Scaling up solar cooking studies: A modeling framework for planning sustainable transition of the bakery sector

Benjamin Pillot, Guillaume Guimbretière, Christophe Révillion, Corrie Mathiak, Romain Authier

Energy Research & Social Science 118 (2024) 103815

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Scaling up solar cooking studies: A modeling framework for planning sustainable transition of the bakery sector

Benjamin Pillot [a,*], Guillaume Guimbretière [b], Christophe Révillion [a], Corrie Mathiak [c], Romain Authier [a]

[a] ESPACE-DEV, Univ Montpellier, IRD, Univ Antilles, Univ Guyane, Univ Réunion, Montpellier, France
[b] UMR LACy, Univ Réunion, CNRS, Météo-France, Saint-Denis, La Réunion, France
[c] Friedrich-Schiller-Universität Jena, Jena, Germany

ARTICLE INFO

Keywords:
Artisan bakeries
Solar energy
Decision-aid
Socio-technical transition
Multi-scale analysis

ABSTRACT

The recent rise of energy prices in Europe has directly impacted retail trade such as artisan bakeries. While energy transition is now a tangible aim for the bakery sector, apprehending its near future requires reconciling scales of analysis: from the baking technology to the territory where bakers and bread consumers will interact, based on aspects such as bakery organization, bread type or population dietary behavior. The solar cooking literature typically synthesizes such a fork in the road: the device (solar cooker) has been deeply scrutinized and improved, but wider socio-technical approaches are now required to eventually trigger changes at the sector level. Based on those elements, we thus propose a modeling framework with spatiotemporal granularity that integrates the various scales of analysis for planning sustainable transition of the bakery sector. We then derive decision-aid indicators for assessing information such as bread accessibility & viability, bread turnover (baked bread that is actually consumed), economic return or environmental impact. Finally, we apply this set of tools to the specific example of direct solar baking and demonstrate the various potential applications – regional to continental-scale spatial mapping, geolocated time series, etc. – by producing benchmark results and scenarios across the western European territory.

1. Introduction and related work

Recently, the sharp rise of energy and electricity prices in Europe, from €0.0820 per KWh in 2020 to €0.1986 per KWh in 2022 for non-household consumers [1], has jeopardized many small-scale commercial activities such as artisan bakeries in France [2]. It shows how much work remains to be done for enhancing *energy resilience* and eventually walking the path of a truly *sustainable energy transition*. In a time of economic instability and increasing environmental change, rational decision support and robust scenarios for sustainable pathways are more needed than ever for helping effective political actions. Accordingly, energy transition analysis and scenarios must follow a more systemic approach and go beyond the sole energy supply dimension, by embracing the corresponding social, cultural and technical changes that will inevitably occur [3–5].

Baking, and by extension cooking, is at the core of the present work. Among human activities, cooking stands for one of the major *energy services*, defined by Fell [6] as functions “performed using energy which are means to obtain or facilitate desired end services or states”. It has long been essential in shaping humanity as we know it today, through externalizing the digestive process and extending the range of comestible food. As emphasized by James C. Scott, “it is virtually impossible to exaggerate the importance of cooking in human evolution” [7]. Regarding baking, it is interesting to note that bread is a very symbol of the social and technological evolution of human nutrition [8]. It is part of the human basic diet since the beginnings of agriculture [8], while wheat is at the heart of food security and power plays all around the world since antiquity [9]. Hence it is a perfect case study for analyzing how human activities of yesterday could adapt to the tomorrow’s world, in particular when considering sustainability issues.

From an energy point of view, in the case of the baker’s activity, the bakery oven primarily requires heat energy. Nowadays heat is mostly converted directly from combustion of wood and fossil fuels [10], or from the electricity provided by the national grid using an electric oven [11]. The energy system being multi-scalar, it is possible to make energy supply more sustainable according to different scales [12]. The current approach focuses on mitigating greenhouse gas (GHG) emissions, and consists in replacing utility-scale power plants based on

* Corresponding author.
E-mail address: benjamin.pillot@ird.fr (B. Pillot).

https://doi.org/10.1016/j.erss.2024.103815
Received 6 May 2024; Received in revised form 5 September 2024; Accepted 21 October 2024

finite resources by renewable energy (RE) systems [13]. Another way is based on substituting the electricity supply locally, using a stand-alone RE system such as solar PV panels coupled with storage [14]. In both cases, the energy transformation chain is based on two conversions, from primary renewable energy (light, motion, etc.) to electricity and then from electricity to heat. This matter of fact is well defined by Howard Odum's *emergy* theory [15], whereby electricity as a very-high quality energy carrier should not be degraded for low-quality purposes such as heating [16]. While related energy conversion systems consume limited materials, such as rare earth elements (REE) [17,18], stand-alone power systems also present issues such as electronic failures and complexity to the extent that most of the technical maintenance cannot be performed by end users [13]. Overall, sustainability should be sought elsewhere when it comes to heat energy supply for household and small commercial activities.

Once we bring together the best scale of application – heat should be produced where it is used – and the cleanest tech for producing heat – a tech based on (1) a one-conversion chain, from primary to heat energy, (2) the least possible material and REE, (3) very reliable in the long-term, as well as (4) easily usable and maintainable by the bakers – we get what we believe the best possible match: artisan bakeries based on solar thermal energy[1] [19,20]. This solar artisan baking is made possible by solar ovens that employ direct sunlight as a cooking source, concentrated through parabolic or flat mirrors [19]. The fact that professional bakeries based on the use of solar ovens already exist – e.g. Neoloco in Normandy, France [20] – demonstrates that the technology is already fully operational. But can we unleash the *solar-baked bread of life* at higher scale ?

1.1. Related work

One of the main underlying questions that originally fed our work about sustainable baking was: how might a technical system regarded as *sustainable* at the individual scale lead to sustainable behaviors and practices on a larger scale, i.e. in a given territory and at the sector level? The long story of solar cooking (SC) actually demonstrates that we need tools to better understand the inherent forces that still prevent worldwide spread of the systems into population's everyday lives [5,21]. Most SC projects and research studies have been focusing on the Global South, typically southeastern Asia or Sub-Saharan Africa [5,22–24]. Beyond the fact that solar potential is substantial in those regions, solar cookers have also been originally promoted by NGOs and international research institutions as low-cost and renewable solutions for addressing the challenges of poverty and energy resource scarcity [25,26]. In a nutshell, the literature on solar cooking is mainly dedicated to the SC devices and various available technologies [27,28]. Advances in the field are fed by technological enhancements and breakthroughs, such as specific designs and panels arrangements [26], indoor/outdoor use [29], or energy storage for cooking at night [21]. This focus made on the sole technology aspect of the problem [26,27] has resulted in leaving aside or misreading other essential elements such as local needs or existing cooking practices [5]. Authors have recently criticized the apparent disconnection between SC studies and projects on the one hand, and the various socio-energy contexts (local needs, existing resources and practices) where they have been implemented on the other [5,30]. Existing local culture is mostly regarded as an *obstacle*, leading to technology-driven responses and changes in order to fit population's current cooking practices. But in the end, there is no sign of improvement in acceptance and adoption of solar cookers on a large-scale basis [5,22]. Similarly, while the clean and low-cost nature of solar cookers has long been confirmed by the literature, there is still a substantial lack of sound impact studies at the sector level [5].

Overall, the gap between the SC technology and the social-ecological system it should eventually fit into has never really been filled by the literature. Rather, the focus has only been given to the technical, economical and innovative aspects of the SC devices [22,31]. On the one hand, innovative designs such as round-the-clock indoor solar cooking [21] are often promoted to match *established* behaviors and practices. Adaptation strategies or changes in user practices are not really discussed, though they will likely be needed for combating climate change and ensuring sustainability in the near future [32]. On the other hand, interlinked technical, economical and environmental analyses are performed in order to assess viability and carbon footprint of different SC systems, according to given operating scenarios (apartment, restaurant, hotel, etc.) [33]. But all in all, authors such as Bielecki et al. [30] or Iessa et al. [5] have shown the existing *pro-solution* or *pro-diffusion* bias in the SC literature: SC systems are often assumed to be a solution to specific issues (e.g. the *fuelwood crisis*), though no empirical evidence support this statement, which not only affects the scientific validity of the true benefits of SC, but also *sacrifice* important functional, social and cultural needs of the users. This is for instance visible in [34]: the authors conducted a fine technical study on the development of a box type solar cooker, but also concluded that the device was *socially acceptable* while there was no emphasis given to the social and cultural context in their work.

Essentially, there is today a need for approaches that integrate SC devices into a wider socio-technical perspective of the transition towards sustainability at the sector level. This new scale of analysis is essential for apprehending SC in various social and cultural contexts, i.e. for assessing how a technological change would eventually meet present and future population's behavior and needs. Furthermore, we believe that, in the context of a sustainable energy transition, those approaches as well as SC *should not be narrowed to the developing countries*. Among those that are showing the way, we may cite the Neoloco solar bakery which is the first ever to be established in Europe [20].

1.2. Summary of contributions

Essentially, it is very unlikely to envisage that a sustainable energy transition would not involve strong cultural and social changes [3,32], or that cleaner, but very different, devices (solar ovens) could perform exactly as the ones we were used to until now (electric ovens). As a result, if solar cooking should fit socio-cultural contexts and current practices [5,30], as a new way of cooking food we believe that it should also be accompanied by appropriate social and cultural changes. Those changes would be *co-constructed* and *co-experimented* with local stakeholders, e.g. through pilot programs, living labs and/or the use of demonstrators. The ultimate goal of such a process is to understand how a technological change (local scale) could in fact lead to sustainability at the regional scale.[2] Our work here aims at feeding this line of research. It is positioned upstream, and intends to both (1) provide a theoretical planning framework[3] to accompany those changes and (2) assist the people involved in transforming the bakery sector. By following a spatiotemporal approach based on the *energy-technology-society* nexus, we derived primary methodological elements for gaining insights into the potential of solar-based bakeries at the sector level. The resulting framework aims to provide decision support tools and scenarios to apprehend whether and how the bakery sector could transition towards sustainability. Besides, we also designed this framework for assisting researchers in their own analysis of SC at the

[1] It is important to note that our purpose in this paper is not to discuss the sustainability of the different options and scales of application regarding heat energy supply. This will be the topic of another paper.

