Optimising Electric Pressure Cooker Energy Usage through Power Spreading Techniques

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***Abstract*—Limited access to sustainable energy sources and clean cooking facilities is an important issue globally, especially in areas with weak infrastructure such as the Global South. Traditional biomass cooking methods lead to substantial indoor air pollution and related health hazards. Electric pressure cookers (EPCs) offer a sustainable alternative, but their high initial power consumption can cause grid overloads. Conventional EPCs control their temperature by cycling the heating element on and off using a thermostat or microcontroller, which switches the power on when the temperature drops below a set point and off when it exceeds it, typically dissipating around 230W. This paper addresses measures to overcome the challenges of transitioning from biofuel cooking to EPCs by exploring the potential of power spreading techniques. The hardware investigated includes a printed circuit board (PCB) designed to regulate voltage, allowing power to be spread and divided rather than simply turned on and off. The study examines simplified yet realistic cooking scenarios, including simultaneous cooking by all users and more practical, staggered cooking schedules. Through simulations and theoretical modelling, optimization measures and the applicability of these scenarios in real-life contexts are analysed. The findings highlight the significance of practical measures to implement sustainable cooking solutions in underserved communities, contributing to the broader goal of sustainable energy access.**

***Index Terms*—Electric pressure cookers (EPCs), power spreading, energy efficiency, equitable access, sustainable energy, indoor air pollution, theoretical modelling, power distribution strategies**

I. INTRODUCTION

In regions like the Global South where energy supplies are few, the death rates from severe indoor air pollution are higher than the combined deaths from HIV/AIDS, malaria, and tuberculosis. This is a result of the conventional cooking techniques being employed, which mostly rely on biomass fuels like charcoal and wood, which contaminate the air indoors. Research and development of greener cooking technology have been prompted by the pressing need to mitigate these health issues.

Electric pressure cookers have become a viable alternative, providing healthier cooking choices while consuming less energy. EPCs can offer a more effective cooking method and drastically reduce indoor air pollution. Nevertheless, the devices themselves present a significant obstacle to implementation in areas with limited and unreliable energy supplies. Their high energy demands during the initial heating phase can cause overloads and blackouts, exacerbating the challenges of accessing energy in these regions.

Typically, conventional EPCs manage their temperature by cycling the heating element on and off, controlled by a thermostat or microcontroller, which switches the power on when the temperature drops below a set point and off when it exceeds it, usually dissipating around 230W. To address the limitations of this approach, researchers such as Sacha Violleau have developed methods to make power consumption variable. This innovation involves using a PCB designed to regulate voltage, enabling more refined control over power distribution. These advancements allow for the exploration of power spreading techniques, which can distribute energy consumption more evenly over time to avoid peak loads and enhance grid stability.

In this research, the potential of power spreading techniques under the possibility of variable power consumption is explored. Power spreading is implemented in three distinct scenarios: continuous operation with power evenly divided among the cookers, staggered activation of cookers, and adjusted power cycles to achieve faster boiling times. The primary research question addressed is: How can power distribution methods be optimised to improve the energy efficiency and performance of electric pressure cookers in regions with limited and unstable energy infrastructure?

Section II provides a comprehensive analysis of the power distribution algorithms used in embedded systems. It explores Dynamic Voltage and Frequency Scaling (DVFS) and Dynamic Power Management (DPM), explaining how these algorithms adjust voltage and frequency based on current workloads to optimise energy usage. Additionally, it delves into the practical implementation of these techniques using a printed circuit board (PCB) designed to regulate voltage, ensuring precise control over power consumption. Furthermore, the section analyses temperature rise and decay using thermodynamic principles and a thermal-electrical analogy, and discusses social implications and various power distribution strategies to ensure effective and efficient power usage.

Following this, Section III presents the findings from the three cooking scenarios, analysing the efficiency of different power distribution strategies through simulations. Section IV interprets the results and explores the practical implications of the research. Finally, Section V summarises the key findings and their significance for sustainable energy access and cleaner cooking solutions.

By addressing these challenges, this research aims to contribute to the broader goal of sustainable energy access and cleaner cooking solutions, ultimately improving the health and well-being of communities in the Global South. The integration of these power management techniques is expected to provide a pathway to more resilient and efficient energy systems, aligning with global sustainability goals. The findings from this research will provide practical guidelines for policy-makers, engineers, and community leaders to enhance energy equity and promote sustainable energy practices in low-resource settings.

II. Analysis

A. Power Distribution Algorithms in Embedded Systems

In the context of optimising power distribution for electric pressure cookers within embedded systems, several advanced power management techniques are crucial. This section explores two significant algorithms: Dynamic Voltage and Frequency Scaling (DVFS) and Dynamic Power Management (DPM), and how these can be applied in this project.

Dynamic Voltage and Frequency Scaling (DVFS) modifies a processor's voltage and frequency according to the current workload. By lowering voltage and frequency during low demand periods, DVFS helps distribute power more effectively, conserving energy and minimising heat production. This approach maintains high performance when needed while conserving energy during less demanding tasks, making it suitable for optimising power consumption in embedded systems. Furthermore, DVFS improves the overall efficiency and reliability of systems by balancing performance and energy use based on real-time demands [5].

Dynamic Power Management (DPM), on the other hand, selectively shuts down or slows down system components when they are idle or underutilised, reducing overall power consumption. By dynamically adjusting the power states based on current usage, DPM enhances energy efficiency without compromising performance. This method is particularly advantageous for embedded systems with varying workloads and can significantly save energy during periods of low activity [4].

A specific application of DPM within this project is the power distribution method developed by Sacha Violleau. This method involves the use of a PCB designed to regulate voltage through Pulse Width Modulation (PWM) signals. The PCB, integrating a TL494 integrated circuit, controls output voltage and adjusts the power consumption of the EPCs. The buck converter in the PCB modifies the duty cycle to achieve effective voltage reduction, allowing for precise and adjustable power consumption. This specific implementation of DPM supports gradual power distribution, maximising energy efficiency and reducing peak loads on the grid [3].

These power management techniques provide a comprehensive understanding of power distribution in embedded systems, ensuring efficient power use while balancing performance and energy consumption. By implementing Sacha Violleau's PCB, the research aims to optimise energy usage, enhance cooking efficiency, and ensure reliable energy availability in areas with inadequate infrastructure.

