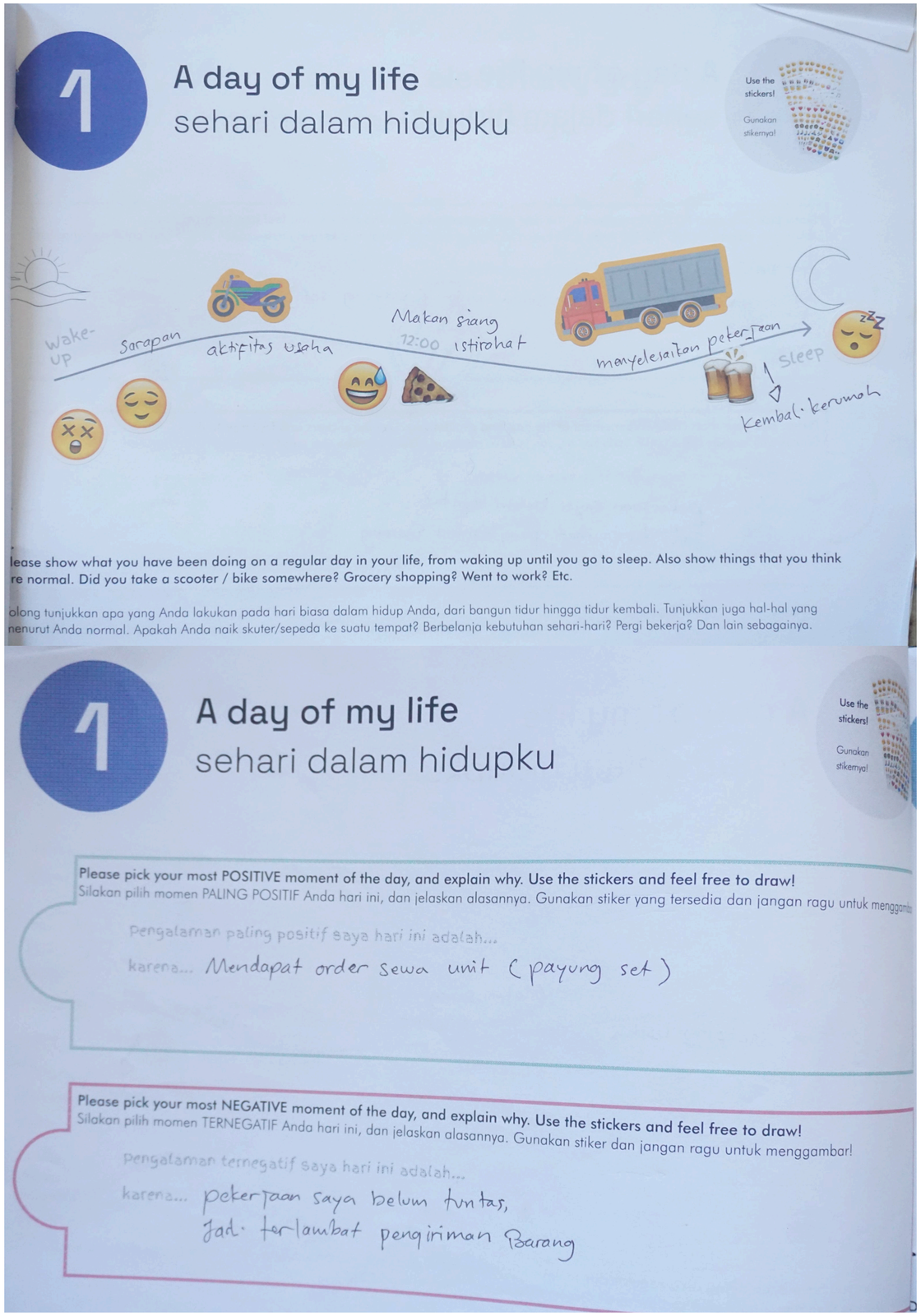
Kepada Yth. Iman Gozali

Dalam 5 tahun mendatang... kita akan menjadi Pantern hidup dan Semoga disaat ini kita sudah memiliki Bussiness Sendiri dengan kita kelola. Harapan kedepan saya tidak lagi bekerja untuk orang lain melainkan untuk diri sendiri. Terimakasih Sudah bertahan sejauh ini dan mohon untuk bersabar sebentar lagi :)

Nadia

INDONESIA

K. Sensitising Booklets, Returned



1

A day of my life
sehari dalam hidupku

Use the stickers!
Gunakan stikernya!

wake-up
Sarapan
aktifitas usaha
Makan siang 12:00
istirohat
menyelesaikan pekerjaan
Sleep
kembali kerumah

lease show what you have been doing on a regular day in your life, from waking up until you go to sleep. Also show things that you think re normal. Did you take a scooter / bike somewhere? Grocery shopping? Went to work? Etc.

olong tunjukkan apa yang Anda lakukan pada hari biasa dalam hidup Anda, dari bangun tidur hingga tidur kembali. Tunjukkan juga hal-hal yang nenurut Anda normal. Apakah Anda naik skuter/sepeda ke suatu tempat? Berbelanja kebutuhan sehari-hari? Pergi bekerja? Dan lain sebagainya.

1

A day of my life
sehari dalam hidupku

Use the stickers!
Gunakan stikernya!

Please pick your most POSITIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen PALING POSITIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker yang tersedia dan jangan ragu untuk menggamb

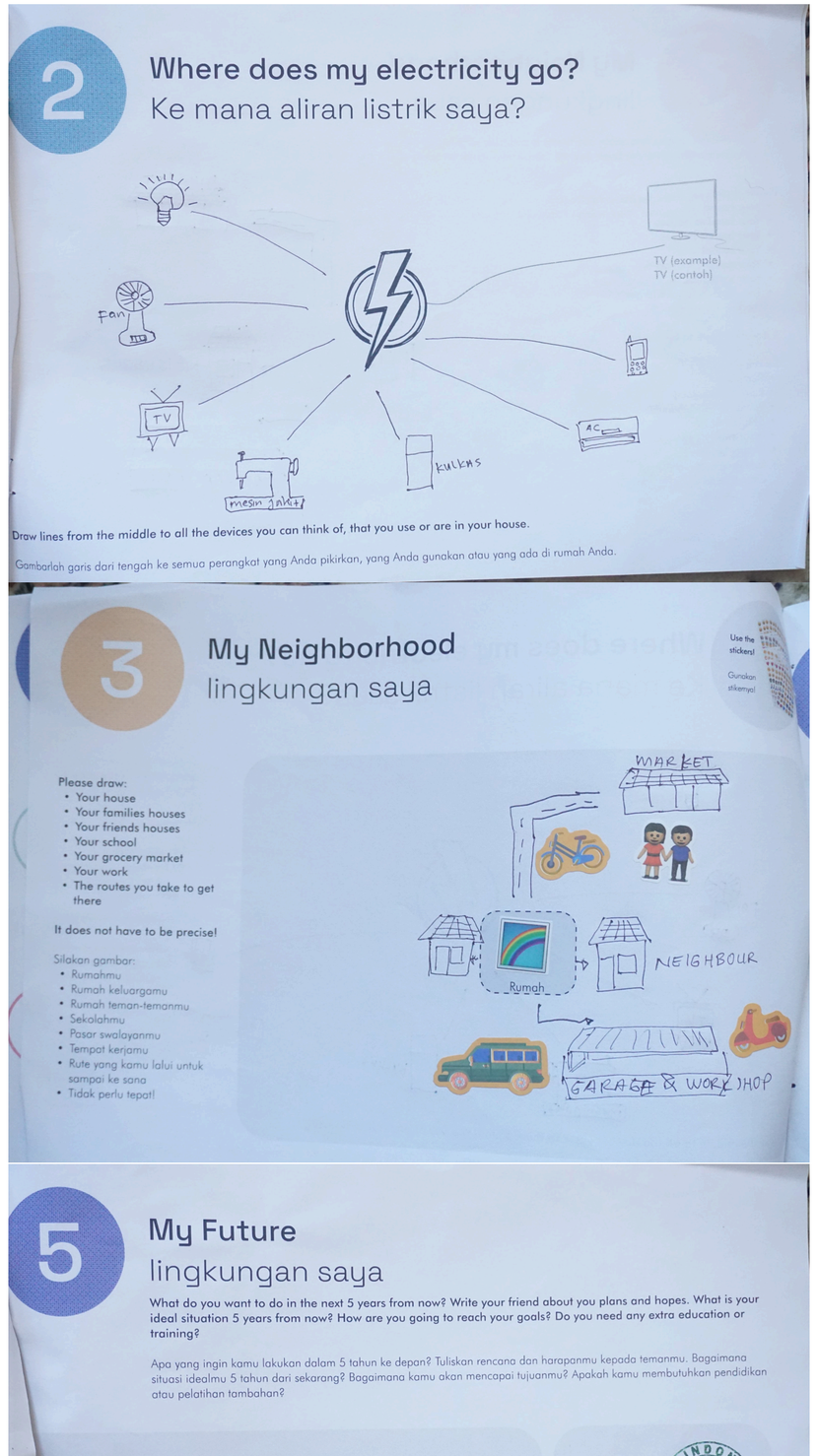
Pengalaman paling positif saya hari ini adalah...