[2] In this work, the *regional scale* stands for sub-national, country or continental scales.

[3] This framework and related tools have been implemented in the `sbk` Python package, available at https://framagit.org/espace-dev/sbktool.

confluence between technical systems and stakeholders (bakers, consumers, etc.) at the territorial scale. Regarding the current literature, there is indeed a need for scaling up the energy system and technology-driven approaches – mostly based on prototyping, testing, improving and comparing SC devices – towards analyzing the integration of SC technologies into the specific socio-cultural context of given territories. We therefore provide mathematical instruments that should help researchers, from social sciences as well as other fields, to ultimately test their own assumptions.

Our contributions can be summarized as follows: (1) the design of a modeling framework with spatiotemporal granularity based on probabilistic approach, for planning transition pathways towards sustainable baking on a large scale; (2) the elaboration of decision support indicators from this framework that provide information such as bread accessibility, viability, economic return or environmental impact; and (3) the implementation of this framework and the corresponding production of benchmark results and scenarios for solar baking across the western European territory, in order to demonstrate the various potential applications.

Overall, we first expose the general problem of sustainable baking and the decision-making approach we developed to address it (Section 2). We then introduce the modeling framework we built accordingly (Section 3), and present some case studies for which it was applied in the context of solar baking (Section 4). Finally, we discuss the corresponding results and future perspectives (Section 5).

2. General problem and proposed approach

2.1. Solar cooking and the socio-technical transition

Among food processing systems, solar baking can typically be regarded as a sub-category of solar cooking [35]. In this work, focus is given to artisan commercial bakeries, where bread is specifically baked to be sold to a community of consumers. As part of the human diet since the Neolithic revolution, bread has long been accompanying the social and technological evolution of human nutrition [8]. By studying traditional food models, one can assess the potential synergies between the use of sustainable technologies and the current social practices & cultural heritage of the populations [36]. Those interactions between socio-technical factors and the energy dimension can be integrated within the larger *nexus* concept [37]. The concept looks at understanding the connections, synergies and trade-offs between the various dimensions of a system. In the present work, we propose to look at the "*energy-technology-society* nexus" (see Fig. 1). In that nexus overview, the fact that people require technology to harvest energy (and get a *service* such as cooking) implies that depending on the energy needs (heat, light, motion, etc.) and the transition objectives at hand (e.g. low-carbon, sustainability), changes will involve the whole socio-technical regime [32]. Similarly, the nexus approach shows that sustainability relies first on improving the synergies between the dimensions of the system, and then on enhancing the inner quality of each dimension separately [37]. In other words, technological innovation cannot stand alone: changes in interlinked social and technical underlying configurations are absolute cornerstones [38]. Undoubtedly, the resulting societal adaptations and systemic changes towards more sustainable ways of life will demand *co-construction* and *co-experimentation* between researchers, local stakeholders and final users, in third places such as *living labs* [38].

2.2. Storylines for sustainable baking

Before implementing such participatory research, we may already look at socio-technical scenarios in *tomorrow's world*. Those scenarios would provide decision support regarding the multidimensional aspects of SC at the sector level. In the *energy-technology-society* nexus, those aspects are primarily related to: (1) energy availability, (2) resulting quantity and quality of cooked food, and (3) whether and how it will eventually be consumed. The idea is to anticipate whether SC systems would fit into the socio-energy context, given local needs, practices, existing resources or human groups (see the case of people with disabilities in [24]). In the case of solar baking, the objective is to assess to which extent solar-based bakeries could run a regional bakery sector. It is important to note that through our approach, we do not try to predict acceptance and adoption of solar bakeries. Rather we propose to foretell how in-place solar bakeries would perform at the sector level given the production and consumption scenarios at hand. Such *storyline* projection requires modeling both technical system and social behavior, as well as their interdependence. Accordingly, we developed a framework that merges quantitative and qualitative facets of the question. On the one hand, we limited the technical analysis to bread production; we do not consider other bakery products such as pastries, croissants, etc. those elements shall be integrated in a future version of the model. On the other hand, we opted for a probabilistic approach to describe bread consumption behavior for any given territory or population, given that distributions can easily be (1) tailored to existing trends, or (2) designed for specific forecast scenarios.

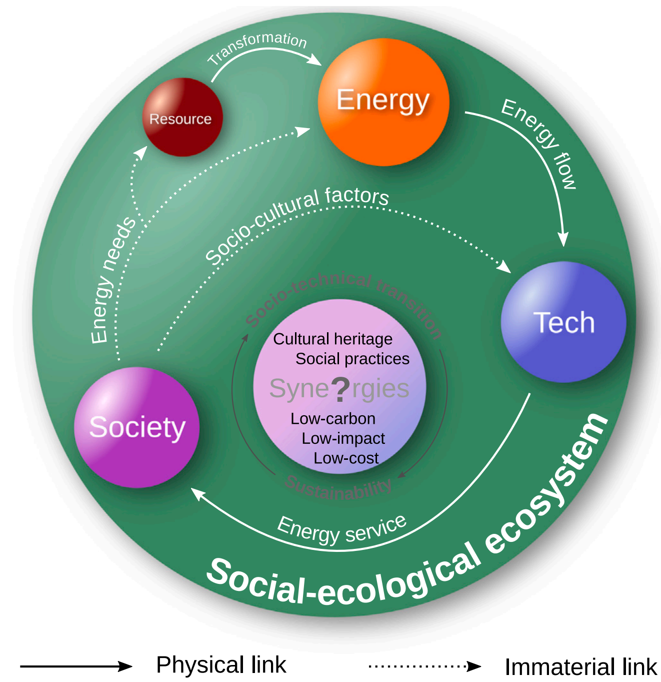


Fig. 1. Simplified view of the *energy-technology-society* nexus approach for a given social-ecological system (SES). Depending on the energy needs of the population, energy conversion through a specific technology might present characteristics that are not directly compatible with the socio-cultural factors at hand. To reach sustainability at the upper scale (i.e. the scale of the SES) thus requires a socio-technical transition whereby synergies and trade-offs between existing socio-cultural practices and the tech's inherent nature are to be found.

2.3. Towards a generic framework for decision support

In this paper, we propose a framework to facilitate the elaboration of realistic sustainable storylines for the bakery sector. This framework is at the heart of our work: it allows bridging both scales of analysis, from one single bakery and its technical system to the entire territory where countless bakeries, bakers and consumers will interact. Overall, our approach was fed by the limitations of technology-driven studies in providing decision aid at the territorial scale and by the need for facilitating future impact studies in the SC field. A very first step was to ensure that this framework was an entry gate for all researchers involved in SC studies, and that they could speak the same language and understand each other. We firmly believe that a shared set of concepts and tools is essential for implementing and confronting hypotheses, as well as carrying out inter-comparison studies of different potential solutions. With this objective in mind, we developed a decision-making framework for *sustainable baking* based on probabilistic analysis of the interface between bread consumption (socio-cultural context) and bread production (energy service). We kept the number of parameters as low as possible to make it easily usable by the whole scientific community involved in sustainable cooking analysis. In particular, though our work was not driven by the methods of social sciences, we hope researchers from that specific field will use, improve and build upon the theoretical framework we developed.

Accordingly, we built mathematical tools (1) at the interface between qualitative and quantitative approaches, and (2) aggregating complex interactions through single parameters that could synthesize the information from more detailed models. The resulting framework is generic in its core, i.e. it can be applied to the baking sector taken as a whole. Eventually, it allows for (1) comparing different baking technologies and systems throughout any given territory, and (2) implementing and testing assumptions and definitions about any baking system and the corresponding social, cultural and economical context of the region under study.

3. Methodology

The methodology upon which we built our framework is presented below. Note that while it was originally thought for solar baking in particular, this framework is eventually suited to all baking technologies, not only solar.

3.1. Theoretical framework foundations

To understand the potential of a baking system at the sector level, it is relevant to look at how a bakery may match its potential market, that is how likely it is for bread baked through some cooking technology to be sold and consumed. Essentially, for a given population sample, bread consumption is defined by both *occurrence* and *intensity*: does an individual consume bread and what quantity if they do? And finally, does this potential consumption match the potential production of the bakery: will the baker eventually sell the bread they make? The probability of consumption p_c, i.e. the probability that produced bread will eventually be sold to end consumers, can first be approximated as the probability of the bread consumption being higher than the bread produced by the solar bakery in a given area:

$$p_c = P\left(q_c \geqslant \frac{X_p}{n_c}\right) \tag{1}$$

where q_c is the final quantity consumed per capita, n_c is the number of bread consumers and X_p is the bread quantity produced by the bakery. Furthermore, for any sample of people, the number of bread consumers n_c is given by the corresponding number of inhabitants n_h and the probability that people actually consume bread. Let $p_{h,c}$ be the probability for a human being to be a bread consumer. Probability of consumption p_c then becomes:

$$\boxed{p_c = P\left(q_c \geqslant \frac{X_p}{n_h\, p_{h,c}}\right)} \tag{2}$$

Eq. (2) is the general basis of our proposed theoretical framework for planning the establishment of bakeries throughout a given territory. This equation can be applied to any type of bakery (solar, electrical, etc.), and connects its level of production (X_p) with the population area (n_h), the **occurrence** of consuming bread ($p_{h,c}$) and the **intensity** of that consumption (q_c). Both underlying parameters q_c and $p_{h,c}$ are represented by probability distributions that can be tailored according to space and time, and the socio-cultural context under study. In the same way, uncertainty related to bread production can be evaluated through probabilistic definition of X_p. It is especially relevant in the case of solar baking, where solar variability will inevitably affect the final quantity of baked bread. Essentially, this framework is simple enough to ensure robustness and ease of implementation, while complexity can still be managed through the definition of only few parameters.