B. Temperature Increase

To analyze the temperature increase within an EPC, the system can be approximated using fundamental thermodynamic principles. The relationship between the heat energy supplied and the resulting temperature rise in the water inside the cooker is given by:

$$Q = m \cdot c \cdot \Delta T \tag{1}$$

Here, Q represents the heat added to the system, m denotes the mass of the water, c signifies the specific heat capacity of water, and ΔT indicates the temperature change.

When heat is supplied at a constant power input P, the total heat energy supplied over a given time t is expressed as $Q = P \cdot t$. Combining these equations:

$$\Delta T = \frac{P \cdot t}{m \cdot c} \tag{2}$$

This formula provides a straightforward method to calculate the temperature increase of water given the heat input, the mass of the water, and its specific heat capacity, assuming no heat losses.

The boiling temperature of water in a pressure cooker is assumed to be approximately 110°C due to the increased pressure inside the cooker. At higher pressures, the boiling point of water rises above the standard 100°C, leading to faster cooking times and more efficient heat transfer.

C. System Approximation

To anticipate the behaviour of the system when the power is turned off and to derive an expression for the water's temperature drop, the EPC was approximated to an electrical system. Using the thermal-electrical analogy, a technique that reduces complex thermal systems to electrical circuits, an electric pressure cooker can be approximated to an electrical system with certain resistances and a capacitance.

To achieve this, losses to the environment or the thermal resistance of the plastic material were not considered. Instead, the focus was solely on the volume, the air and water inside the pot, and the metal walls of the inner pot. Specifications of a commercial SEB ACTUA 6L pressure cooker were utilised for the model. This cooker has a nominal capacity of 6 litres and weighs 3.0 kg. The lateral walls are 1 mm thick, with a diameter of 22 cm at the middle and 18 cm at the bottom. For simplification, the pot was assumed to be a perfect cylinder with a radius of 20 cm [2].

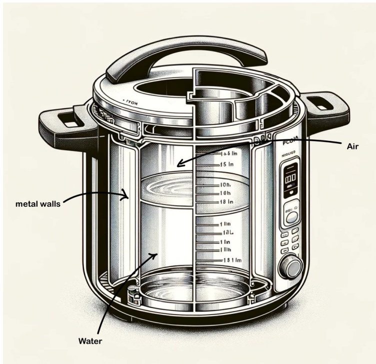


Fig. 1: EPC sketch

The water inside the cooker is represented by both a resistance (thermal resistance) and a capacitance (thermal capacitance). The capacitance represents the water's capacity to hold heat energy, while the resistance indicates how difficult it is to heat the water. Since the air inside the cooker also opposes the flow of heat, it is modelled as an additional resistance. Lastly, a resistance represents the cooker's metal body, which transfers heat from its interior to the exterior, demonstrating its thermal conductivity.

The electrical circuit analogous to the EPC can be found in Figure 2. The water and air resistances are in parallel, reflecting how both are heated simultaneously by the heater element. The metal resistance is in series with this parallel combination, representing the subsequent heat conduction through the metal body. The capacitance of the water is then connected in series and is particularly important, as it accounts for the thermal energy storage. When the cooker is switched off, the stored heat in the water continues to dissipate, similar to how a capacitor in an electrical circuit discharges over time.

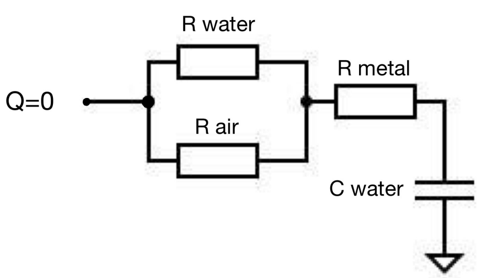


Fig. 2: EPC circuit for zero input

To determine the thermal resistance of each material, the equation used is:

$$R_{\text{thermal}} = \frac{L}{kA} \tag{3}$$

Where L is the thickness, k is the thermal conductivity, and A is the surface area of each material. The surface area of the pot and the volume were calculated based on its cylindrical shape and given dimensions. Given that the total volume of the pot is 6 litres and there is only 1 litre of water inside, the height of the water and air inside the pot was calculated accordingly. The specific heat capacity of the water ($c_{\text{water}} = 4180\,\text{J/kg}\cdot\text{K}$) was used for the capacitance. The obtained thermal resistances of the materials are shown in Table I.

TABLE I: Thermal conductivity of materials

Material	**Thermal conductivity (k)**	**Thermal resistance (R_{th})**
water	0.026 w/(mK)	29.6 K/W
air	0.598 w/(mK)	3.28 K/W
stainless steel	15 w/(mK)	0.004 K/W

D. *Exponential Temperature Decay*

The temperature response of an electric pressure cooker can be analysed using a thermal-electrical analogy. By modelling the EPC's thermal properties with electrical circuit components, we can predict the system's temperature behaviour over time, especially during the heat dissipation process when the power is turned off.

To determine the temperature $T(t)$ of the system when the input heat is zero, we first calculate the total thermal resistance of the system. Given that the thermal resistances of air and water are in parallel, and the thermal resistance of the metal is in series with this combination, the total resistance R_{total} is calculated as follows:

$$R_{\text{total}} = \frac{R_{\text{air}} + R_{\text{water}}}{R_{\text{air}}R_{\text{water}}} + R_{\text{metal}} \tag{4}$$

Substituting the values gives $R_{\text{total}} = 2.957\,\frac{\text{K}}{\text{W}}$. The thermal time constant τ is then calculated by multiplying the total thermal resistance by the thermal capacitance:

$$\tau = R_{\text{total}} \times C \approx 12360\,\text{s} \tag{5}$$

The temperature $T(t)$ of the system when the input heat is zero follows an exponential decay function. This can be expressed as:

$$T(t) = T_{\text{initial}} \cdot e^{-\frac{t}{\tau}} + T_{\text{ambient}} \tag{6}$$

Here, T_{initial} is the initial temperature at $t = 0$, and T_{ambient} is the ambient temperature at 25°C. This equation describes the exponential decay of the system's temperature towards the ambient temperature with a time constant of 12360 seconds.