karena... Mendapat order sewa unit (payung set)

Please pick your most NEGATIVE moment of the day, and explain why. Use the stickers and feel free to draw!
Silakan pilih momen TERNEGATIF Anda hari ini, dan jelaskan alasannya. Gunakan stiker dan jangan ragu untuk menggambar!

Pengalaman ternegatif saya hari ini adalah...

karena... pekerjaan saya belum tuntas,
jadi terlambat pengiriman Barang



2

Where does my electricity go?
Ke mana aliran listrik saya?

Fan
TV
TV (example)
TV (contoh)
AC
mesin jahit
kulkas

Draw lines from the middle to all the devices you can think of, that you use or are in your house.

Gambarlah garis dari tengah ke semua perangkat yang Anda pikirkan, yang Anda gunakan atau yang ada di rumah Anda.

3

My Neighborhood
lingkungan saya

Use the stickers!
Gunakan stikernya!

Please draw:
- Your house
- Your families houses
- Your friends houses
- Your school
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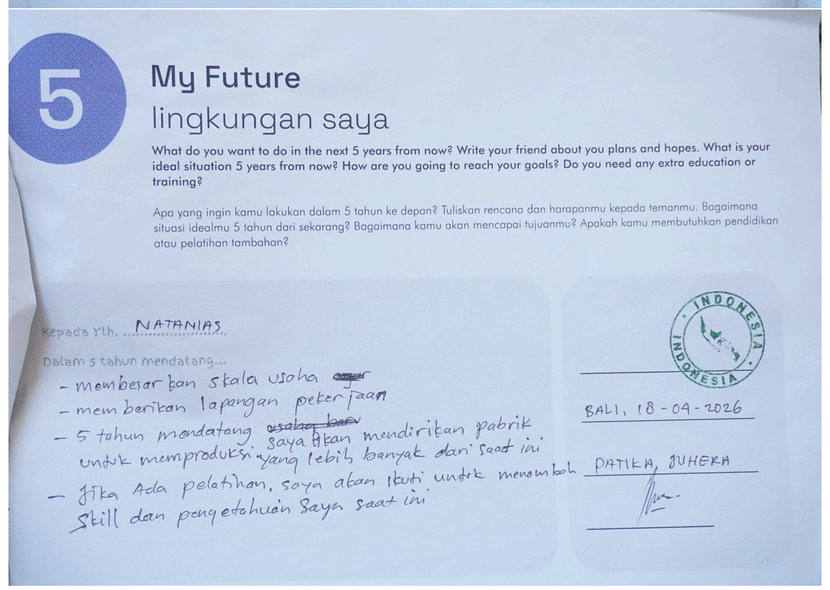
- Sekolahmu
- Pasar swalayanmu
- Tempat kerjamu
- Rute yang kamu lalui untuk sampai ke sana
- Tidak perlu tepat!

MARKET
Rumah
NEIGHBOUR
GARAGE & WORKSHOP



5

My Future
lingkungan saya

What do you want to do in the next 5 years from now? Write your friend about you plans and hopes. What is your ideal situation 5 years from now? How are you going to reach your goals? Do you need any extra education or training?

Apa yang ingin kamu lakukan dalam 5 tahun ke depan? Tuliskan rencana dan harapanmu kepada temanmu. Bagaimana situasi idealmu 5 tahun dari sekarang? Bagaimana kamu akan mencapai tujuanmu? Apakah kamu membutuhkan pendidikan atau pelatihan tambahan?

Kepada Yth. NATANIAS

Dalam 5 tahun mendatang...
- membesarkan skala usaha ~~saya~~
- memberikan lapangan pekerjaan
- 5 tahun mandatang ~~usaha baru~~ saya akan mendirikan pabrik untuk memproduksi yang lebih banyak dari saat ini
- Jika ada pelatihan, saya akan ikuti untuk menambah skill dan pengetahuan saya saat ini