3.2. When consumers become b-consumers : transition towards solar baking

We can go further into how solar bakery production actually matches potential bread consumption. In the previous analysis we can look at the probability for a bread consumer to specifically consume bread from one bakery. In this way, we may apprehend how relevant would in fact be a transition towards solar baking for in-place electrical bakeries in the short or mid-term. Obviously, this transition would necessarily be associated with new dietary behavior because of the new type of baked bread (long-conservation bread is better suited to solar baking [39]). The theoretical generic framework we propose below allows for apprehending the levers that would incite bread consumers to eventually buy bread from a new solar bakery, only by adapting a limited set of specific parameters.

The following equation is an adaptation of Eq. (2) to the case of b-consumption, where bread is specifically consumed from one bakery. Note that bread consumers buying bread from a bakery b located at distance d are defined as *b-consumers* or *b-customers* alike in the rest of the paper. For the sake of clarity, we only present the end result but the various mathematical steps are thoroughly described in Appendix A. In summary, probability of consumption in bakery b with respect to distance d is given by:

$$\boxed{p_c^b(d) = P\left(q_c \geqslant \frac{\mu_R\, X_p}{N_{c,b}\, F_R(d)\, E\left[R_{0,d}\right]}\right)} \tag{3}$$

Eq. (3) is the second pillar of our general framework. This is an enhanced version of Eq. (2), decoupled into 3 main elements: (1) the level of production of the bakery X_p, (2) the available pool of potential consumers $N_{c,b}$, and (3) a distance-based probability factor $\frac{\mu_R}{F_R(d)\, E\left[R_{0,d}\right]}$ related to the geographic distribution of these consumers near the bakery. The maximum number of b-consumers $N_{c,b}$ is given by Eq. (A.7) in Appendix A and depends on η_h, the population density, μ_R, the average radius distance R of the pool of b-consumers, and the probability criteria encompassing all other drivers of bread consumption, besides distance. Finally, $F_R(d)$ is the cumulative distribution function of the b-customers around bakery b and $E\left[R_{0,d}\right]$ the expected value of radius distance R in the interval $[0; d]$. One may see Eq. (3) as the *transitional* version of Eq. (2): in the case of a solar baker that would look for establishing their bakery in a given territory, or an actual baker that would seek to transform its current bakery into a solar one, the equation gives relevant information about the territorial potential for transition. This information can be built upon the probability criteria $p_{c,b}$ and $p_{h,c}$, through aggregating the various social, cultural and economical underlying drivers. For instance, the current factors that drive bread consumers towards long-conservation bread, or the potential drivers that could lead future consumers towards buying from a solar bakery. Based on this equation, it is possible to elaborate forecast scenarios for a given territory in order to analyze both (1) the current obstacles to the development of solar baking and (2) the potential corresponding leverages.

3.3. Economic income and sustainability outcome

Probability of consumption alone does not give complete information about the level of viability of a bakery. The other essential criterion is the potential for bread production in a given period of time. It is particularly true in the case of solar baking, where this potential is directly affected by the available solar energy potential.

Depending on the quantity of bread that can actually be baked and the underlying population area, the volume of marketable bread and thus the bakery's revenue will differ. As a result, we define the *bread turnover* R_B, standing for the bread quantity a baker should actually be able to periodically sell to a community of bread consumers. It is given by:

$$\boxed{R_B = X_p\, p_c} \tag{4}$$

In the case X_p stands for the available potential for bread production over a given period of time, the maximum bread turnover can be retrieved according to nominal bread production X_p^*:

$$\max\left[R_B\right] = R_B\left(X_p^*\right) \quad \text{with} \quad \left.\frac{d R_B}{d X_p}\right|_{X_p^*} = 0 \tag{5}$$

Eq. (4) is the third pillar of the proposed planning framework. Typically, the bread turnover is essential to evaluating the economic performance and viability of a bakery as well as its corresponding sustainability. Based on the rate of return α (in €) of one tonne of bread, or the rate of GHG emissions β (in CO_2e) of one tonne of baked and consumed bread, it is for instance possible to define indicators such as the economic return R or the carbon footprint C of a bakery:

$$\begin{cases} R = \alpha\, R_B \\ C = \beta\, R_B \end{cases} \tag{6}$$

Typically, both α and β can aggregate multidimensional cost aspects (e.g. flour supply, fuel use, oven type, etc.) and be weighted according to life-cycle assessment (LCA). Though the elaboration of a thorough LCA and economic analysis is beyond the scope of this work, we give below some insights on how it can be taken into consideration in Eq. (6). In the case of the economic return, life-cycle analysis can for instance be achieved through the use of a *levelized rate of return*. In the energy literature, techno-economic analysis over the lifetime of a system is typically performed through the levelized cost of energy (LCOE) and its multiple variations, such as the levelized cost of heat (LCOH) [40] or the levelized cost of cooking a meal (LCCM) [41]. The latter is the cost for cooking a meal with a certain fuel-technology combination for cookstoves. Adapting the LCCM definition to the bakery oven results in the *levelized cost of baking bread* (LCBB). Finally, by assuming a constant bread turnover R_B from year to year, the levelized rate of return over the technology lifetime is derived from the discounted difference between the levelized sum of cash flows from bread sales and the LCBB. The approach is shown in Appendix B.

Regarding environmental impact and specifically the carbon footprint C, Herez et al. have highlighted how resulting emissions of carbon dioxide depend on the cooking technology [33]. Based on the chemical equations of combustion, they estimated the amount of CO_2 produced by the combustion of liquefied petroleum gas (LPG) in different scenarios (home, restaurant, hotel, etc.). The same can apply here to generate a range of β values (CO_2e/kg) corresponding to as many baking technologies. The carbon footprint C of baking bread with these technologies over their lifetime can finally be assessed through Eq. (6).

3.4. Towards indicators for decision support

In this section, we present two indicators built upon the previously depicted framework. The aim is twofold: first (1) to propose normalized information about the territorial potential of different baking technologies, and then (2) to show how the proposed theoretical framework can efficiently be tailored to different types of analysis. Typically, general indicators can be derived from either Eq. (2) or Eq. (3) to give useful information about the potential of a baking technology over time and throughout a given territory. In this section, we only consider such indicators for *accessibility* and *viability*, but other relevant concepts might be derived from the core framework alike.

3.4.1. Accessibility

In order to develop density-based indicators, we here consider Eq. (3) over the whole R-distribution, that is: $F_R(d \to \infty)\, E\left[R_{0,d\to\infty}\right] = \mu_R$. From there, it is possible to build an indicator standing for *bread accessibility* (b_a), defined as the probability of *global access* to bread in general as well as to specific types of bread. For greater clarity, we moved the detailed mathematical construction of this indicator to Appendix C. Eventually, it is defined as the probability for the level of consumption of a pool of bread consumers to be greater than a given optimal level of production:

$$b_a = P\left(X_p^* \leqslant N_{c,b}^{nom}\, Q|_{p_c=x}\right) \tag{7}$$

where X_p^* stands for an optimal quantity of bread to be sold, $Q|_{p_c=x}$ is the amount of bread produced per capita for which the probability of consumption p_c is equal to a specific value x, and $N_{c,b}^{nom}$ is the pool of bread consumers distributed around the bakery according to a predefined nominal R-distribution with mean value μ_R^{nom}. Depending on how the R-distribution is tuned, different mobility scenarios can thus be tested (i.e. soft or hard mobility), resulting in as many CO_2 emission schemes.

3.4.2. Sustainable viability

Finally, we can look at *viability*, which is a concept that encompasses accessibility: for a solar bakery to be viable, baked bread must be *accessible* to the population (geographically and economically), **and** production must be significant enough. We therefore define the *bread viability* indicator (b_v) as the product between accessibility and the probability that production X_p reaches a maximum theoretical and ideal quantity of baked bread X_p^*, that is:

$$b_v = b_a \cdot P\left(X_p \geqslant X_p^*\right) \tag{8}$$

The level of sustainability for a viable bakery is based on multiple criteria, such as input energy, conversion technology, crop and flour supply, mobility, etc. In first approximation, we consider that bakeries highly accessible to bread consumers will likely result in *soft* mobility (on foot, bicycle, etc.), hence reduced CO_2 emissions and more sustainable bread supply.

3.5. Spatial mapping

Assessing the territorial potential of a given baking technology (e.g. solar baking) can be achieved through spatial mapping of the previous indicators: it allows for identifying the best spots where baking facilities such as solar bakeries could be established. To do so, we may define a geographical mesh of N regular cells dividing the whole territory under study, and then compute corresponding indicators in every cell $i = 1, 2, \ldots, N$. Accordingly, when Eq. (2) is for instance implemented in every cell i, it thus takes the form:

$$p_c^i = P\left(q_c^i \geqslant \frac{X_p^i}{n_h^i\, p_{h,c}^i}\right) \tag{9}$$

Spatial mapping of every indicator is retrieved in the same way. From Eq. (6), economic return R^i and carbon footprint C^i in cell i will for instance depend on spatialized rate of return α^i and rate of GHG emissions β^i, as well as on the corresponding bread turnover R_B^i in cell i.

3.6. Time dependency

To avoid adding too much complexity in the framework's main equations, we voluntarily did not integrate the time t. However, variables such as bread production X_p and bread consumption per capita q_c implicitly depend on the time range over which they are integrated. According to the selected heat source and bakery configuration, as well as consumer's behavior, they can also be considered as time dependent.

In the same way, population density η_h may differ from season to season in some regions, depending on short-term population flows, such as in tourist areas. Overall, the theoretical framework will therefore adapt to the time granularity of selected input data and production scenarios, and generate results accordingly: static or dynamic mapping over small and large areas, time series for given locations, etc.

3.7. Linking the planning framework to real bakery modus operandi

In order to understand how real-world assumptions can be tested within the boundaries of the proposed framework, we here depict the case of the NeoLoco solar bakery located in Normandy, France. NeoLoco was created by A. Crétot in 2018, and is the first ever solar bakery to be established in Europe [20]. The NeoLoco *modus operandi* is based on baking bread once in a week, either through the use of solar energy when possible or wood combustion otherwise. Sales strategy is articulated around pre-ordering, two self-managed points of sale and cargo bike deliveries along a 18 km axis between 2 cities [39]. Through the years, A. Crétot developed its own expertise. Accordingly, he found 4 primary configurations for solar baking [39]: (1) 100% solar-based baking, (2) hybridized (e.g. solar-wood) baking, the one NeoLoco is based on, (3) seasonal solar baking, and (4) ancillary solar baking.