E. *Future Hardware Implementation Prospects*

According to Sacha Violleau's research [3], the PCB designed for the Electrical Pressure Cooker project is crucial for regulating and reducing power consumption. The PCB generates Pulse Width Modulation (PWM) signals through the integration of a TL494 integrated circuit, which controls the output voltage and, consequently, the power consumption of the EPC. A buck converter is used to regulate the PWM signals by modifying the duty cycle, which results in effective voltage reduction. Because of its precise adjustable power consumption, this design allows the EPC to be adjusted to various scenarios of energy supply.

The original PCB design was modified to resolve issues with short circuits and overheating. It was discovered during the redesign that a diode's configuration was incorrect and that it was necessary to adjust some of the board's footprints. In order to simplify the design, a few components were also removed. These modifications enhanced the control and efficiency of the PCB, incorporating more robust components and optimised routing. The Appendix contains the modified PCB layout (see appendix A).

Later on in the project, the PCB can be utilised to apply the power spreading method that is described in the simulation section. By gradually increasing the distribution of power demand, this approach aims to maximize energy efficiency without significantly extending cooking times. However, integrating and testing this method with the PCB was beyond the scope of this research.

F. Social Implications and Distribution Strategies

While the technological aspects of power distribution in EPCs are crucial, it is equally important to consider the social implications of these methods. For this study, four EPCs are going to be considered. This project examines three primary scenarios for power distribution:

In Scenario 1, everyone receives an equal share of power, meaning the maximum power is divided by the number of active devices. This approach ensures that each user gets an equal portion of the available power. Nonetheless this method may not be optimal for all users, leading to inefficient power usage if some users do not need their full share at certain times.

In Scenario 2, EPCs stagger their cooking times to optimise power usage. For example, some users start cooking at different times to ensure that not all devices are drawing power simultaneously. This method improves overall energy efficiency and reduces peak loads on the grid. However, it introduces complexities in ensuring that all users have access to the power they need when they need it, potentially causing dissatisfaction if not managed properly.

In Scenario 3, two EPCs operate simultaneously, followed by another two EPCs starting their cooking cycles after the first pair. This scenario aims to balance the load more efficiently than Scenario 1 by having only a portion of the devices active at any given time, while still allowing for significant overlap in usage. This method can further reduce peak loads and improve energy distribution but may also require careful coordination to ensure all users are accommodated effectively. Potential issues could arise if users view the staggered start times as unfair or if the complexity of coordinating the schedule becomes unmanageable.

Addressing these social implications requires specific types of research beyond the technological focus of this project. Future work should involve community engagement to understand cultural, economic, and social factors influencing cooking habits and power needs. Ensuring effective power distribution will require a participatory approach where community members contribute to the design and implementation phases, aligning the system with local requirements and fostering trust among users. Although this project focuses on making efficient power distribution technologically feasible using methods like Sacha Violleau's PCB, it is essential to conduct further research to address the social aspects and ensure that the benefits of optimized power distribution are accessible to all users.

III. Simulation Results

This section details a simulation analyzing the temperature behaviour of water in the four EPCs with varying power inputs. The objective is to understand the efficiency of different power distribution strategies.

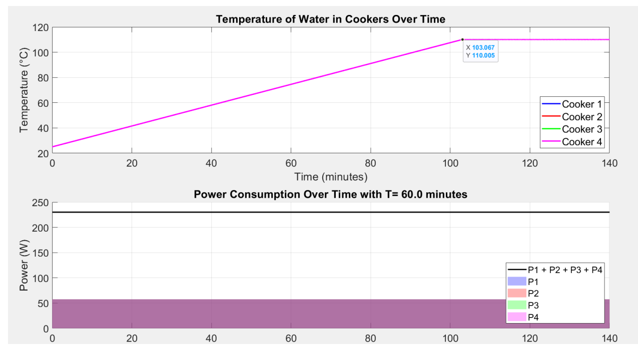


Fig. 3: Scenario 1: Continuous power distribution among four EPCs

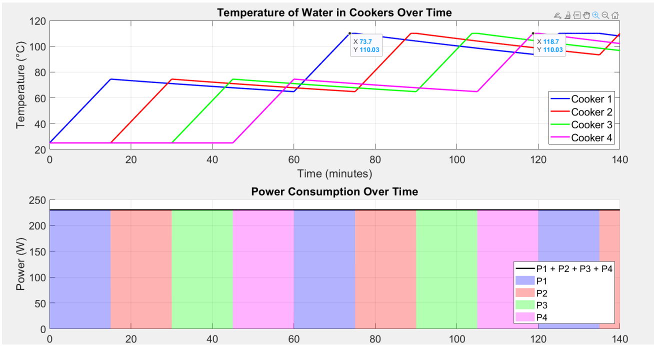
Starting at 25°C and targeting 110°C, each cooker contains 1 kg of water with a specific heat capacity of 4180 J/(kg·°C). The simulation runs for periods with switching intervals ranging from 40 to 120 minutes, adjusting power input cycles to optimise energy usage and boiling speed. Once the water reaches 110°C, the temperature remains constant because any additional heat converts the water to steam. The simulation accurately reflects this by maintaining the temperature at 110°C even if power continues to be applied, ensuring a realistic representation of the boiling process.

In Scenario 1 (Figure 3), each cooker operates continuously with a maximum power of 230W divided equally among the four cookers (57.5W each). This uniform power distribution is maintained throughout the entire period.

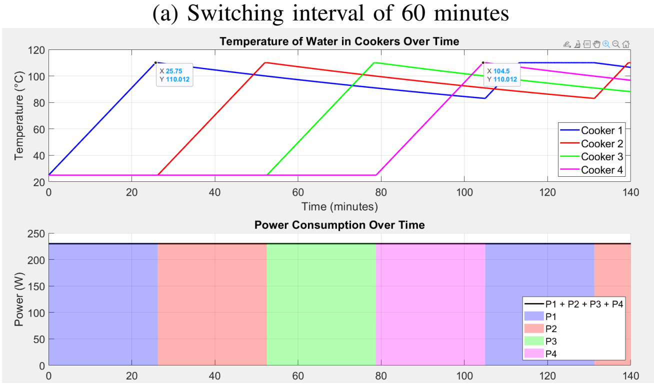
In Scenario 2 (figure 4), each cooker follows a distinct power cycle: Cooker 1 uses a maximum of 230W for the first quarter, then turns off. Cooker 2 activates in the second quarter, Cooker 3 in the third, and Cooker 4 in the final quarter. The temperature and power input are updated each second, applying power if below 110°C and using exponential cooling otherwise.