INDONESIA

BALI, 18-04-2026

DATIKA JUHERA

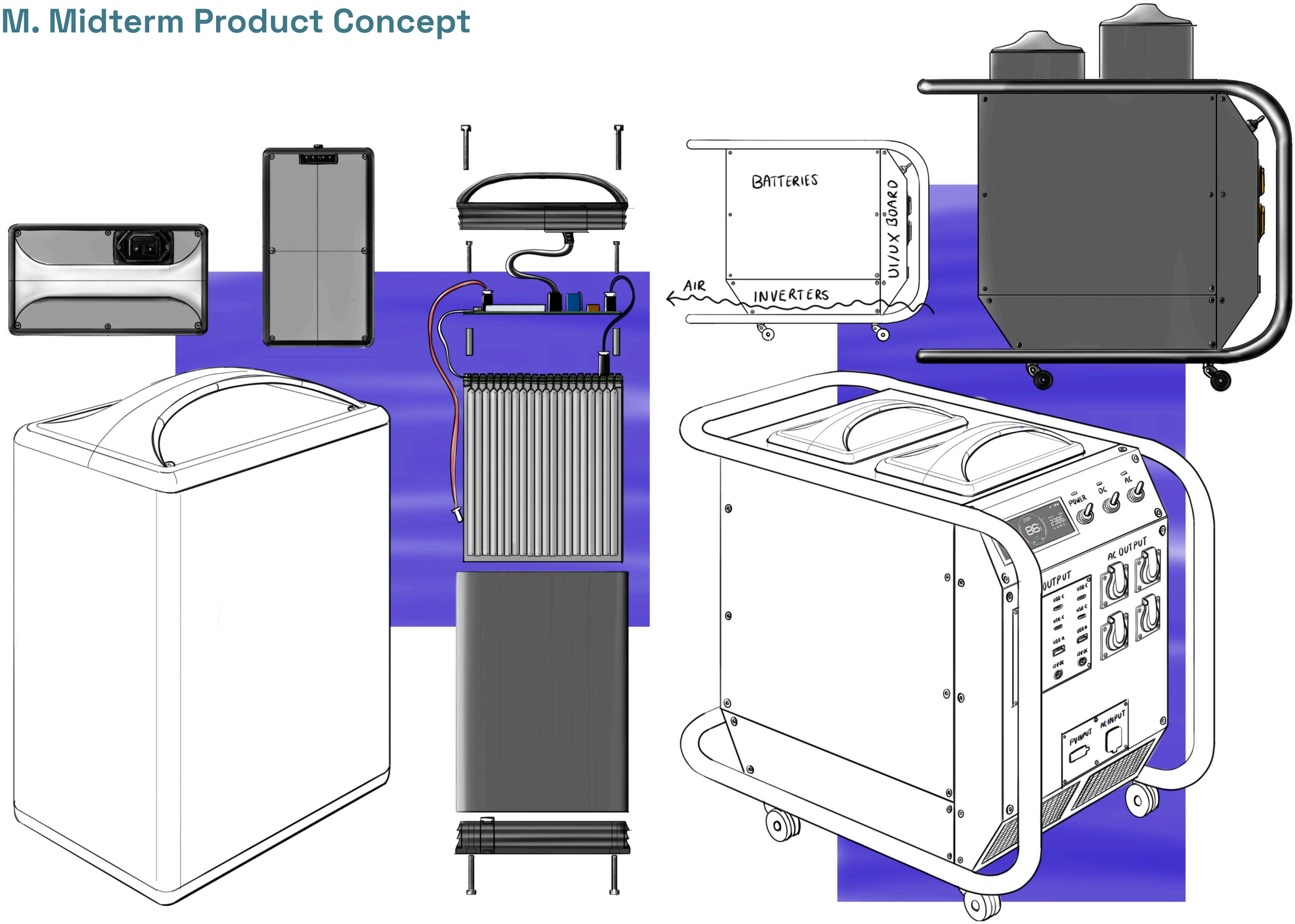
L1. Program of Requirements

PoR	NODE BAWA MICROSTORAGE DOCKING UNIT					
#	Requirement / Wish	Aspect	Explanation	Source	Testing / Prototyping	Validation
NP1	Can supply a continuous power of at least 800W.	Performance	Minimum of Tier 4, MTF.	Chapter 1		
NP2	Can supply a peak power power of at least 2000W.	Performance	Minimum of Tier 5, MTF.	Chapter 1		
NP3	Is compatible with 72V batteries.	Performance	To work with the 72V "sweet spot".	Chapter 3/4		
NP4	AC and DC outputs can be turned on and off independently.	Performance	Keeping the converters on at all times is a waste of energy.	Chapter 4		
NP5	Must feature internal buffer batteries to store off-peak grid energy and discharge it to swappable packs during peak demand, smoothing grid strain.	Performance		Gemini		
NP6	AC-to-DC conversion efficiency must exceed 92%. to minimize thermal waste and maximize cost-effectiveness.	Performance	To minimize thermal waste and maximize cost-effectiveness.	Gemini		
NP7	Operational capability in ambient temperatures ranging from -20°C to +55°C.	Performance	Determined by cell chemistry.	Gemini		
NP8	Must be capable of charging 2 batteries simultaneously.	Performance	To split home and vehicle use.	Gemini		
NP9	Casing and internal modules must utilise a maximum of three standardised fastener types (e.g., Hex)	Performance	To minimise required field tooling.	Gemini		
NR1	Has exposed and easy-to-reach screws.	Repairability	For ease-of-disassembly	Chapter 3/4		
NR2	Does not make use of single-use snap fits.	Repairability	For ease-of-disassembly	Chapter 3/4		
NR3	Does not make use of proprietary digital handshakes.	Repairability	For ease-of-disassembly	Chapter 3/4		
NR4	Uses only open-source communication platforms.	Repairability	For ease-of-disassembly	Chapter 3/4		
NR5	Must feature an external diagnostic port and over-the-air API.	Repairability	For technicians to read error codes without opening the chassis.	Gemini		
NR6	Routine component replacements (e.g., cooling fans, screens) must be achievable by one technician in under 30 minutes.	Repairability	Individual component replacing must be financially viable.	Gemini		
NS1	Has an IP rating of at least IP54	Safety	Dust protected and splash proof. To fit with the context of the user.	Gemini		
NS2	Uses IP-certified input and output ports.	Safety	Standard for potential outdoor applications	Chapter 3/4		
NS3	Ventilation inlets and outlets should not be easily blocked under standard use practises.	Safety	Blocking the inlets and outlets can lead to overheating, but people might not be aware of this.	Chapter 4		
NS4	The outer shell must achieve an IK10 impact rating.	Safety	To withstand vandalism or accidental vehicle collisions.	Gemini		
NS5	Must feature Ground Fault Circuit Interrupter (GFCI) protection and hardware-level surge isolation.	Safety	To prevent an electric short.	Gemini		
NS6	A high-visibility, easily accessible mechanical shut-off button that instantly severs all grid and internal power routing.	Safety	In case of instable national grid.	Gemini		
NU1	Has the footprint of a comparable, 4-stroke generator: 500-700mm squared.	Use/Ergonomics	Dimensions of a 4-stroke generator with comparable output.	Chapter 1		
NU2	Has at least 2 AC outputs.	Use/Ergonomics	Comparable Generators have 1-2, Microstorage 2-4.	Chapter 3/4		
NU3	Has at least 2 USB-C ports.	Use/Ergonomics	Comparable Microstorage has 2-4.	Chapter 3/4		
NU4	Has at least 2 12V barrel ports.	Use/Ergonomics	Comparable Microstorage has 2. Necessary for DC home appliances.	Chapter 3/4		
NU5	Has at least 2 USB-A ports.	Use/Ergonomics	Comparable Microstorage has 2-4.	Chapter 3/4		
NU6	Has a DC PV input.	Use/Ergonomics	Solar charging is a core function.	Chapter 3/4		
NU7	Has an AC input.	Use/Ergonomics	Grid charging is a core function.	Chapter 3/4		
NU8	Has a grounding terminal.	Use/Ergonomics	Necessary for safety of electric shock.	Chapter 3/4		
NU9	Has an interface for monitoring the batteries' SoC.	Use/Ergonomics	Necessary for basic interaction.	Chapter 3/4		
NU10	Has an interface for monitoring the batteries' SoH.	Use/Ergonomics	Necessary for maintenance.	Chapter 3/4		
NU11	The Node Bawa has an interface for monitoring the time-to-full/empty of the batteries.	Use/Ergonomics	Necessary for basic interaction.	Chapter 3/4		
NU12	The Node Bawa has a rubust frame, proteced by a metal cage.	Use/Ergonomics	The livelihoods of people in the GS do not resonate with "clean" plastic cases.	Chapter 2/4		
NU13	Features must be accessible without an external application.	Use/Ergonomics	An app should not be necessary for functionality.	Chapter 4		
NU14	Interface must display relevant information pertaining to the PAYG financing model.	Use/Ergonomics	Quick checks of PAYG status should be possible without an app or a digital scoreboard.	Chapter 3/4/6		
NU15	Must be able to drain batteries in parallel or separately.	Use/Ergonomics	One battery must stay as fully charged as possible for use on a bike.	Chapter 5		
NU16	Has swivel-style wheels.	Use/Ergonomics	For mobility purposes.	Chapter 2/4		
NU17	Details of the PAYG financing and the battery statistics are available in an app or digital dashboard.	Use/Ergonomics	Complex details should be outsourced to a larger interface.	Chapter 6		
NU18	Ventilation filters can be removed and cleaned by using widely available tools.	Use/Ergonomics	For Instance, a single Philips-style screw to remove the cover.	Chapter 4		
NU19	The interface remains highly visible in direct sunlight.	Use/Ergonomics	Necessary for outdoor use in global south.	Gemini		
NU20	Clear, distinct auditory feedback (beeps or tones) to confirm secure battery locking and unlocking.	Use/Ergonomics	Auditory cues are essential for confirmation of correct use.	Gemini		
NU21	Active cooling systems (HVAC/fans) must not exceed 65 dB at a distance of 1 meter to comply with residential noise ordinances.	Use/Ergonomics	The main advantage of the battery is its silence, compared to generators.	Gemini		
NU22	Makes use of colour-coded affordances to nudge the user on how to interact with the device.	Use/Ergonomics	Non-technical people should be included in the use case.	Gemini		