Typically, each configuration can be characterized within our planning framework, and combined with various production scenarios, in order to determine which one(s) would eventually be the most suited in a given territory. Implementing those configurations can be achieved through the modeling of specific parameters, such as bread production X_p or population density η_h. For instance, estimated bread production X_p allows for evaluating how the selected system configuration (full solar, hybridized, ancillary) would perform. In the same way, modeling the temporal evolution of solar production coupled with population density variations will highlight the performances of seasonal solar baking. Hypotheses beyond production scenarios can also be tested, such as the delivery strategy prioritized by the baker through tuning R-distribution and the distance parameter d.

4. Planning solar thermal baking: a benchmark of European case studies

We applied the previous framework to solar thermal baking (without storage) in various territories and contexts across western Europe. Still, this framework can be applied to all types of baking configurations and technologies alike, in particular for determining the best bakery organizations at the territorial scale. The main purpose behind the case studies presented in this section is to illustrate how, for many different contexts, it can eventually provide insightful information and scenarios regarding the sustainable future of artisan baking.

4.1. Territories under study

Three case studies were selected to emphasize the planning framework. The resulting benchmark is based on different territories, scales and scenarios: (1) spatial mapping of bread viability over Western Europe, (2) impact of seasonal baking in southern France, and (3) potential economic contribution of solar baking in the main Swedish cities.

4.2. Population data

As detailed in the previous sections, the planning framework is fed by population data, such as population count or density. In this work, we retrieved and used two specific open-source datasets from the WorldPop project [42]: (1) the latest (2020) population density data available for western European countries at 1 km resolution, and (2) the 2007 dynamic mapping of population density that was retrieved from mobile phone data over France and Portugal at 100 m resolution [43].

4.3. Solar resource

4.3.1. Direct normal solar radiation

Solar thermal bakery is fueled by solar Direct Normal Irradiance (DNI), which is concentrated through parabolic or flat mirrors into the solar cooker's focus [19,44]. In first instance, knowledge of both (1) spatial and (2) temporal distribution of the DNI is essential to assess how solar baking may match the current and future behavior of potential bread consumers. Satellite-based models stand for a good trade-off between accuracy and the need for apprehending the geographical distribution of solar radiation [45]. However, all models are not equal in terms of temporal and spatial resolution as well as final precision or data access [45,46]. In the case of territories located in Europe and Africa, the SARAH dataset derived from Meteosat 11 satellite images and Heliosat method, and released by the Satellite Application Facility on Climate Monitoring (CM SAF), provide good balance between all these requirements [47,48]. Data access is also kept as straightforward as possible in order to get a full dataset of semi-hourly DNI maps, and accuracy is close to the one from other satellite-based products such as NSRDB and CAMS [45,47]. In this work, we used SARAH-3 DNI data [49] covering the 2020 period.

4.4. Solar bakery and oven model

The sbk Python package allows for users to implement their own solar cooking and baking models. Numerous physical and mathematical models actually exist in the literature and can provide a very good estimate of solar bread production X_p, depending on the solar resource, environmental parameters and the characteristics of the system [35,50,51]. This estimate can then be incorporated into the various equations of the planning framework. In order to illustrate how this can be achieved, we have opted in this work for an *ad hoc* empirical implementation based on A. Crétot's own way of baking bread in the sun at NeoLoco [20].

This model is based on a set of empirical filters with Direct Normal Irradiance (DNI) as the main input, and depicted in Fig. 2. The solar oven model is derived from simple DNI thresholding combined with accounting for continuous *bakeable* hours. This thresholding empirical technique is the one used by A. Crétot at NeoLoco to ensure a stable baking temperature within the oven. One hour is considered *bakeable*, i.e. inner temperature is sufficiently high to actually bake bread, when DNI is greater than a specific threshold, and *not bakeable* otherwise. A batch of bread is regarded to be baked if a set of continuous hours is equal to the time used to preheat the oven plus the time required for baking bread once the oven is preheated. The output is twofold: (1) the number of days where it is possible to bake at least one batch of bread and (2) the number of bread batches that have been baked at the end of a day. It stands for the resource most relevant to the baker: the available *baking time* over the year.

The baking time resource is then used as an input to a bakery configuration model defining ideal/possible bread production over time, according to consumption, conservation and production scenarios. According to those scenarios and the quantity of bread to be baked per batch, derived from the oven capacity, it finally gives an estimate of the bread production over a given period of time.

4.5. Solar oven characteristics

Input data implemented in the oven model have been derived from the direct solar bakery used by NeoLoco [20], that is the *Lytefire Deluxe Big Oven + Roaster*, which is a mobile solar oven developed by the Lytefire company [52]. Main characteristics are depicted in Table 1. Note that the Lytefire required preheat time is always deducted from each set of continuous *bakeable* hours within a day, which is the worst case scenario: in reality, the baker generally uses firebricks to keep thermal inertia between cloudy events.

Table 1
Lytefire Deluxe Big Oven + Roaster main characteristics [52].

Mirror size (m^2)	Nominal power (W)	Qty per batch (kg)	Preheat time (h)	Time per batch (h)
11	7500	30–38	2	1

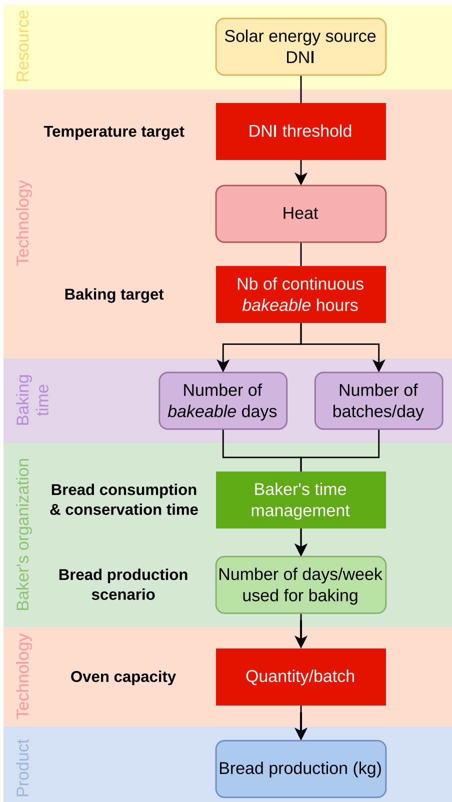


Fig. 2. Empirical solar oven and bakery workflow model developed and used in this work.

Fig. 3. Lytefire Deluxe Big Oven + Roaster developed by the Lytefire company [52], and used as benchmark data in the present study.
Source: NeoLoco.

4.6. Consumption behavior and probability distributions

In the proposed modeling framework, every variable can be represented by a continuous or discrete probability distribution. This is where territorial hypotheses at hand can be tested to assess the level of confluence between production technology and population dietary behavior. In this work, we used Monte Carlo analysis to build output probability of consumption and bread viability from predefined probability distributions for the following variables: q_c, X_p^*, μ_R^{nom}, $p_{h,c}$, $p_{c,b}$. For each iteration, the process consists in sampling at random values from the corresponding distributions and generate the corresponding outcome accordingly. Through multiple iterations, each individual output is then counted in order to reconstruct the corresponding probability distribution. In the case of Eq. (3), values from the reconstructed distribution $Q = \frac{\mu_R X_p}{N_{c,b} F_R(d) E\left[R_{0,d}\right]}$ are compared for each iteration to the values from the q_c distribution, in order to retrieve one single-point estimate of p_c^b. The same applies to estimates of the bread accessibility and viability factors respectively.

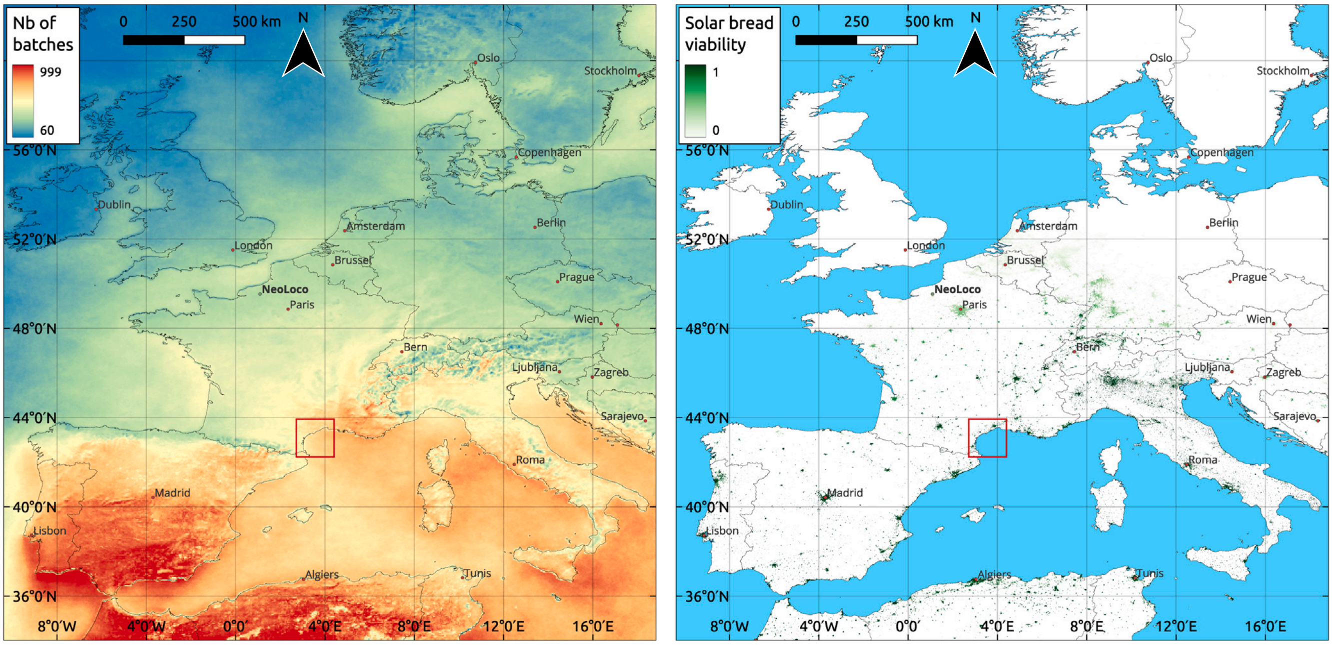
When possible, we built probability distributions from available data, such as bread consumption in some European countries [53–55]. For all indicators, computation is always performed over the entire R-distribution, corresponding to the nominal number of b-consumers $N_{c,b}$. It ensures that the shape of the distribution does not matter in the proposed scenarios. Furthermore, all other distributions are considered as (truncated) normal distributions, and for each case study, we highlight the hypotheses made on corresponding parameters: mean and standard deviation (SD).