In Scenario 3 (Figure 5), power cycles are adjusted to potentially boil water faster. Cooker 1 and Cooker 2 operate at 115W for the first half of the switching interval, then turn off, while Cooker 3 and Cooker 4 operate at 115W in the second half. The temperature and power input are updated every second, applying power if the temperature is below 110°C and using exponential cooling otherwise.

Figures 6a and 6b illustrate the ratio τflb (first-to-last boiling), defined as the time taken for the water in Cooker 1

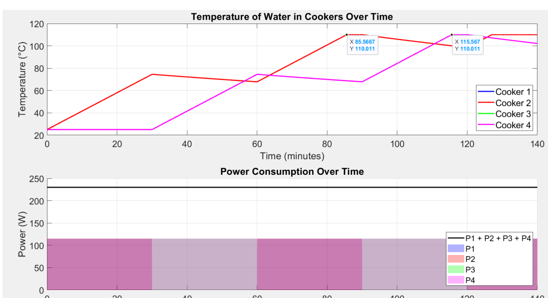


(a) Switching interval of 60 minutes

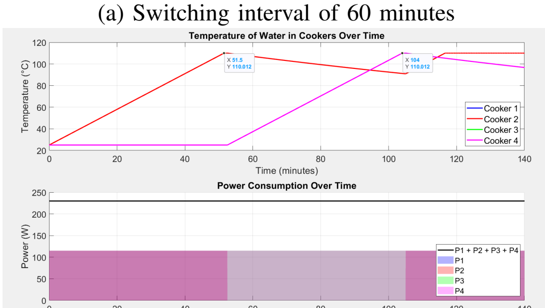


(b) Switching interval of 105 minutes

Fig. 4: Scenario 2: Staggered power cycles for the EPCs



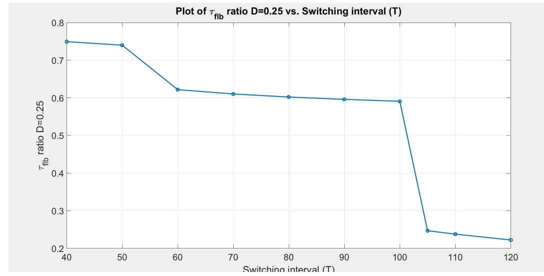
(a) Switching interval of 60 minutes



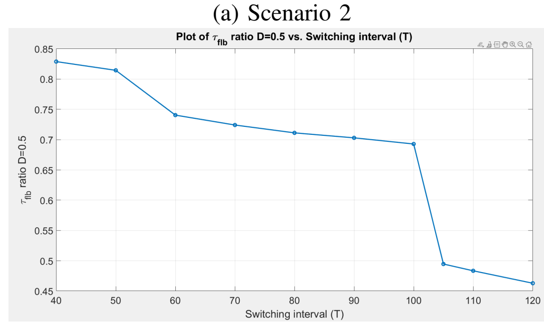
(b) Switching interval of 105 minutes

Fig. 5: Scenario 3: Two EPCs followed by another two with switching intervals for faster boiling

(first) to reach boiling divided by the time taken for the water in Cooker 4 (last) to reach boiling across different switching intervals. This ratio helps identify the optimal interval for



(a) Scenario 2



(b) Scenario 3

Fig. 6: First-to-last boiling ratio τ_{flb}

boiling efficiency by providing a comparative measure to determine which interval offers the best energy usage and heating efficiency performance.

IV. Discussion

In this research, the effectiveness of power spreading techniques in optimising the time required for four electric pressure cookers to reach the boiling point is examined. The qualitative analysis reveals that the quickest way to bring all EPCs to the boiling point is to distribute the power equally and simultaneously among all cookers (Scenario 1). This method minimises the initial high power demand that is usually required by EPCs, which can strain local power grids and cause grid overloads. From a hardware perspective, this equal distribution is beneficial because it ensures that the load on the PCB and its components, such as the TL494 integrated circuit and buck converter, remains consistent and within safe operating limits. This consistent load prevents the PCB from experiencing high current spikes that could lead to overheating, short circuits, or component failure. By maintaining a stable and equal power distribution, the hardware operates more efficiently and reliably, enhancing the overall durability and performance of the EPC system.

However, further analysis revealed that Scenario 2, which staggers the power distribution, is nearly as effective as Scenario 1, with a difference of only approximately one minute in the total cooking time. This reveals that a more balanced approach to power distribution can be just as effective as equal power distribution, while potentially providing additional benefits in specific contexts.

To provide an objective comparison, a quantitative measure, the first-to-last boiling ratio (τ_{flb}), was introduced as explained in the Simulation Results section III. A systematic comparison of the efficiency of various power distribution periods was provided using τ_{flb}. The results show that the graph can be separated into three levels based on the number of cycles required for the EPCs to reach the boiling point, as seen in Figure 6. From 40 to about 50 minutes, the cookers require three cycles. From 60 to 100 minutes, two cycles are required, but from 105 to 120 minutes, just one is required. This transition demonstrates how changing the power distribution switching interval may significantly enhance the efficiency of the boiling process. All comparisons on efficiency in this analysis are based on this τ_{flb} ratio to ensure an objective evaluation of the different power distribution scenarios.

The most efficient switching intervals for achieving the boiling temperature quickly are 60 and 105 minutes. These periods represent the transitions from three to two cycles and from two to one cycle, respectively. When comparing those two intervals, it became clear that 105 minutes is technically faster, as all cookers reach boiling within a total of 104 minutes. In contrast to a 60 minute interval that takes about 115 to 118 minutes in total, adding around 11 to 14 minutes delay to the total cooking time, depending on the scenario one chooses. However, in the 60-minute interval, since two cycles are needed, the water in all four cookers starts warming up from the first cycle, which can be used as a head start for cooking. This advantage is not present in the 105-minute interval scenarios. Specifically, in Scenario 2, the last cooker needs to wait around 78 minutes before the EPC can turn on to start cooking, causing a significant delay. The 60-minute interval ensures that all cookers begin heating sooner, allowing for more efficient and timely meal preparation. This finding can be considered important for optimising energy use in contexts where power resources are limited and need to be managed efficiently.