L2. Program of Requirements, Swappable Battery

PoR	NODE SWAPPABLE BATTERY					
#	Requirement / Wish	Aspect	Explanation	Source	Testing / Prototyping	Validation
BP1	Can supply a continuous power of at least 500W.	Performance	This is the minimum continuous power of a LEV battery to maintain temperature.	Chapter 5		
BP2	Can supply a peak power of at least 2000W.	Performance	This is the minimum for peak power to drive uphill etc.	Chapter 5		
BP3	Is based on a 72V architecture.	Performance	Sweet spot for a 150cc equivalent bike and viable for home applications.	Chapter 5		
BP4	Makes use of pouch cells	Performance	The market is moving towards pouch cells due to their higher density.	Chapter 3/4		
BP5	Is compatible with both Lithium and Sodium Ion cells.	Performance	Different climates and regions need different tech.	Chapter 3/4		
BP6	Has a minimum pack capacity of 1.5kWh.	Performance	To support urban commuting ranges for electric two-wheelers.	Chapter 5		
BP7	Must safely accept fast-charging currents to reach 0-80% State of Charge (SoC) in under 60 minutes.	Performance	Quick charging is necessary to maintain high-speed swapping logistics.	Gemini		
BR1	Has exposed and easy-to-reach screws.	Repairability	The batteries' internals must be replaceable separately.	Chapter 4		
BR2	Does not make use of single-use snap fits.	Repairability	The batteries' internals must be replaceable separately.	Chapter 4		
BR4	Must feature tamper-evident seals and specialized fasteners.	Repairability	To prevent non-mechanics from opening up the case.	Chapter 4		
BR5	Cells can be replaced without replacing other components of the Battery.	Repairability	Bricking the entire battery when the SoH is low is a waste of valuable resources.	Chapter 4		
BR6	The BMS allows component and cell replacement without "bricking" the entire unit.	Repairability	Bricking the entire battery when replacing cells or other parts is a waste of resources.	Chapter 3/4		
BR7	Critical components can be replaced in parallel steps.	Repairability	The disassembly map should be a horizontal architecture after removing the case.	Chapter 4		
BR8	Components are not secured with glue or epoxy.	Repairability	The batteries' internals must be replaceable without removing the glue.	Chapter 3/4		
BR9	Uses only open-source communication platforms.	Repairability	Local servicing agents should be empowered to service the batteries.	Chapter 3/4		
BR10	Does not make use of proprietary digital handshakes.	Repairability	Local servicing agents should be empowered to service the batteries.	Chapter 3/4/5		
BR11	Does not make use of fire-retardant tape.	Repairability	The batteries' internals must be replaceable without removing the tape.	Chapter 3		
BR12	Single-use connectors, such as zip-ties, may be used only if they are widely available and non-proprietary.	Repairability	For cable organisation, these may be necessary, but they should be avoided as much as possible.	Chapter 3		
BR12	The ouder casing is sealed using rubber or siliconde gaskets	Repairability	To maintain IP rating while being disassemblable.	Gemini		
BS1	Complies with IEC fire safety standards.	Safety	For instance, by using fibreglass or aluminium to encase the cells.	Chapter 4/5		
BS2	It is vibration and shock-proof according to the IEC norms.	Safety	The batteries must be able to handle rough riding situations without issues	Chapter 4/5		
BS3	Has an IP rating of at least IP67.	Safety	"dust tight" and "water jet" proof to fit the monsoon season and handle floods.	Gemini		
BS4	Has a waterproof power connector.	Safety	The connector should not be prone to water ingress in humid situations.	Chapter 4/5		
BS5	Must maintain electrical and structural integrity after a 1.5-meter free-fall onto concrete on any axis or corner.	Safety	Robustness is necessary for long-term use in global south use cases.	Gemini		
BS6	Must include a directional, waterproof pressure-relief valve.	Safety	To safely vent gases during a thermal event without rupturing the main casing.	Gemini		
BU1	Is compatible with a seperate DC Buck dongle	Use/Ergonomics	To be able to use the battery separately as an even more mobile power source.	Chapter 5/6		
BU2	Has dimensions that are comparable to other swappable scooter batteries.	Use/Ergonomics	Using the same dimensions is not always permitted, but OEM scooters must be easily adaptable.	Chapter 5		
BU3	Has a pin-connector at the bottom to allow for easy docking.	Use/Ergonomics	To limit the friction of swapping and mirroring the ease of informal refueling in the global south.	Chapter 5		
BU4	Has a handle that is sized according to global P3-P97 standards.	Use/Ergonomics	All people need to be able to hold it safely.	Chapter 5		
BU5	Total pack mass must strictly not exceed 12 kg.	Use/Ergonomics	To ensure safe, one-handed lifting by the target demographic.	Gemini		
BU6	The carrying handle must provide a minimum clearance of 35 mm and feature a non-slip texture.	Use/Ergonomics	To accommodate thick gloves and feature a non-slip texture.	Gemini		
BU7	Internal cells and the BMS must be distributed so the centre of gravity aligns directly beneath the handle.	Use/Ergonomics	For reducing wrist torque during transport.	Gemini		
BU8	The geometry must be feature distinct, coupled to the location of the connector.	Use/Ergonomics	Foolproof keying to make backward insertion physically impossible.	Gemini		
BU9	The points of interaction must have low thermal conductivity.	Use/Ergonomics	To ensure the pack does not feel dangerously hot to the touch immediately after heavy discharge.	Gemini		

M. Midterm Product Concept

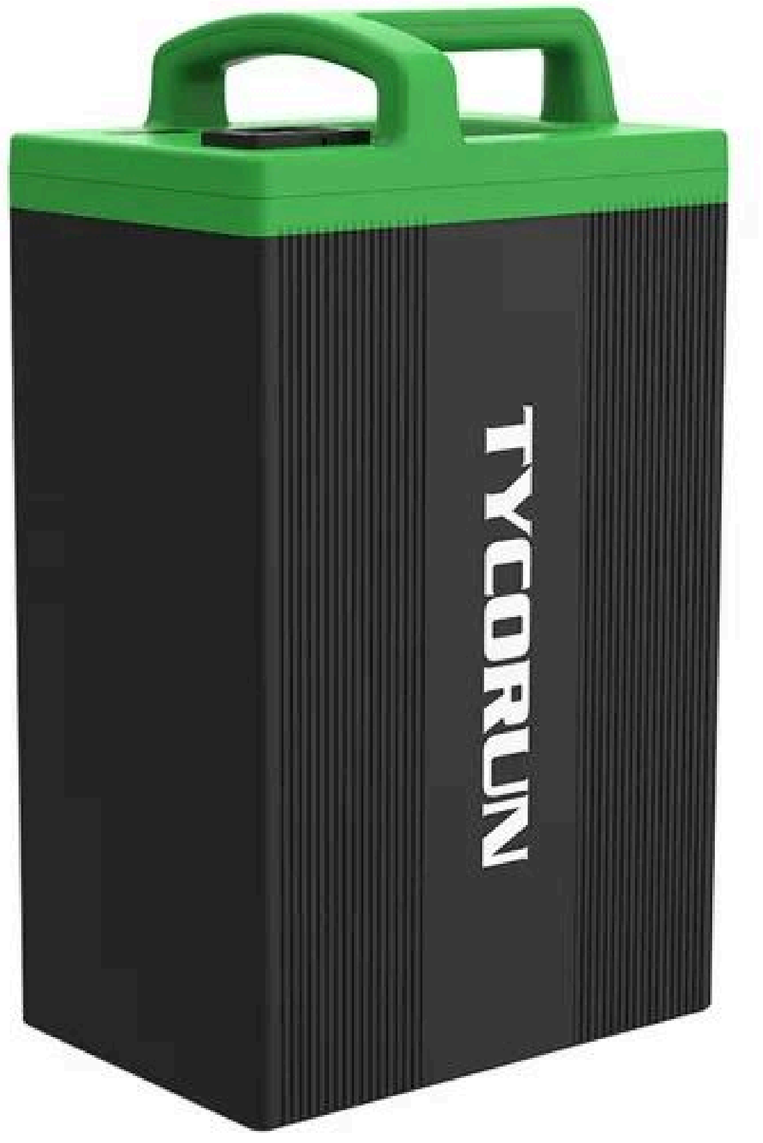


N. Swappable Batteries Compared

	Niu M+	Tycorun LFP	Tycorun 208	Tycorun LFP	Honda e:MPP	Gogoro	Phylion 7248	Phylion 7625	Niu M1	Tianneng 7230	Sunmobility
Openness	Closed/ Proprietary	Fully Open / Platform-Agnostic	Fully Open / Platform-Agnostic	Fully Open / Platform-Agnostic	Alliance-Open / Federated	Semi-Closed / Single-Platform	Fully Open / Platform-Agnostic	Fully Open / Platform-Agnostic	Closed/ Proprietary	Fully Open / Platform-Agnostic	Alliance-Open / Federated
Voltage	48V	76V	60V	72V	50V	50V	72V	76V	48V	72V	48V
Capacity	26Ah	40Ah	45Ah	30Ah	26Ah	39Ah	48Ah	25Ah	32Ah	32Ah	-
	1248Wh	3040Wh	2700Wh	2304Wh	1300Wh	1950Wh	3456Wh	190Wh	1536Wh	2304Wh	2100Wh
Dimensions	175×160×290 mm	225×170×325 mm	170×180×306 mm	159×230×375 mm	177×156×298 mm	168×168×355 mm	270×165×415 mm	-	-	220×160×333 mm	210×210×380 mm