5. Results and discussion

In this section, we instantiate the planning framework for direct solar baking without storage in different contextual cases and scenarios: mapping of solar bread viability over western Europe, temporal profiles of seasonal baking in southern France and yearly economic impact of ancillary solar baking in the Swedish main three cities. Note that the core idea is to demonstrate how the framework can usefully be applied to different situations. Assumptions are therefore made on bread production, consumption and consumer behaviors that do not necessarily fit reality in all of its many dimensions. Nonetheless, it provides a first overview of what a transition of the bakery sector towards direct solar energy could look like in the near future.

5.1. Solar bread viability in Western Europe

Before proposing some emphasis on specific European regions, we first get a global picture of the solar baking potential across western Europe. Based on the *ad hoc* oven model depicted in Fig. 2, we computed the theoretical number of batches that could be baked with the Lytefire oven over the year. The result is shown in Fig. 4(a). As expected, the gradient from northern Europe to southern Europe (and northern Africa) follows the corresponding availability of direct solar energy, though some areas have higher or lower potential than their immediate surroundings in northern or southern Europe respectively, depending on their corresponding climate. In order to assess the whole solar bread market, we computed the corresponding solar bread viability from Eq. (8) and probability distributions depicted in Table 2: it is presented in Fig. 4(b). This indicator is comprised between 0 and 1, and typically highlights where consumption and production better match. As a result, densely populated areas under 50°N latitude have $b_v > 0$, while cities (e.g. Paris, Bern, Wien and Budapest) or regions (e.g. northern Italy vs. north of the Balkans, southern France vs. northern Spain) on the same parallel but with different climate conditions subsequently present different viability levels. Essentially, most of the densely populated areas located under 48°N (e.g. southern France, Portugal, Spain except the northern region, northern Africa, Italy, Switzerland) present especially high solar bread viability ($0.8 < b_v \leqslant 1$). On the other hand, populated areas of northern Europe (London, Berlin, Copenhagen, etc.) presents limited viability levels ($b_v \approx 0$) according to the given hypotheses.



(a) Number of batches

(b) Solar bread viability

Fig. 4. Yearly number of batches baked with the *Lytefire Deluxe Big Oven* visible in Fig. 3 and derived from the *ad hoc* model depicted in Fig. 2, and solar bread viability computed from Eq. (8) over Western Europe. The red square gives the location of the *Occitanie* coastline depicted in Fig. 5.

Table 2
Parameters of the (truncated) normal distributions taken into consideration for the case study presented in Section 5.1.

q_c (kg/year)		X_p^* (t/year)		μ_R^{nom} (km)		$p_{h,c}$		$p_{c,b}$	
Mean[a]	SD	Mean[b]	SD	Mean	SD	Mean	SD	Mean	SD
50	25	15	2.5	0.44	0.1	0.75	0.1	0.95	0.05

[a] According to [54].
[b] 2 full batches (38 kg) per day during 200 days with the Lytefire.

The maps depicted in Fig. 4 are at 1 km resolution and freely accessible from a Dataverse repository.[4] Any area (region, country, etc.) that would be of interest to the reader can therefore be enlarged at will. In summary, the bread viability indicator emphasizes suitable areas for alternative baking based on the hypotheses at hand. By then focusing on those specific areas, one could test the final robustness of more detailed temporal scenarios: this is what we achieve in the following section through studying the *Occitanie* coastline highlighted by the red square in Fig. 4.

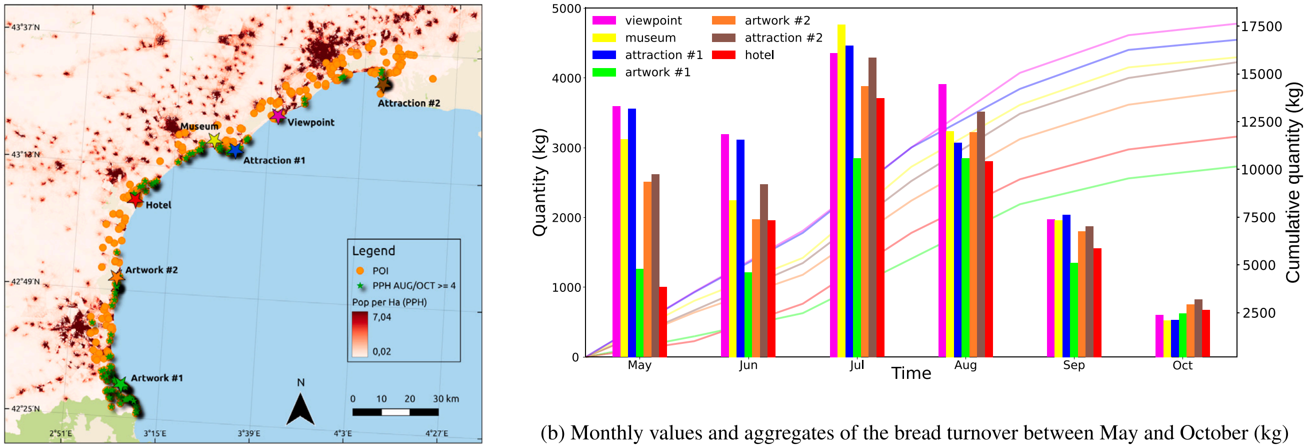
5.2. Sunny tourism scenario for solar baking in southern France

As proposed by A. Crétot [39] and depicted previously, alternative bakery organizations might be better suited to the direct solar fuel. In this way, a particular scenario based on seasonal production in sunny regions is described, adapted to touristic areas which turn densely populated only during some period in the year. This is a nice case study for the present planning framework as long as data are available. In the global view depicted in Fig. 4, one can observe how southern France appears as a great place to start for solar baking, with a very high b_v value. Going through more detailed scenarios seem therefore relevant for exploring the temporal patterns of both solar energy and population. Using 2007 population dynamics data from WorldPop [43] and the national database of points of interest (POI), we eventually identified POIs with the highest population density ratio between August (peak season) and October (low season). From those candidates, we randomly selected 7 POIs homogeneously distributed along the coastline, and corresponding to various touristic labels (e.g. viewpoint, hotel, museum, etc.). Coastline POIs, potential candidates and final selection are visible in Fig. 5(a) in combination with WolrdPop density data. Time series of the bread turnover was then computed based on Eq. (4), for all months where population density data were actually available, from May to October. Regarding the probability factors, we voluntarily chose to combine *best-case* values with a short R-distribution of the consumers around the bakery. Hypotheses are given in Table 3, and the final result is depicted in Fig. 5(b). The bread turnover informs on which quantity of bread baked by the baker shall eventually be sold and consumed by a community of bread consumers. In the present case, all POIs present a clear seasonal effect, but some more than others (e.g. *hotel* and *artwork #1*). October bread turnover is minimal ($R_B < 1\mathrm{t}$) while July turnover is maximal among all scenarios, with production capacities up to 4–5 tons: it gives credit to the seasonal production scenario proposed by A. Crétot [39]. Furthermore, 6 out of the 7 POIs allow for producing and selling 10 tons or more of bread in 4 months, i.e. by September, and more than 15 tons for 4 of them after 6 months (*viewpoint*, *museum*, *attraction #1* and *artwork #2*). Though those results remain mostly theoretical and based on the quality of available data, it shows how relevant could be a seasonal organization in the case of artisan solar bakeries located in sunny touristic areas. Ultimately, a solar oven such as the solar Lytefire is transportable through the associated roaster: we may think about further alternative seasonal scenarios where the artisan baker is mobile and actually *follows* (to some extent) the same or different communities of consumers from season to season.

5.3. Hybridized or ancillary solar baking: the Swedish case

Another organization proposed by A. Crétot [39] was about ancillary solar baking whereby sun is used as a backup resource. We therefore tested this assumption in a territory where the solar resource is assumed to be rather low in order to see to which extent it could fuel the bakery sector. To stay aligned with the NeoLoco organization model, we considered a *once in a week* production scenario, where the

[4] https://data.ird.fr/.



(a) Selected POIs

(b) Monthly values and aggregates of the bread turnover between May and October (kg)

Fig. 5. Selected POIs over the *Occitanie* coastline in southern France, and their corresponding bread turnover temporal profiles, showcasing the *sunny tourism* scenario based on the bakery organizations proposed by A. Crétot [39].

Table 3
Parameters of the normal distributions taken into consideration for the *sunny tourism scenario* presented in Section 5.2.

q_c (kg/month)		R-distribution (km)		$p_{h,c}$		$p_{c,b}$	
Mean[a]	SD	μ_R	σ_R	Mean	SD	Mean	SD
6.5	2.5	0.11	0.08	0.95	0.05	0.75	0.05

[a] Using the highest values from [53].

best day of the week – in terms of solar radiation – is always used to bake bread.

Then, we selected the three biggest cities in southern Sweden depicted in Table 4 and Fig. 6: Malmö, Gothenburg and Stockholm. We built specific consumption profiles, i.e. probability distributions, from the study realized by Sandvik et al. [55] in the country in 2014. We considered normal distributions for bread-related variables in Eq. (4), that is bread consumption (q_c), probability of being a bread consumer ($p_{h,c}$) and probability of being a b-consumer ($p_{c,b}$). Probability main parameters (mean, SD) are given in Table 4. We made the hypothesis of a solar bakery exclusively producing and selling whole-grain bread. As it allows for longer conservation and is highly nutritive, it is therefore better suited to the temporal variability of solar baking than other types of bread.