Realistically, the choice of scenario depends on how the cookers are being used. If not all cookers need to be used simultaneously, Scenario 2, where the first EPC boils water in just 25 minutes, is preferable because it allows for flexibility in usage. This scenario enables users to start cooking at different times, which can be beneficial in settings where staggered meal preparation is common, reducing the strain on the power grid and ensuring that energy is available when needed. In a community with staggered cooking times, Scenario 2 would suit a neighbourhood where people cook at different intervals, thus distributing the load over a longer period.

If two cookers need to operate simultaneously, followed by another two, Scenario 3 would be more efficient. This scenario reduces the peak power demand by spreading the power consumption over time, allowing the first two cookers to reach a relatively high temperature before the next two start their cycles. This staged approach helps manage the power load more effectively and ensures that each pair of cookers receives adequate power to function optimally without overloading the power grid. Scenario 3 might be best for smaller clusters of households that cook in shifts, further smoothing out the power demand and preventing peaks.

When all cookers need to be used simultaneously, Scenario 1 is the optimal choice because it utilises the designed hardware modules to evenly distribute power among all EPCs at the same time. In a community where all households tend to prepare meals at the same time, Scenario 1 is ideal as it spreads the load evenly across all cookers, avoiding peak demand issues. Thus, the preferred scenario depends significantly on the specific use case and the patterns of energy use within a community.

It is important to mention that the simulations are based on ideal conditions, assuming a maximum power of 230W for all cookers, which is not realistic for an actual grid due to power losses. Additionally, the simulations focus solely on bringing water to a boil at a specific temperature. When cooking food, additional variables need to be considered, as they will affect power distribution and efficiency. For example, different types of food require varying amounts of energy to cook, which could impact the effectiveness of power spreading strategies. Moreover, the first-to-last boiling ratio (τ_{flb}) is not an ideal measure because it simplifies complex dynamics and does not account for intermediate temperature changes or the specific energy needs of different foods. However, it does provide a useful and honest comparison by offering a straightforward way to evaluate the relative performance of different power distribution strategies. By focusing on the time it takes for all cookers to reach boiling, τ_{flb} highlights the effectiveness of each scenario in terms of synchronizing the boiling process and managing power distribution. For further research, it is essential to account for realistic conditions, such as cooking various meals and considering power losses, to ensure more accurate real-life scenarios. Additionally, further studies are needed to assess the long-term effects on both the EPCs and the power infrastructure and to evaluate the economic viability of these power spreading techniques to ensure they are both sustainable and practical.

V. Conclusion

This research has highlighted the significant potential of power spreading techniques in optimising the energy usage of electric pressure cookers and addressing the critical challenges associated with transitioning from traditional biomass cooking to electric cooking in regions with limited and unreliable energy supplies. Through various simulations, practical methods for enhancing energy efficiency across different cooking scenarios have been identified.

The findings from the simulations underscore that equal power distribution among all cookers (Scenario 1) is the most effective and quickest method for minimising the initial high power demand, which often results in local grid overloads. However, Scenario 2, which employs staggered power distribution, has shown to be nearly as effective, offering the added advantage of flexibility in cooking times. Scenario 3, involving the sequential operation of cookers, has effectively reduced peak power demand, demonstrating the importance of adapting power distribution strategies to specific usage patterns.

These insights answer the primary research question affirmatively, confirming that optimized power distribution methods for variable EPC power consumption can be successfully applied to enhance energy efficiency. Such findings are pivotal for the development of sustainable cooking solutions and the enhancement of energy access in underserved communities. The implementation of advanced power management techniques, such as the PCB designed by Sacha Violleau, presents a viable path towards more resilient and efficient energy systems, aligning with broader sustainability goals.

Additionally, this research highlights the broader implications of these technological advancements. The transition to electric cooking solutions not only mitigates indoor air pollution but also significantly reduces health hazards associated with traditional biomass cooking methods. By implementing power spreading techniques, the reliability and stability of local energy grids can be improved, making sustainable cooking solutions more feasible in regions with weak infrastructure.

To ensure the practical applicability of these power spreading techniques, future research should involve comprehensive community engagement to understand the cultural, economic, and social factors influencing cooking habits and energy needs. Participatory approaches should be employed, allowing community members to contribute to the design and implementation phases. Additionally, future studies must account for real-world conditions, such as the variety of meals cooked, potential power losses, and the long-term effects on both EPCs and power infrastructure. Evaluating the economic viability of these techniques is essential to ensure they are sustainable, practical, and cost-effective for widespread adoption.

In conclusion, this research provides a solid foundation for the development of sustainable cooking solutions in low-resource settings. By addressing the technical and social dimensions of power distribution in EPCs, the study offers practical guidelines for policy-makers, engineers, and community leaders. Implementing these findings can significantly contribute to enhancing energy equity, promoting sustainable energy practices, and improving the health and well-being of communities in the Global South. As the world continues to seek solutions to global energy challenges, the insights from this research are poised to make a meaningful impact on sustainable energy access and clean cooking solutions.

VI. Declaration

During the preparation of this work, the author used ChatGPT and Grammarly for help with writing and improving text in order to deliver a professional and coherent-sounding text. ChatGPT was also utilised as an aid for the code used to simulate the findings and generation of a simple EPC device depicted in figure 1. After the use of these tools/services, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

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Appendix A
PCB Schematics and Layout