0. TYCORUN 72V LFP Battery Pack Specsheet

TYCORUN



TYCORUN 72V 30Ah LiFPO4 Battery Specifications	
Projet	**Spécifications**
Taille de la batterie	76,8V 30Ah
Cellule de batterie	3.2v 30ah
ARE	1P24S
Taille/mm	159 (L) *230 (W) *395 (H) mm
Level of protection	IP67
Rated power (Wh)	2304
Standard charge/discharge current	0,5C / 1C
Maximum sustained discharge current	2C
Méthode de communication/4G/GPS	CAN/4G/GPS
Load operating temperature	-10~60℃
Discharge operating temperature	-20~65℃
Charging/discharging connector	DM80 (top)
Number of cycles/time	2000 (70%DOD)
Poids/Kg	20 kg

https://batteryswapstation.com/fr/product/72v-30ah-lifepo4-battery/#listing-home

P. Chogori Banga X100 Connector Specsheet

Banga X100 2+1+7 (100A+25A+5A)

Hybrid Connector for Residential & Portable Energy Storage

Advantages

- Snap lock mechanism
- Self-locking button to prevent accidental unlocking
- Up to 6 signal pins
- Audible click when lock engaged
- RoHS and REACH compliant

Catalogue Solution

Mating Cycle: ≥3,000 Cycles	Voltage Rating: 630V DC(Power) +100 V DC(Signal)	Operating Temperature: -40°C to 105°C
Wire Processing: Crimp/ Solder	Current Rating: 100A+25A+5A	IP Rating: IPX7 mated; IPX7 panel side
Insulation Resistance: >100MΩ	Peak Current: Power 180A 30S	Salt Spray: 5% Nacl, 48H
Wire Gauge: Power 25mm², Signal 20AWG/Max	Withstand Voltage: 2,500V AC	Flammability Rating: UL94V-0

https://www.chogori-tech.com/product/info.aspx?itemid=322

Q. Docking Module Simulation Input Variables Calculations

These calculations are generated by Gemini based on the specifications of the selected Tycorun battery

Battery Specifications Baseline

- **Nominal Voltage (U):** $72\ \text{V}$ ($76.8\ \text{V}$ nominal cell configuration)
- **Nominal Capacity (Q):** $30\ \text{Ah}$
- **Total Energy Capacity:** $2,304\ \text{Wh}$
- **Internal Resistance (R_{internal}):** $30\ \text{m}\Omega$ ($0.03\ \Omega$)

Configuration 1: Standard Continuous Load (30A Setting)

1. System Output Power

$$P_{\text{output}} = 72\ \text{V} \times 30\ \text{A} = 2,160\ \text{W} \quad (2.16\ \text{kW})$$

2. Relative Heat Loss Analysis

Stepping up the system architecture to a 72V topology restricts relative line and component heat dissipation down to 3.2% of the baseline heat generation compared to lower-voltage alternatives.

3. Absolute Heat Generation (Wattage)

$$P_{\text{heat}} = I^2 \times R_{\text{internal}}$$

$$P_{\text{heat}} = (30\ \text{A})^2 \times 0.03\ \Omega = 27\ \text{W}$$

4. SolidWorks Flow Simulation Inputs

- **Heat Source Selection:** Surface Heat Source (applied to the **inner walls** of the hollow battery casing).
- **Thermal Value:** $27\ \text{W}$
- **Environmental Boundary Condition:** Ambient fluid temperature set to 35°C **to** 40°C.

Configuration 2: Maximum Sustained Peak Load (60A Setting)

1. System Output Power

$$P_{\text{output}} = 72\ \text{V} \times 60\ \text{A} = 4,320\ \text{W} \quad (4.32\ \text{kW})$$

2. Relative Heat Loss Analysis

Doubling the current draw from 30A to 60A results in a $4\times$ **increase** in internal thermal energ generation inside the pack framework.

3. Absolute Heat Generation (Wattage)

$$P_{\text{heat}} = I^2 \times R_{\text{internal}}$$

$$P_{\text{heat}} = (60\ \text{A})^2 \times 0.03\ \Omega = 108\ \text{W}$$

4. SolidWorks Flow Simulation Inputs

- **Heat Source Selection:** Surface Heat Source (applied to the **inner walls** of the hollow battery casing).
- **Thermal Value:** $108\ \text{W}$
- **Study Type Setting:** Transient (Time-Dependent) study configured for $1,800\ \text{seconds}$ ($30\ \text{minutes}$) to observe thermal saturation inside the IP67 enclosure.

R. Integrated Prototype User Test

Node Bawa User Test

This test will take approximately 10 minutes.

Welcome to the Node Bawa User Test
This user test is part of a master's thesis research project titled *"Repairable, Modular and Open-Source Energy Storage for Weak-grid Regions of the Global South"*. The study is being conducted by Sam Boermans at Delft University of Technology (TU Delft).

This is a non-functioning physical prototype of the Node Bawa system. We are testing the physical interaction, ergonomics, and clarity of the design. Please "think aloud" as you perform each task so we can understand your process.

- **Purpose:** The purpose of this session is to evaluate the physical interaction and ergonomics of the Node Bawa dummy prototype.
- **Voluntary & Anonymous:** Your participation is entirely voluntary, and you are free to stop the test at any time without giving a reason. All data collected is 100% anonymous and will be used purely for academic research.
- **Contact:** If you have any questions, please contact Sam Boermans at sboermans@tudelft.nl.

By proceeding to the tasks below, you acknowledge that you have read this information and consent to participate in the study.

sam.boermans@gmail.com Ander account

Niet gedeeld

I have read the introduction and agree to participate.

- ◯ Agree

Can I take pictures for use in the report? Faces will be blurred.

- ◯ Ofcourse
- ◯ Rather not

Task 1: Modular Assembly

Instructions: Set up the system. Please connect the Inverter Module (the one with the screen) to the Docking Module (the bigger one). Connect them electrically (with the plug), and mechanically (using the grey handles!).

The orange visual cues made it obvious how the locking mechanism works.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

Aligning the two modules together felt natural and did not require awkward positioning.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

The physical effort required to slide and snap the modules into place was acceptable.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

The lifting handles provided a comfortable and balanced grip.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

It was intuitive to find and connect the electrical plug between the two modules.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

R. Integrated Prototype User Test

Task 2: The Battery Swap

Instructions: You just arrived with your electric scooter. Please remove its battery, place it in the docking station, and connect the internal cable.

The physical transfer from the motorcycle to the docking station was manageable.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The top-loading lid remained securely out of the way while inserting the battery.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The handle on the battery provided a secure and comfortable grip.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Plugging the internal cable into the docked battery was straightforward and required minimal effort.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Task 3: Charging with a Solar Panel

Instructions: Connect the solar panel cable to the appropriate port on the system to begin charging the battery.

It was immediately clear which port was intended for the solar panel input.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The physical location of the input port was accessible and comfortable to reach.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The labeling and physical location of the ports made it easy to differentiate the input from the outputs.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Connecting the solar cable to the system felt secure and straightforward.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Task 4: Powering an Appliance

Instructions: You have to charge the laptop and phone using the system. Connect them to the Node Bawa and turn on the power for the respective ports.

It was immediately clear which ports were intended.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Plugging a cable into the lower AC outlets was comfortable and ergonomic.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The physical buttons to activate the power were logically placed in relation to the outlets they control.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

The overall visual layout of the control panel made the power-on sequence intuitive without a manual.

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

S. NODE BAWA Parts and Disassembly Maps

UI FRONT PLATE
Houses UI/DC outputs.

DISPLAY
5 inch touch display.

TOGGLE SWITCHES
POWER, DC and AC.

12V BARREL PORTS
For DC home appliance.

USB-C PORTS
For charging devices.