To get a first picture of the scenario over the whole country, we computed solar bread viability for a reduced nominal quantity X_p^* of 6 tons over the year (see Table 4). The result is depicted in Fig. 6(b) and emphasizes how and where solar energy could partially fuel the bakery sector across the Swedish territory. While viability of full solar production was near 0 in the European case of Fig. 4(b), Fig. 6(b) alternatively shows viability of partial solar production. Next, we focused on the potential contribution of solar baking over time in the three cities previously depicted according to the hypotheses at hand: (1) by computing the bread turnover R_B over each week, and (2) by computing the corresponding ratio between solar-based production and full bread production. Results are presented in Fig. 6(c). Weekly values have been aggregated over each month, thus some of the monthly values are larger than others. Overall, backup solar operation starts in March in all cities and reaches its peak as early as May, until the end of August. Depending on the population density, bread produced and consumed differs by 100 kg per month between Gothenburg (lowest) and Stockholm (highest). Interestingly, though Stockholm presents the lowest potential in terms of yearly solar production (279 batches), but the highest bread turnover, the city outperforms Malmö (319 batches) in terms of solar contribution throughout the year. On the other hand, while Gothenburg shows the lowest bread production among the three cities, solar contribution remains close to the one in Stockholm at the end of the year. In fact, the city even presents the highest – as well as the earliest maximum – solar contribution over the year, with more than 60% of the bakery retail activity based on solar energy by end June. Essentially, solar energy stands for at least 40% of the baking activity in all cities.

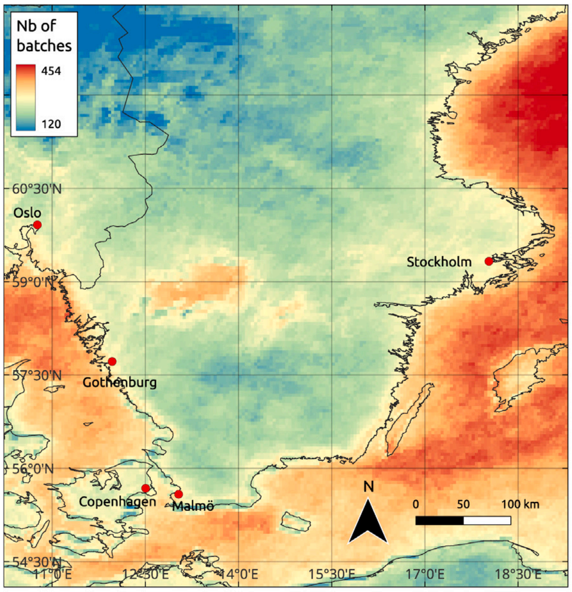
5.4. Triggering sustainability at regional scale

5.4.1. Solar baking and new organization models

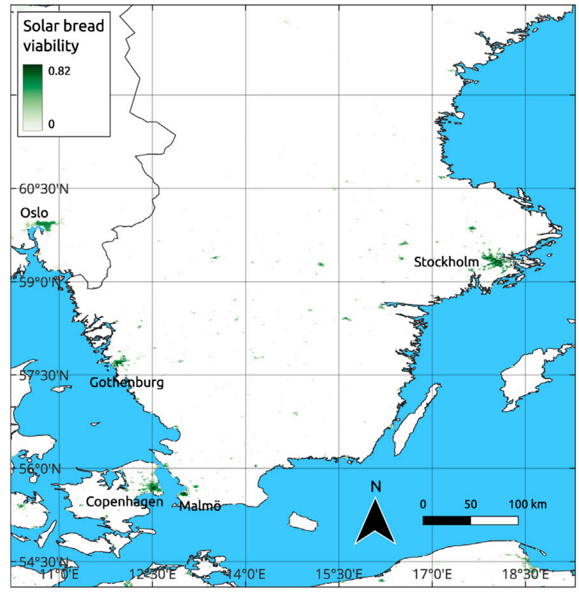
As thoroughly experimented by Crétot [39] and others, and emphasized in the temporal scenarios over Occitanie and Sweden, a bakery sector fueled by solar energy actually requires new organization models. Variability of solar thermal baking with no storage indeed implies finding alternative scenarios for bread production, distribution and consumption. For a given territory, those scenarios will directly depend on how *production time* is managed, based on (1) the available *bakeable* hours in a day, and (2) the available *bakeable* days throughout the year. Typically, the establishment of solar-based artisan bakeries will rely on the baking of long-term conservation bread such as *sourdough bread*. In that case, bread directly acts as the *energy reservoir* and allows for smoothing the production curve over substantial time periods (≈1 week). This is for instance the strategy employed by NeoLoco: bread is only baked once in a week, always on the same day, using either solar or wood resource.

5.4.2. From collective storylines to practical actions

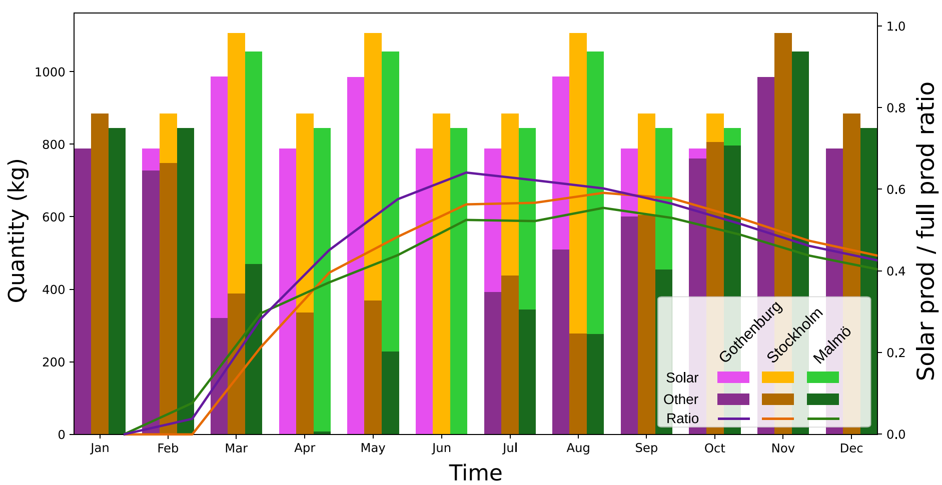
As already said previously, the modeling framework we built aims to help develop alternative storylines and scenarios for tomorrow's bakery sector. Those storylines are complementary to the other multiple actions required for engaging the communities into sustainable practices at regional scale. Prospective scenarios can help for instance future solar bakers – or bakers with more sustainable practices – to project themselves into their future activity. On the other hand, in Reunion island we plan to set up demonstrator programs for professionals located on the hotspots identified by the model. Various stakeholders involved in solar baking have shown their interest for both the model and its future declination through such concrete applications. In any case, our framework cannot stand alone and is intended to complement more practical actions to be held in the future.



(a) Yearly nb of solar batches



(b) Viability of partial solar production



(c) Monthly sum of the weekly bread turnover, corresponding solar contribution (kg) and solar to full production ratio

Fig. 6. Yearly number of batches (a) and viability of a given solar-based contribution to baking (b) across Sweden; corresponding hybrid/ancillary solar baking for the *once in a week* scenario (c) in the 3 main Swedish cities (Stockholm, Gothenburg and Malmö).

Table 4
Potential solar bread production, population density and features of the whole-grain bread consumption considered in the 3 Swedish cities of the case study depicted in Section 5.3.

City	Solar batches (nb/year)	Pop. density (hab/km^2)	q_c (g./day)[a]		X_p^* (t/year)		μ_R^{nom} (km)		$p_{h,c}$[b]		$p_{c,b}$[c]		R-distribution (km)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	μ_R	σ_R
Gothenburg	285	3443												
Malmö	319	4030	67	37	6.0	1.0	0.11	0.1	0.98	0.02	$\frac{526}{1435}$	$\frac{50}{1435}$	0.11	0.08
Stockholm	279	4715												

[a] Whole-grain consumers reported eating 67 g. of whole-grain bread per day in [55].
[b] 98% of the Swedish population reported eating bread in a 2010–11 national dietary survey [55].
[c] 526 out of 1435 total respondents were whole-grain bread consumers in [55].

5.4.3. *The need for third places*

Many other organization models are still to be found before we unleash the *solar-baked bread of life* at the sector level. Among practical actions, participatory research and *living labs* could be of great value to help build new *collective storylines*, and get deeper insights into the *energy-tech-society* nexus [38]. Living labs are third places where experimentation, experience and feedback are horizontally shared among all involved stakeholders, including researchers. From there, one may envisage that researchers could help identify, capture and replicate the major transforming factors towards sustainability. This is the path followed by A. Crétot, the very first solar baker in Europe [39]. While he demonstrates every week that solar baking is already today's reality, he also works on making NeoLoco more than just a solar bakery. Beyond bread production and retail, he develops new food processes, provides training and knowledge transfer for bakers, and participates to the elaboration of new bakery organization models by interacting with local stakeholders. Essentially, NeoLoco already embodies what makes the quintessence of a living lab and replicating this kind of facility will undoubtedly uncover pathways to sustainability.

6. Conclusion

In this paper, we presented a framework for planning sustainability pathways of artisan bakeries. It is based on multi-scale modeling of the interactions between technique (bread production) and social factors (bread consumption). Outputs from bottom-up bakery modeling, dietary behavior profiles and territorial trends are combined through a probabilistic approach. The model is kept as simple as possible, so that complex interactions are handled through just a few number of parameters. From this framework, we derived decision aid indicators providing relevant information to the decision-maker and stakeholders such as bread accessibility, viability and turnover. We also demonstrated that it can further take into consideration economic analysis over lifetime or LCA methods in a straightforward manner. Potential applications are eventually illustrated through benchmark scenarios for solar thermal baking across western Europe. In those examples, bread production was derived from satellite-based estimates of the available solar energy and an *ad hoc*, simple oven model mimicking a real-life solar bakery (NeoLoco). In the end, resulting scenarios corroborate the potential for *solar bread economy* across the continent, even in regions where solar energy is much more limited (e.g. Sweden).