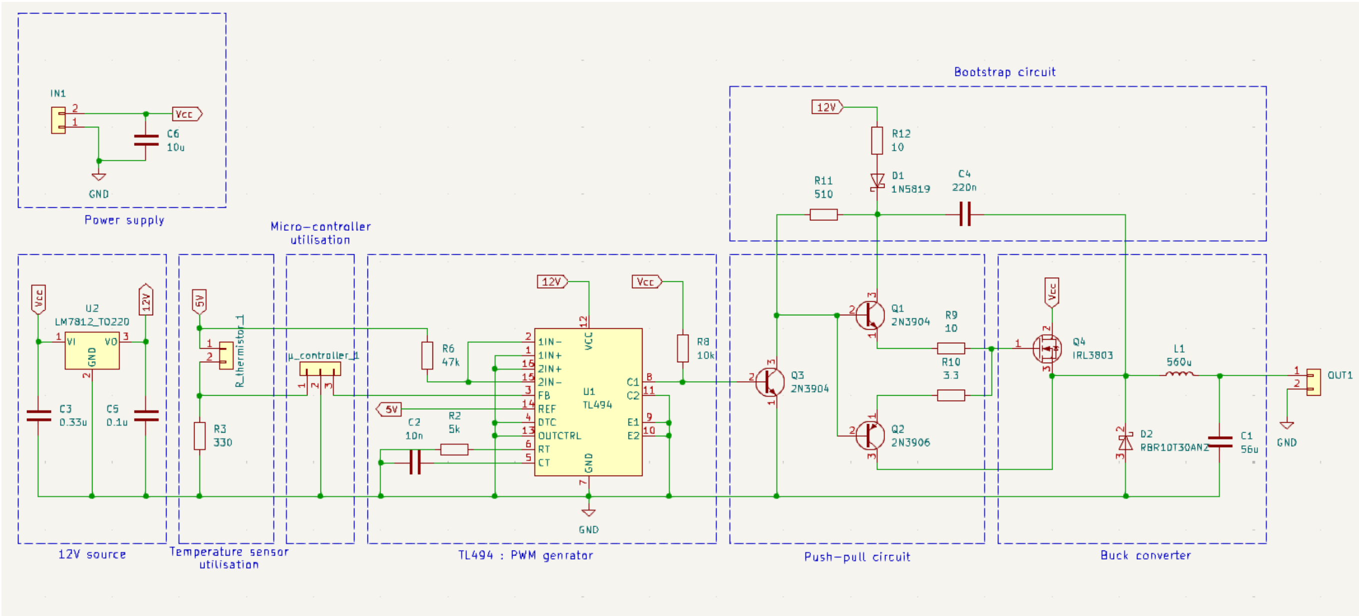

Fig. 7: PCB electronic card schematic

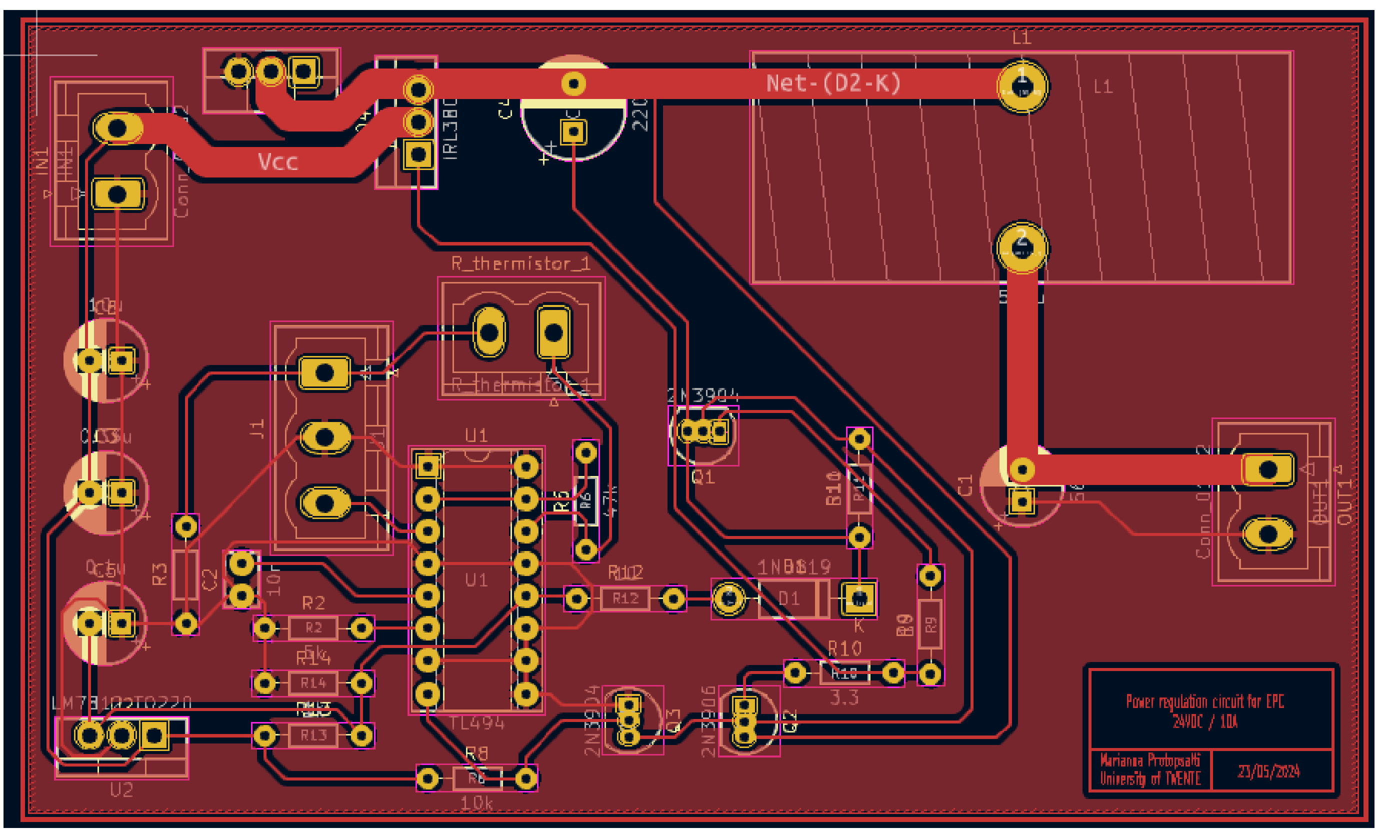

Fig. 8: PCB routing placement

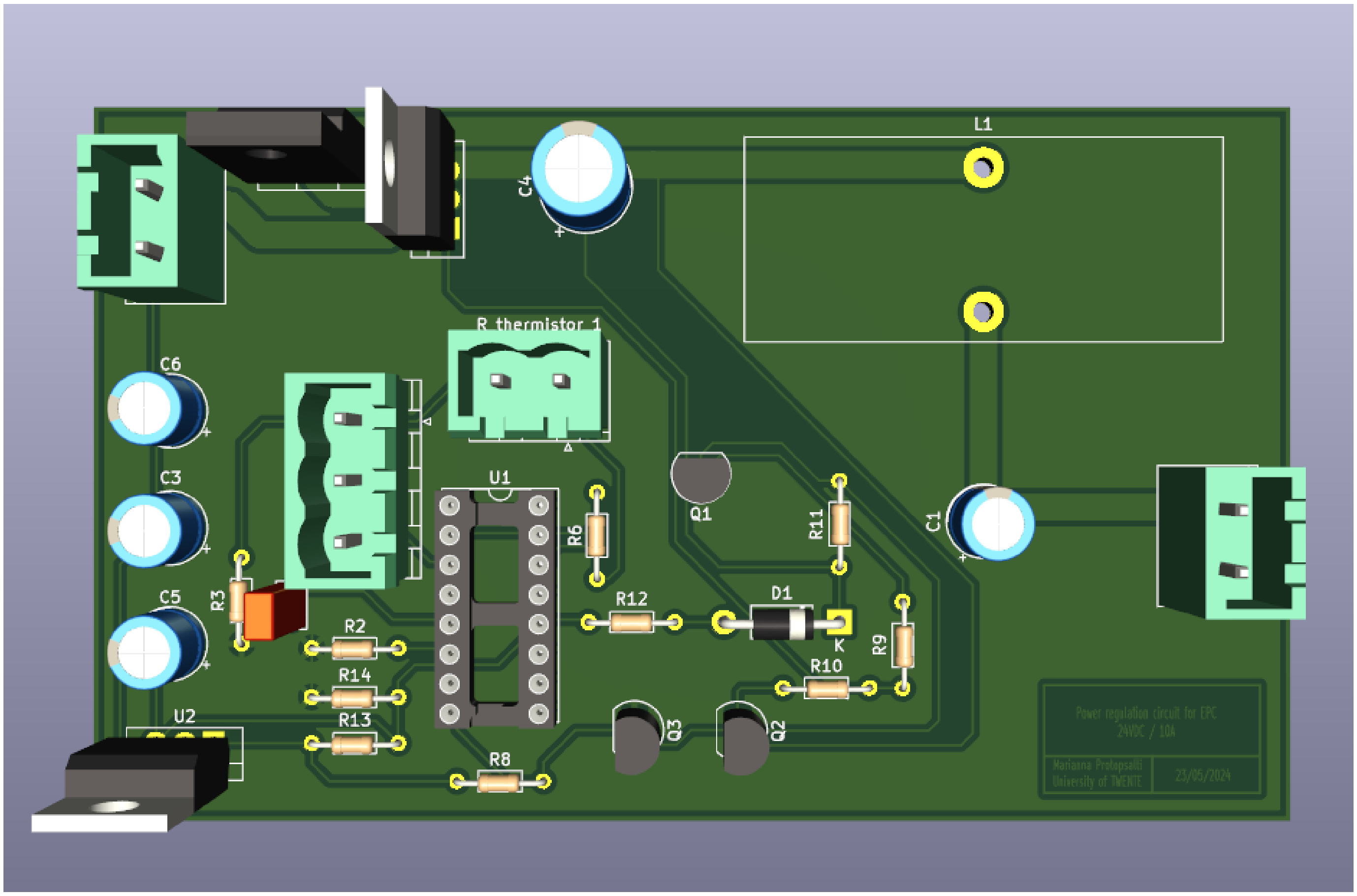

Fig. 9: 3D view

APPENDIX B
MATLAB CODE

Here is the MATLAB code used in the simulations:

```
% Parameters
T_initial = 25; % Initial temperature (C)
T_boiling = 110; % Boiling temperature (C)
c = 4180; % Specific heat capacity of water (J/(kg C))
m = 1; % Mass of water (kg)
t_total =60 * 60; % period multiplied by 60 to have it in seconds (change this value as needed)
period=t_total/60;
D = 0.25; %Change this to 0.5 to get scenario 3
T = t_total;
R = 2.9557; % Resistance factor for exponential cooling


% Power inputs for each cooker

P1 = [230 * ones(1, round(D * T)), 0 * ones(1, round((1 - D) * T))]; % Cooker 1 power input
P2 = [0 * ones(1, round(D * T)), 230 * ones(1, round(D * T)), 0 * ones(1, round((1 - 2*D) * T))]; % Cooker 2 power input
P3 = [0 * ones(1, round(2*D * T)), 230 * ones(1, round(D * T)), 0 * ones(1, round((1 - 3*D) * T))]; % Cooker 3 power input
P4 = [0 * ones(1, round(3*D * T)), 230 * ones(1, round((D) * T))]; % Cooker 4 power input

%Equal power distribution
% P1 = [ 57.5 * ones(1, round((1-D) * T)),57.5 * ones(1, round((D) * T))];
% P2 = [ 57.5 * ones(1, round((1-D) * T)), 57.5* ones(1, round((D) * T))];
% P3 = [ 57.5* ones(1, round((1-D) * T)), 57.5 * ones(1, round((D) * T))];
```

```
% P4 = [ 57.5 * ones(1, round((1-D) * T)), 57.5 * ones(1, round((D) * T))];

P1 = [P1 P1];
P2 = [P2 P2];
P3 = [P3 P3];
P4 = [P4 P4];

P1 = [P1 P1];
P2 = [P2 P2];
P3 = [P3 P3];