DC TOP PLATE
Houses the DC board.

SIDE PANELS
Protects the module.

INTERLOCKING HOOKS
Modular interconnections.

HEAT SINK
For cooling AC board.

GRIP ASSEMBLY
Modular Interconnections

LID
To protect the battery.

HANDLE LOCK
Keeps the lid closed.

SPRING PAD
To clamp the battery.

GAS STRUTS
To assist opening lid.

PLUGS
Modular interconnections.

CHOGORI CABLE
Connects to the battery.

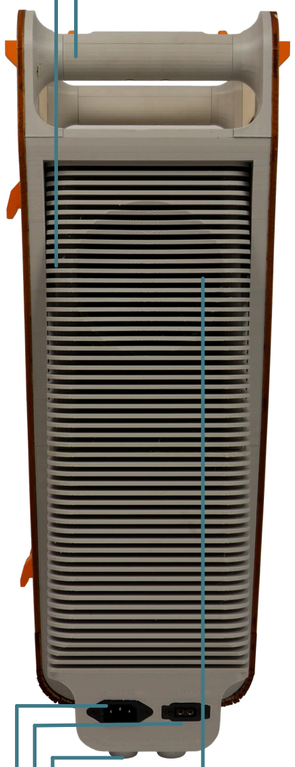
TYCORUN 72V LFP
Swappable LEV Battery

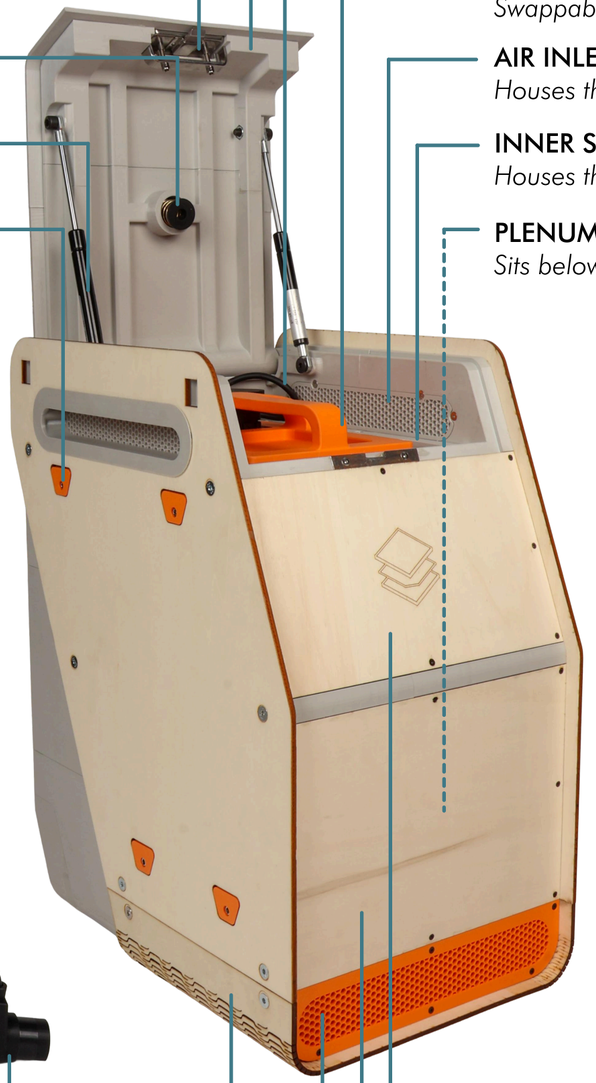
AIR INLET / GRIPS
Houses the battery.

INNER SLEEVE
Houses the battery.

PLENUM BASE + FAN
Sits below inner sleeve.

INVERTER MODULE





DOCKING MODULE

AC FRONT PLATE
Houses AC outlets.

AC OUTLETS
For AC appliances.

AIR INLET
For cooling inverter module.

BOTTOM PANEL
Protects the module.

FAN
For cooling inverter module.

RUBBER FEET
For module to stand on.

PV INPUT
For PV charging.

AC INPUT
For AC charging.

CHOGORI INPUT
For connecting the moc

REAR PLATE
Improves internal access.

REAR PIECE
Removable to swap Chogori orientation L/R.

REAR AIR OUTLET
Swappable LEV Battery

CHOGORI CABLE
For connecting the modules

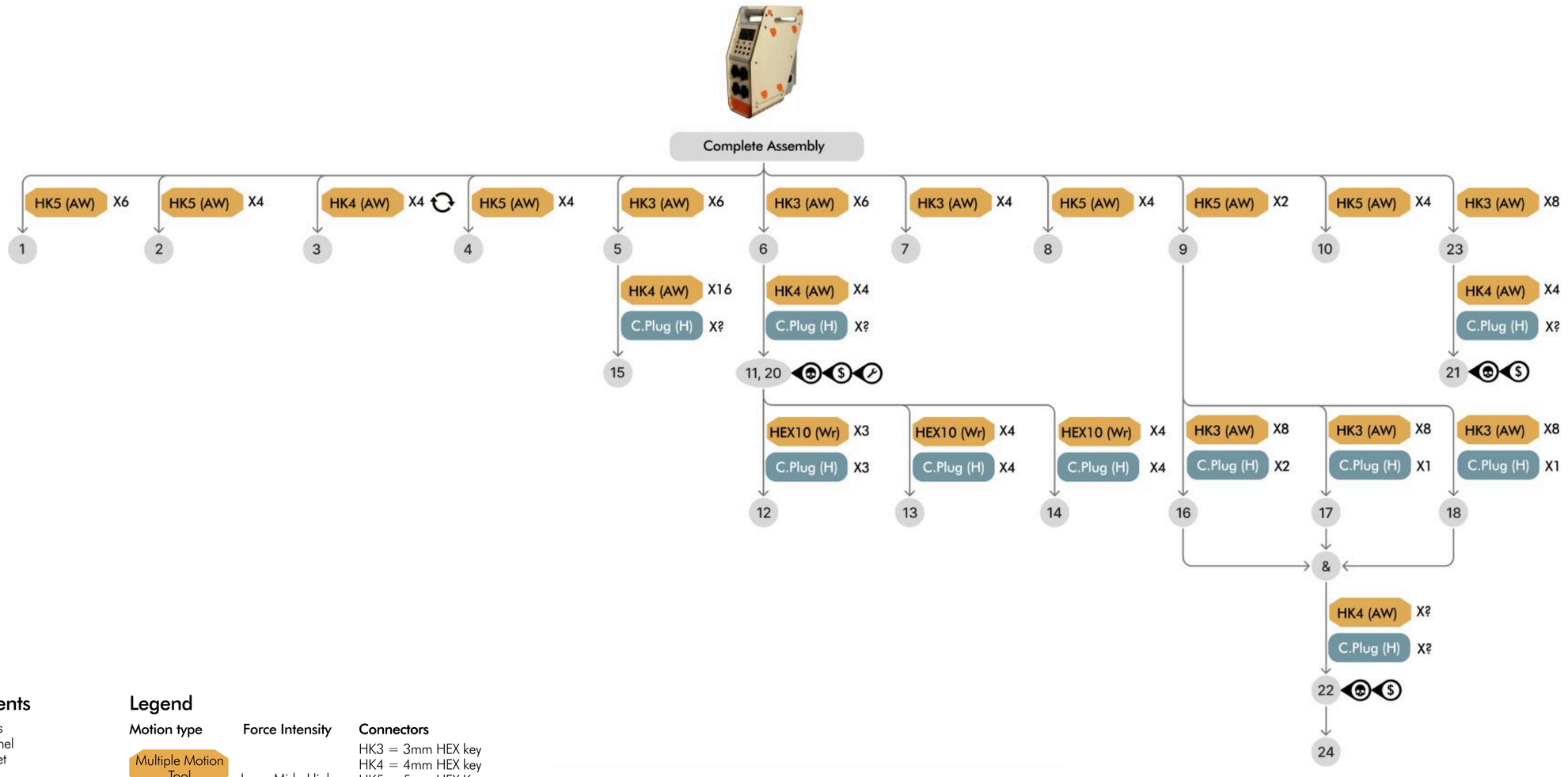
HIGHER FRONT PLATE
For accessing temperature sensor.