The main goal behind this work was to facilitate the exploration of the interactions between technology and society in planning more sustainable social-energy systems. The resulting modeling framework can be seen as a *canvas* for implementing and testing alternative scenarios and storylines for tomorrow's bakery sector. Quality of those storylines can further be refined through more detailed models or intertwined causality systems underpinning the key parameters behind bread production and consumption behavior. Spatial and temporal granularity might also be enhanced and corresponding behavioral factors integrated into agent-based models [56] or city digital twins [57]. Ultimately, this *scientific storytelling* shall accompany and complement more practical actions – demonstrator programs, participatory research, etc. – which are essential to trigger sustainability on a larger scale.

CRediT authorship contribution statement

Benjamin Pillot: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Guillaume Guimbretière:** Writing – review & editing, Visualization, Validation, Software, Investigation, Conceptualization. **Christophe Révillion:** Writing – review & editing, Visualization, Validation, Software. **Corrie Mathiak:** Writing – review & editing, Validation, Software. **Romain Authier:** Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Probability of *b*-consumption

Here are summarized the various steps for retrieving Eq. (3) (Section 3.2). First, Eq. (2) can be adapted to the case of *specific consumption* from one bakery. In that case, probability of consumption p_c^b in bakery b is given by:

$$p_c^b(d) = P\left(q_c \geqslant \frac{X_p}{N_{c,b}(d)}\right) \tag{A.1}$$

where $N_{c,b}(d)$ is the total number of bread consumers c lying in the disc area defined by radius distance d around the bakery b they buy from. Hence it is the integral of the number of b-consumers lying in the surface element $dS = r\,dr\,d\theta$ at distance r and direction θ, i.e. the product between corresponding density of b-consumers $\eta_{c,b}(r,\theta)$ and the surface element dS:

$$N_{c,b}(d) = \int_0^d \int_0^{2\pi} \eta_{c,b}(r,\theta)\; r\,dr\,d\theta \tag{A.2}$$

The density of b-consumers can be decomposed into the density of bread consumers $\eta_c(r,\theta)$ and the probability there are b-customers among them. We split this probability into two components: a probability of consumption factor $p_{c,b}$ and an isotropic probability density function $f_R(r,\theta) = f_R(r)$ of the b-consumers around bakery b. The first aggregates the drivers for specifically buying bread baked in bakery b while the second is a distance-based factor reflecting the probability for a consumer located at distance $r = R$ of a bakery to buy bread from. Finally, we can retrieve the density of bread consumers from population density: $\eta_c(r,\theta) = \eta_h(r,\theta)\, p_{h,c}$. Eq. (A.2) thus becomes:

$$N_{c,b}(d) = p_{c,b}\, p_{h,c} \int_0^d \int_0^{2\pi} \eta_h(r,\theta)\; f_R(r)\; r\,dr\,d\theta \tag{A.3}$$

Eq. (A.3) can either be (1) computed numerically through discrete integration by using existing population density grids (e.g. WorldPop [42], Meta high resolution population density maps [58]) and predefined density functions f_R, or (2) approximated analytically by considering the *circle* of bread consumers around bakery sufficiently small so the population density is regarded as constant, i.e. independent of both the distance and the direction, that is $\eta_h(r,\theta) = \eta_h$. Here, we only present the analytical approach. By considering the population density constant in the disc area defined by radius distance d, Eq. (A.3) therefore becomes:

$$N_{c,b}(d) = 2\pi\, p_{c,b}\, p_{h,c}\, \eta_h \int_0^d f_R(r)\, r\,dr \tag{A.4}$$

Using the definition of the first central moment, we get:

$$\begin{aligned}\int_0^d f_R(r)\, r\,dr &= \left(F_R(d) - F_R(0)\right)\, E\left[R_{0,d}\right] \\ &= F_R(d)\, E\left[R_{0,d}\right]\end{aligned} \tag{A.5}$$

where $F_R(r)$ is the corresponding cumulative distribution function of the b-customers around bakery b, such as $F_R(d) = P(R \leqslant d)$ and $E\left[R_{0,d}\right]$ the expected value of radius distance R in the interval $[0;d]$. By merging Eqs. (A.3) and (A.5), it finally results in:

$$N_{c,b}(d) = 2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, F_R(d)\, E\left[R_{0,d}\right] \tag{A.6}$$

from Eq. (A.6), we can also retrieve the whole number of b-customers $N_{c,b}$ for a given bakery by integrating over the entire distribution:

$$N_{c,b} = 2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, \mu_R \tag{A.7}$$

where μ_R is the mean of the probability density function $f_R(r)$. By rearranging Eqs. (A.6) and (A.7), we can define the number of b-consumers $N_{c,b}(d)$ within radius distance d as a function of the nominal number of potential b-consumers $N_{c,b}$ and a factor standing for the R-distribution $f_R(r)$ of these consumers around the bakery, that is:

$$N_{c,b}(d) = N_{c,b}\, \frac{F_R(d)\, E\left[R_{0,d}\right]}{\mu_R} \tag{A.8}$$

Finally, Eq. (3) in Section 3.2 is retrieved through rearranging Eqs. (A.1) and (A.8):

$$p_c^b(d) = P\left(q_c \geqslant \frac{\mu_R\, X_p}{N_{c,b}\, F_R(d)\, E\left[R_{0,d}\right]}\right) \tag{A.9}$$

Appendix B. Levelized rate of return over lifetime

B.1. Levelized cost of baking bread (LCBB)

Based on the definitions of the levelized cost of (heat) energy (LCOE or LCOH) or the levelized cost of cooking a meal (LCCM) [40,41], we can derive the levelized cost of baking bread (LCBB) in €/kg applied to the fuel-oven-flour triple combination over the lifetime of the baking technology:

$$LCBB = LCBB_{oven} + LCBB_{flour} + LCBB_{fuel} = \frac{I + \sum_{t=1}^{n} \frac{O\&M_t}{(1+r)^t} + \sum_{t=1}^{n} \frac{FL_t}{(1+r)^t} + \frac{E_b}{\eta_s} \sum_{t=1}^{n} \frac{F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{R_{Bt}}{(1+r)^t}} \tag{B.1}$$

where I is the initial investment (€), $O\&M_t$ the operation and maintenance costs (€) at year t, FL_t the flour supply (€) at year t, F_t the fuel cost (€/MJ) at year t, R_{Bt} the bread turnover (kg) at year t, E_b the final energy (MJ) required for baking 1 kg of bread, η_s the oven efficiency (%), r the discount rate (%), and n the oven lifetime in years.

B.2. Levelized sum of cash inflows from bread sales

Let b_t be the cash inflow (€) at year t from bread sales, and r the discount rate (%). The levelized sum of cash inflows B (in €/kg) collected over the entire lifetime n (in years) of a given baking technology is defined as:

$$B = \frac{\sum_{t=1}^{n} \frac{b_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{R_{Bt}}{(1+r)^t}} \tag{B.2}$$

B.3. Levelized rate of return

Ultimately, a levelized rate of return α (€/kg) over the technology lifetime n can be derived from Eq. (6) (Section 3.3) by assuming a constant bread turnover R_B per year t. It is done by calculating the life-cycle economic return R from either Eq. (6) or the discounted difference between the levelized sum of cash inflows B and the LCBB:

$$R = \alpha\, R_B = (B - LCBB) \cdot \sum_{t=1}^{n} \frac{R_{Bt}}{(1+r)^t}$$

By regarding the bread turnover as independent of year t, i.e. $R_{Bt} = R_B$, the levelized rate of return over the technology lifetime is further given by:

$$\alpha = \sum_{t=1}^{n} \frac{B - LCBB}{(1+r)^t} \tag{B.3}$$

Appendix C. Bread accessibility

Here we consider Eq. (3) (Section 3.2) over the whole R-distribution, that is: $F_R(d \to \infty)\, E\left[R_{0,d\to\infty}\right] = \mu_R$. Let $\mu_R|_{p_c=x}$ be the average radius of the R-distribution of the consumers around a bakery for which the probability of consumption p_c is equal to a specific value x. In order to retrieve $\mu_R|_{p_c=x}$, we can use the corresponding cumulative frequency distribution F of the probability distribution of the bread quantity consumed per capita $P\left(q_c\right)$, according to the amount of bread Q produced per capita:

$$Q = \frac{X_p}{2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, \mu_R} \tag{C.1}$$

Then, we can express the probability $p_c = x$ of the bread quantity consumed q_c being higher than a specific amount of bread $Q|_{p_c=x}$ within a given area defined by average radius $\mu_R|_{p_c=x}$ from the bakery with respect to F:

$$p_c = P\left(q_c \geqslant Q|_{p_c=x}\right) = 1 - F\left(Q|_{p_c=x}\right) = x \tag{C.2}$$

From this equation, we therefore get $Q|_{p_c=x}$ using the percent point function F^{-1}, that is the inverse of the cumulative frequency distribution:

$$Q|_{p_c=x} = F^{-1}(1-x) \tag{C.3}$$

Accordingly, we finally get $\mu_R|_{p_c=x}$ from Eqs. (C.1) and (C.3):

$$\mu_R|_{p_c=x} = \frac{X_p}{2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, Q|_{p_c=x}} \tag{C.4}$$

It is now possible to define $\mu_R^*\big|_{p_c=x}$ as the average radius of the R-distribution around the bakery corresponding to selling an optimal quantity of bread X_p^*. Using previous equation, it follows:

$$\mu_R^*\Big|_{p_c=x} = \frac{X_p^*}{2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, Q|_{p_c=x}} \tag{C.5}$$

A normalized accessibility indicator – we refer as to *bread accessibility* – can finally be retrieved through analyzing the likelihood for $\mu_R^*\big|_{p_c=x}$ to be lower than a predefined nominal value μ_R^{nom} corresponding to a specific set of b-customers $N_{c,b}^{nom}$:

$$\begin{aligned} b_a &= P\left(\mu_R^*\Big|_{p_c=x} \leqslant \mu_R^{nom}\right) \\ &= P\left(X_p^* \leqslant 2\pi\, p_{c,b}\, p_{h,c}\, \eta_h\, \mu_R^{nom}\, Q|_{p_c=x}\right) \\ &= P\left(X_p^* \leqslant N_{c,b}^{nom}\, Q|_{p_c=x}\right) \end{aligned} \tag{C.6}$$

The average radius of access $\mu_R^*\big|_{p_c=x}$ can be seen as an ideal case, whereby it is admitted that the bread produced (X_p^*) will be fully delivered to the $N_{c,b}^{nom}$ bread consumers distributed around the bakery.