P4 = [P4 P4];

t_total = length(P1);

% Initialize temperature arrays
T1 = T_initial * ones(1, t_total);
T2 = T_initial * ones(1, t_total);
T3 = T_initial * ones(1, t_total);
T4 = T_initial * ones(1, t_total);

% Simulate the heating process
for t = 2:t_total+1
    % Determine power input for each cooker at current time
    if (T1(t-1) < 110)
        power1 = P1(t-1); % Cycle every 10 minutes
    else
        power1 = 0;
    end
    if (T2(t-1) < 110)
        power2 = P2(t-1); % Cycle every 10 minutes
    else
        power2 = 0;
    end
    if (T3(t-1) < 110)
        power3 = P3(t-1); % Cycle every 10 minutes
    else
        power3 = 0;
    end
    if (T4(t-1) < 110)
        power4 = P4(t-1); % Cycle every 10 minutes
    else
        power4 = 0;
    end

    % Calculate temperature increase due to heating
    delta_T1 = (power1 * 1) / (m * c); % Assuming 1 second time step
    delta_T2 = (power2 * 1) / (m * c); % Assuming 1 second time step
    delta_T3 = (power3 * 1) / (m * c); % Assuming 1 second time step
    delta_T4 = (power4 * 1) / (m * c); % Assuming 1 second time step

    % Update temperature based on power input and time step
    if t < t_total+1 % Prevent index out of bounds
        T1(t) = T1(t-1) + delta_T1;
        T2(t) = T2(t-1) + delta_T2;
        T3(t) = T3(t-1) + delta_T3;
        T4(t) = T4(t-1) + delta_T4;
    end

    % Apply exponential cooling if cookers are off
    if power1 == 0
        T1(t) = (T1(t-1) - T_initial) * exp(-1 * 1 / (R * c))+T_initial;
    end

    if power2 == 0
        T2(t) = (T2(t-1)-T_initial) * exp(-1 * 1 / (R * c))+T_initial;
    end