LOWER FRONT PLATE
For accessing DC converter.

FRONT AIR OUTLET
For cooling docking module.

BOTTOM PANEL
Protects the module.

S1. NODE BAWA Inverter Module Disassembly Map



Components

1. Side Panels
2. Bottom Panel
3. Rubber Feet
4. Plugs
5. Lower Front Plate
6. Higher Front Plate
7. Air Inlet Front
8. Interlocking Hooks
9. Heat Sink
10. Grip Assembly
11. Display
12. Toggle Switches
13. 12V Barrel Ports
14. USB-C Ports
15. AC Outlets
16. Chogori Input
17. AC Input
18. PV Input
19. Fan
20. UI Board
21. DC Board
22. AC Board
23. Top Plate
24. Main Frame

Legend

Motion type

Multiple Motion Tool

Single Motion Tool

Hand Motion

Force Intensity

Low Mid High

Connectors

HK3 = 3mm HEX key
HK4 = 4mm HEX key
HK5 = 5mm HEX Key
HEX10 = 10mm HEX Washer
C.PLug = Cable Plug

Penalties

= Product Manipulation

= Low Visibility/Identifiability

= Uncommon Tool

= Non-Reusable Connector

Type of Tool

(H) = Hand
(AW) = Allen Wrench / Hex Key
(Wr) = Wrench

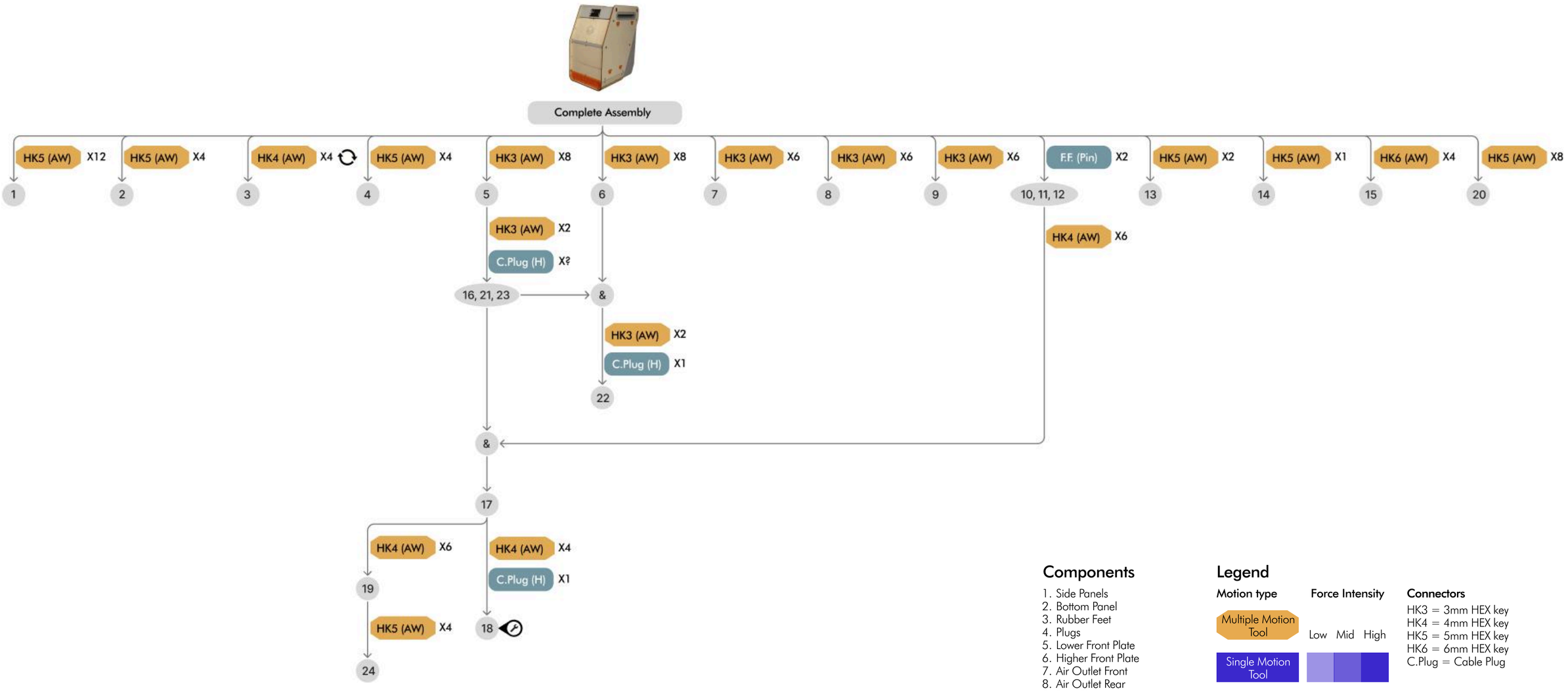
Target Components

= Failure Indicator

= Environmental Indicator

= Economic Factor

S2. NODE BAWA Docking Module Disassembly Map



Components

1. Side Panels
2. Bottom Panel
3. Rubber Feet
4. Plugs
5. Lower Front Plate
6. Higher Front Plate
7. Air Outlet Front
8. Air Outlet Rear
9. Rear Plate
10. Lid
11. Lid Hinge Rods
12. Lid Hinge Springs
13. Handle Lock
14. Pressure Pad
15. Gas Struts
16. Chogori Battery Cable
17. Inner Sleeve
18. Fan
19. Plenum Base
20. Side Grips
21. 72V→ 12V DC Converter
22. Mechanical Thermal Switch
23. Chogori Module Cable
24. Rear Piece
25. Main Frame

Legend

Motion type

Multiple Motion Tool

Single Motion Tool

Hand Motion

Force Intensity

Low Mid High

Connectors

HK3 = 3mm HEX key
HK4 = 4mm HEX key
HK5 = 5mm HEX key
HK6 = 6mm HEX key
C.Plug = Cable Plug

Penalties

= Product Manipulation

= Low Visibility/Identifiability

= Uncommon Tool

= Non-Reusable Connector

Type of Tool

(H) = Hand
(AW) = Allen Wrench / Hex Key
(Pin) = 1mm pin (small AW can also be used)

Target Components

= Failure Indicator

= Environmental Indicator

= Economic Factor

T. Project Brief

Project Proposal form
IDE Master Graduation Project

In this proposal the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document needs to be prepared for the Kick-off meeting and should be submitted in MyCase.

Name student Sam Boermans **Student number** 5027241

Project title Repairable, Modular and Open-Source Energy Storage for Weak-grid Regions of the Global South

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

MSc programme ☐ Design for Interaction ■ Integrated Product Design ☐ Strategic Product Design

☐ Other *(in case of a double degree outside IDE):* _____

Introduction

Describe the context of your project in the box below; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Biosphere Solar (client) makes open source, repairable solar panels. They want to extend their Circular values to Energy Storage Systems (ESS), Micro Storage and Smart PV in the global south. Were it is economically impossible to extend the governmental electricity grid, or where the grid is unstable, new companies like SunKing are growing fast with their off-grid solar energy systems and Pay-As-You-Go models (PAYGo; Reynolds & Paixão, 2024; Zebra et al., 2021). Sales of off-grid solar energy kits reached 9.3 million units globally in 2024, with over 250 million people receiving Tier 1 (Figure 1) electricity supply that lifts families out of extreme energy poverty (GOGLA, 2024). Instead of replacing old energy systems, people tend to 'stack' their energy to have a more reliable system as a whole (Masera et al., 2000). Higher Tier energy users, such as households and SME's rely heavily on small Backup Generators (BUGs; International Finance Corporation, 2019). The 20-30 million units account for approximately 350-500GW of power capacity, equal to about 700-1000 large coal power stations (Figure 2). About 10% household's income is spent on fuel to power the BUGs. These BUGs are inefficient and polluting, but highly repairable (dirty-but-open). Alternative Energy Storage systems that are on the market right now are cleaner, but practically unrepairable ('Black box': clean-but-closed). The opportunity in this domain lies in a clean-and-open solution for higher tier energy users.