```

```matlab
    if power3 == 0
        T3(t) = (T3(t-1)-T_initial) * exp(-1 * 1 / (R * c))+T_initial;
    end

    if power4 == 0
        T4(t) = (T4(t-1)-T_initial) * exp(-1 * 1 / (R * c))+T_initial;
    end
end

% Final temperatures after t_total seconds
final_temperature1 = T1(end);
final_temperature2 = T2(end);
final_temperature3 = T3(end);
final_temperature4 = T4(end);

fprintf('Final␣temperature␣of␣the␣water␣inside␣Cooker␣1␣after␣%.0f␣minutes:␣%.2fC\n', t_total / 60, final_temperature1);
fprintf('Final␣temperature␣of␣the␣water␣inside␣Cooker␣2␣after␣%.0f␣minutes:␣%.2fC\n', t_total / 60, final_temperature2);
fprintf('Final␣temperature␣of␣the␣water␣inside␣Cooker␣3␣after␣%.0f␣minutes:␣%.2fC\n', t_total / 60, final_temperature3);
fprintf('Final␣temperature␣of␣the␣water␣inside␣Cooker␣4␣after␣%.0f␣minutes:␣%.2fC\n', t_total / 60, final_temperature4);

% Define total time in minutes
t_total_minutes = t_total / 60;

% Calculate the period of on and off switching
cycle_time_seconds = D * T; % on time in seconds
off_time_seconds = (1 - D) * T; % off time in seconds

cycle_time_minutes = cycle_time_seconds / 60; % on time in minutes
off_time_minutes = off_time_seconds / 60; % off time in minutes

% Plot temperatures
time = (0:t_total-1) / 60; % Time in minutes

figure;

subplot(2, 1, 1); % Subplot for temperatures
plot(time, T1(1:t_total), 'b-', 'LineWidth', 2);
hold on;
plot(time, T2(1:t_total), 'r-', 'LineWidth', 2);
plot(time, T3(1:t_total), 'g-', 'LineWidth', 2);
plot(time, T4(1:t_total), 'm-', 'LineWidth', 2);
xlim([0 140]);
xlabel('Time␣(minutes)', 'FontSize', 16);
ylabel('Temperature␣(C)', 'FontSize', 16);
title(sprintf('Temperature␣of␣Water␣in␣Cookers␣Over␣Time'), 'FontSize', 14);
% title(sprintf('Temperature of Water in Cookers Over Time with T= %.1f minutes',  period), 'FontSize', 14);
legend('Cooker␣1', 'Cooker␣2', 'Cooker␣3', 'Cooker␣4', 'FontSize', 12);
grid on;
hold off;

subplot(2, 1, 2); % Subplot for power
hold on;
plot(time, P1 + P2 + P3 + P4, 'k-', 'LineWidth', 2, 'DisplayName', 'P1␣+␣P2␣+␣P3␣+␣P4');
fill([time, fliplr(time)], [P1, zeros(size(P1))], 'b', 'FaceAlpha', 0.3, 'EdgeColor', 'none', 'DisplayName', 'P1');
fill([time, fliplr(time)], [P2, zeros(size(P2))], 'r', 'FaceAlpha', 0.3, 'EdgeColor', 'none', 'DisplayName', 'P2');
fill([time, fliplr(time)], [P3, zeros(size(P3))], 'g', 'FaceAlpha', 0.3, 'EdgeColor', 'none', 'DisplayName', 'P3');
fill([time, fliplr(time)], [P4, zeros(size(P4))], 'm', 'FaceAlpha', 0.3, 'EdgeColor', 'none', 'DisplayName', 'P4');

```

```
xlim([0 140]);
xlabel('Time␣(minutes)', 'FontSize', 16);
ylabel('Power␣(W)', 'FontSize', 16);
title(sprintf('Power␣Consumption␣Over␣Time'), 'FontSize', 14);
% title(sprintf('Power Consumption Over Time with T= %.1f minutes',  period), 'FontSize', 14);
legend show;
grid on;
hold off;
```

Listing 1: MATLAB Code for Simulations of cooking scenarios

```
% Given values
data = [
    40, 0.82889;
    50, 0.81447;
    60, 0.74052;
    70, 0.72415;
    80, 0.7112;
    90, 0.70298;
    100, 0.69282;
    105, 0.4946;
    110, 0.4834; % Correcting the format
    120, 0.46287;
];

% Create a table
R2 = array2table(data, 'VariableNames', {'Period_T', 'Tob_ratio_D_0_5'});

% Display the table
disp(R2);

% Plot the values against each other
figure;
plot(R2.Period_T, R2.Tob_ratio_D_0_5, 'o-', 'LineWidth', 2, 'MarkerSize', 6);
xlabel('Period␣(T)');
ylabel('\tau_{flb}␣ratio␣D=0.5');
title('Plot␣of␣\tau_{flb}␣ratio␣D=0.5␣vs.␣Period␣(T)');
grid on;

% Given values
data = [
    40, 0.74924;
    50, 0.73985;
    60, 0.621735;
    70, 0.610245;
    80, 0.60216;
    90, 0.59593;
    100, 0.5908;
    105, 0.24689;
    110, 0.2379; % Correcting the format
    120, 0.2223;
];

% Create a table
R2 = array2table(data, 'VariableNames', {'Period_T', 'Tob_ratio_D_0_25'});

% Display the table
disp(R2);

% Plot the values against each other
figure;
plot(R2.Period_T, R2.Tob_ratio_D_0_25, 'o-', 'LineWidth', 2, 'MarkerSize', 6);
xlabel('Period␣(T)');
ylabel('\tau_{flb}␣ratio␣D=0.25');
title('Plot␣of␣\tau_{flb}␣ratio␣D=0.25␣vs.␣Period␣(T)');
grid on;
```

Listing 2: MATLAB Code for first to last boiling ratio τ_{flb}