→ *space available for images / figures on next page*

Introduction (continued): space for images

CAPACITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Power Capacity Ratings (minimum in W or daily Wh)		3 W	50 W	200 W	800 W	2,000 W
		12 Wh	200 Wh	1.0 kWh	3.4 kWh	8.2 kWh
Supported Appliances		Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
Typical Supply Technologies		Solar lantern	Rechargeable battery, SHS	Medium SHS, fossil fuel-based generator, mini-grid	Large SHS, fossil fuel-based generator, mini-grid, central grid	Large fossil fuel-based generator, central grid

Figure 1: Tiers of capacity of electricity supply (Bhatia & Angelou, 2015)

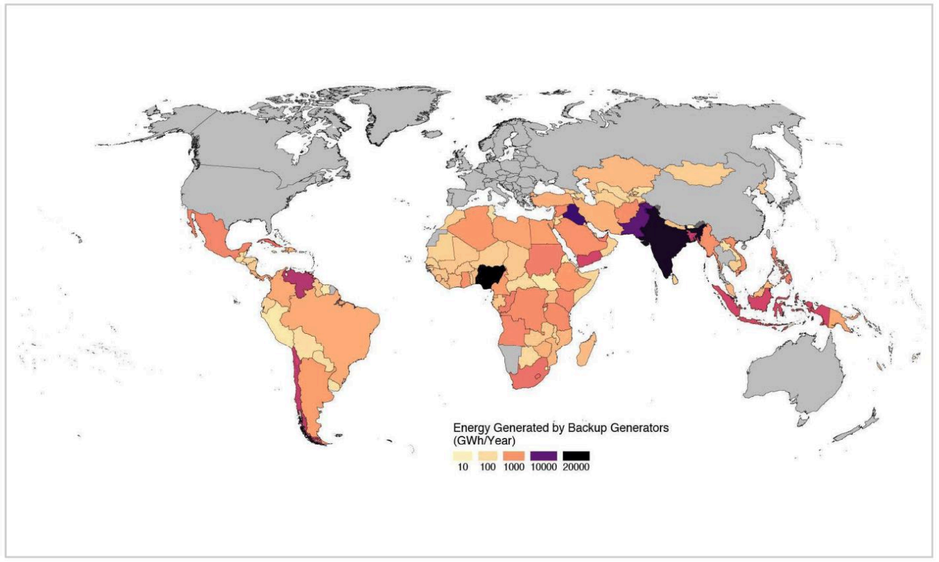


Figure 2: Energy generated by BUGs (International Finance Corporation, 2019)

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

The problem is a lack of clean-and-open systems that share the convenience, reliability, and repairability of the dirty-but-open diesel "Bugs." Biosphere Solar has partnered with **Hoymiles**, a Chinese company specialized in ESS, Microstorage, and Microinverters. They also partnered with organizations working on micro- and mini-grids in the **Global South**, specifically in Nigeria, India, and Indonesia. The intention is not to lift people from Tier 0 to Tier 1 electricity, but to research a serious alternative to the extensive generator culture of **higher-tier users**. Within this project, the opportunity is to develop a **TRL-3/5 product concept** that shows what clean-and-open microstorage could look like for these users. With TRL 3 as a lower limit for more technical subparts, and TRL 5 for use-related subparts. By exploring existing energy-stacking habits and local repair rituals in these "BUG societies," I can define the system's core functions and architecture. This creates added value by providing stakeholders with a validated roadmap to disrupt fossil-based fuel consumption, proving that high-tech performance can coexist with open repairability. That is the philosophy of Biosphere Solar.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project (1 sentence. As you graduate as an industrial design engineer, your assignment will start with a verb (Investigate/Design/Validate/Create), and you may use the format:
(Investigate/Design/Validate/Create) ***a*** *(what will be the deliverable → prototype/roadmap/process/intervention /approach/guideline/strategy/…)* ***to*** *(what should it do →(create/understand/evaluate/validate/improve/execute/ analyse/…) (the objective → experience/value/process/product/…)* ***for*** *(whom → target group/client/…)* ***in*** *(what context).*

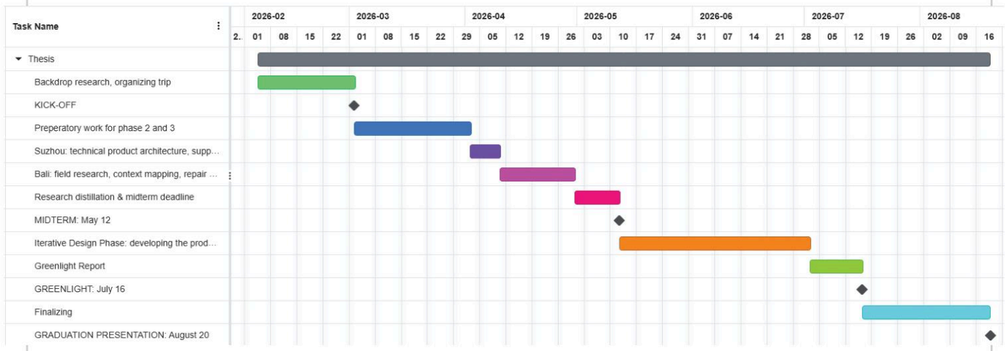
Design a TRL-3/5 product concept for a modular microstorage system to demonstrate the feasibility of a clean-and-open energy architecture for Tier 3 & 4 micro-entrepreneurs and households in the weak-grid contexts of the Global South.

Explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words).

This Research-through-Design project follows three phases:
1. Preperatory work for phase 2 and 3. Literatury research to prepare and define the research to be done abroad. Research product architecture as well as possible.
2. Supply Chain Contextualization (Discover): Exploratory research in China (Suzhou/Shanghai) visualizes the production context and components. At the Hoymiles (or comparable brand) manufacturing plant or disassembling an energy storage unit. This identifies the industrial logic and off-the-shelf component availability behind the 'Blackbox' architecture, creating the industrial baseline for repairability.
3. Contextmapping (Define): Ethnographic fieldwork (Bali) employs observations and possibly generative sessions to map local repair rituals and energy stacking habits. This contextualizes the technical findings to define human requirements for repairability.
4. Iterative Embodiment Design (Develop): Insights are synthesized into a TRL-3/5 concept using embodiment design. Functions are clustered into systems to isolate critical components. The design is validated through prototyping and user testing.

Project planning

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include the ***Kick-off****,* ***Midterm Evaluation****,* ***Green Light*** *and* ***Finalisation*** *(ceremony). Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities). Add (an image of) the planning in the box below. If it is not readable, you can add the planning as an attachment to My Case along with this Proposal.*



Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some (max 5) personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology (200 words max).

I know from experience that working for Biosphere gives me a very meaningful experience. I really need to intellectually resonate with the values of the company I would work for. Otherwise it can be hard to maintain a longterm focus.
The last year I had no choice but to study with very low presure, due to some first year courses that were only given during specific quarters. I am very excited to completely submerge myself in a process again like I haven't experienced since AED - almost 2 years ago. I also thrive on individual projects like these.

I did follow 'Design for the Circular Economy' during the bachelors, but I often felt a disconnect with the hard realities of global supply chains and product safety regulations that dictate actual final product design. I really want to bridge this gap in my professional influence in the first discovery phase by directly observing the manufacturing context in China.

The contextmapping phase and local research will test the limits of my social research skills. I am naturally more introverted so this is really an exciting moment to get more comfortable in unique settings.

The embodiment phase would be my most comfortable phase. I really love submerging myself completely uring this hase of rapid prototyping.

REFERENCES

GOGLA. (2024). *Annual Report 2024*.

International Finance Corporation. (2019). *The Dirty Footprint of the Broken Grid: The Impacts of Fossil Fuel Back-up Generators in Developing Countries.* World Bank Group.

Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). *From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model.* World Development, 28(12), 2083–2103.

Reynolds, O., & Paixão, S. (2024). *Global Off-Grid Solar Market Report: Annual Sales & Impact Data (2024 Public Report)*. GOGLA.

Zebra, E. I. C., van der Windt, H. J., Nhumaio, G., & Faaij, A. P. C. (2021). *A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries. Renewable and Sustainable Energy Reviews,* 144, 111036.