Data availability

Data will be made available on request.

References

[1] Eurostat, Electricity prices for non-household consumers - bi-annual data (from 2007 onwards), 2023, URL https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205/default/table?lang=en.

[2] L. Monde, Crise Énergétique : Des Centaines De Boulangers Manifestent À Paris Pour Demander Davantage D'aides Au Gouvernement, Le Monde, 2023, URL https://www.lemonde.fr/economie/article/2023/01/23/hausse-des-prix-de-l-energie-des-centaines-de-boulangers-manifestent-pour-demander-davantage-d-aides-au-gouvernement_6159011_3234.html.

[3] J. Köhler, F.W. Geels, F. Kern, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalo, K. Jenkins, P. Kivimaa, M. Martiskainen, A. McMeekin, M.S. Mühlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B. Sovacool, B. Turnheim, D. Welch, P. Wells, An agenda for sustainability transitions research: State of the art and future directions, Environ. Innov. Soc. Transitions 31 (2019) 1–32, http://dx.doi.org/10.1016/j.eist.2019.01.004.

[4] B.K. Sovacool, What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda, Energy Res. Soc. Sci. 1 (2014) 1–29, http://dx.doi.org/10.1016/j.erss.2014.02.003.

[5] L. Iessa, Y.A. De Vries, C.E. Swinkels, M. Smits, C.A. Butijn, What's cooking? Unverified assumptions, overlooking of local needs and pro-solution biases in the solar cooking literature, Energy Res. Soc. Sci. 28 (November 2016) (2017) 98–108, http://dx.doi.org/10.1016/j.erss.2017.04.007.

[6] M.J. Fell, Energy services: A conceptual review, Energy Res. Soc. Sci. 27 (2017) 129–140, http://dx.doi.org/10.1016/j.erss.2017.02.010.

[7] J.C. Scott, Against the Grain: a Deep History of the Earliest States, Yale University Press, 2017.

[8] S. Reboud, C. Tanguy, L'innovation ordinaire d'un produit du quotidien : l'exemple du pain Ordinary – Innovation of an everyday product: The example of bread, Technol. Innov. (2021) 1–14, URL www.observatoiredupain.fr/.

[9] S. Abis, Le blé : Géohistoire d'un grain au cœur du pouvoir, Geoecol. 77 (5) (2015) 195, http://dx.doi.org/10.3917/geoec.077.0195.

[10] F.A. Manhiça, C. Lucas, T. Richards, Wood consumption and analysis of the bread baking process in wood-fired bakery ovens, Appl. Therm. Eng. 47 (2012) 63–72, http://dx.doi.org/10.1016/j.applthermaleng.2012.03.007.

[11] N. Therdthai, W. Zhou, Recent advances in the studies of bread baking process and their impacts on the bread baking technology, Food Sci. Technol. Res. 9 (3) (2003) 219–226, http://dx.doi.org/10.3136/fstr.9.219, Publisher: Japanese Society for Food Science and Technology.

[12] L. Clarke, Y.-M. Wei, A.D.L.V. Navarro, A. Garg, A. Hahmann, S. Khennas, I. Azevedo, A. Löschel, A. Singh, L. Stega, G. Strbac, K. Wada, Energy Systems, in: IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III To the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA, 2021, http://dx.doi.org/10.1017/9781009157926.008.

[13] B. Pillot, M. Muselli, P. Poggi, J.B. Dias, Historical trends in global energy policy and renewable power system issues in Sub-Saharan Africa: The case of solar PV, Energy Policy 127 (2019) 113–124, http://dx.doi.org/10.1016/j.enpol.2018.11.049.

[14] J. Meyer, S. Von Solms, Bake bread while the sun shines: Solar bakery for off-grid rural community development, in: 2018 International Conference on the Domestic Use of Energy, DUE 2018, Cape Peninsula University of technology, 2018, pp. 1–5, http://dx.doi.org/10.23919/DUE.2018.8384408.

[15] H.T. Odum, Environment, Power, and Society for the Twenty-First Century: The Hierarchy of Energy, Columbia University Press, 2007, URL http://www.jstor.org/stable/10.7312/odum12886.

[16] S. Ulgiati, H.T. Odum, S. Bastianoni, Emergy use, environmental loading and sustainability an emergy analysis of Italy, Ecol. Model. 73 (3–4) (1994) 215–268, http://dx.doi.org/10.1016/0304-3800(94)90064-7.

[17] T. Dutta, K.-H. Kim, M. Uchimiya, E.E. Kwon, B.-H. Jeon, A. Deep, S.-T. Yun, Global demand for rare earth resources and strategies for green mining, Environ. Res. 150 (2016) 182–190, http://dx.doi.org/10.1016/j.envres.2016.05.052.

[18] G. Pitron, La Guerre Des Métaux Rares: La Face Cachée De La Transition Énergétique Et Numérique, Les liens qui libèrent, 2018.

[19] I. Ayub, A. Munir, A. Ghafoor, W. Amjad, M.S. Nasir, Solar thermal application for decentralized food baking using scheffler reflector technology, J. Sol. Energy Eng. Trans. ASME 140 (6) (2018) 1–9, http://dx.doi.org/10.1115/1.4040206.

[20] NeoLoco, Artisanat solaire - Graines NeoLoco, 2023, URL https://neoloco.fr/.

[21] K. Varun, U.C. Arunachala, P.K. Vijayan, Sustainable mechanism to popularise round the clock indoor solar cooking – Part I: Global status, J. Energy Storage 54 (April) (2022) 105361, http://dx.doi.org/10.1016/j.est.2022.105361.

[22] A. Saxena, B. Norton, V. Goel, D.B. Singh, Solar cooking innovations, their appropriateness, and viability, Environ. Sci. Pollut. Res. 29 (39) (2022) 58537–58560, http://dx.doi.org/10.1007/s11356-022-21670-4.

[23] J. Vanschoenwinkel, S. Lizin, G. Swinnen, H. Azadi, S. Van Passel, Solar cooking in Senegalese villages: An application of best-worst scaling, Energy Policy 67 (2014) 447–458, http://dx.doi.org/10.1016/j.enpol.2013.12.038.

[24] A. Bhakta, E. Brown, N.E. Groce, Clean cooking for every 'body': Including people with disabilities in modern energy cooking services in the global south, Energy Res. Soc. Sci. 108 (2024) 103399, http://dx.doi.org/10.1016/j.erss.2023.103399.

[25] A. Shahsavari, M. Akbari, Potential of solar energy in developing countries for reducing energy-related emissions, Renew. Sustain. Energy Rev. 90 (June 2017) (2018) 275–291, http://dx.doi.org/10.1016/j.rser.2018.03.065.

[26] U.C. Arunachala, A. Kundapur, Cost-effective solar cookers: A global review, Sol. Energy 207 (July) (2020) 903–916, http://dx.doi.org/10.1016/j.solener.2020.07.026.

[27] R. Khatri, R. Goyal, R.K. Sharma, Advances in the developments of solar cooker for sustainable development: A comprehensive review, Renew. Sustain. Energy Rev. 145 (May) (2021) 111166, http://dx.doi.org/10.1016/j.rser.2021.111166.

[28] E. Cuce, P.M. Cuce, A comprehensive review on solar cookers, Appl. Energy 102 (2013) 1399–1421, http://dx.doi.org/10.1016/j.apenergy.2012.09.002.

[29] M. Aramesh, M. Ghalebani, A. Kasaeian, H. Zamani, G. Lorenzini, O. Mahian, S. Wongwises, A review of recent advances in solar cooking technology, Renew. Energy 140 (2019) 419–435, http://dx.doi.org/10.1016/j.renene.2019.03.021.

[30] C. Bielecki, G. Wingenbach, Rethinking improved cookstove diffusion programs: A case study of social perceptions and cooking choices in rural guatemala, Energy Policy 66 (2014) (2014) 350–358, http://dx.doi.org/10.1016/j.enpol.2013.10.082.

[31] R. Patel, V. Patel, Scheffler reflector for cooking application: a review, Int. J. Ambient Energy 43 (1) (2022) 2606–2618, http://dx.doi.org/10.1080/01430750.2020.1758778.

[32] F.W. Geels, B.K. Sovacool, T. Schwanen, S. Sorrell, The socio-technical dynamics of low-carbon transitions, Joule 1 (3) (2017) 463–479, http://dx.doi.org/10.1016/j.joule.2017.09.018.

[33] A. Herez, M. Ramadan, M. Khaled, Review on solar cooker systems: Economic and environmental study for different lebanese scenarios, Renew. Sustain. Energy Rev. 81 (May 2017) (2018) 421–432, http://dx.doi.org/10.1016/j.rser.2017.08.021.

[34] A. Harmim, M. Merzouk, M. Boukar, M. Amar, Solar cooking development in Algerian Sahara: Towards a socially suitable solar cooker, Renew. Sustain. Energy Rev. 37 (2014) 207–214, http://dx.doi.org/10.1016/j.rser.2014.05.028.

[35] I. Ayub, A. Munir, W. Amjad, A. Ghafoor, M.S. Nasir, Energy- and exergy-based thermal analyses of a solar bakery unit, J. Therm. Anal. Calorim. 133 (2) (2018) 1001–1013, http://dx.doi.org/10.1007/s10973-018-7165-3.

[36] B.K. Sovacool, S. Griffiths, Culture and low-carbon energy transitions, Nat. Sustain. 3 (9) (2020) 685–693, http://dx.doi.org/10.1038/s41893-020-0519-4.

[37] J. Liu, V. Hull, H.C.J. Godfray, D. Tilman, P. Gleick, H. Hoff, C. Pahl-Wostl, Z. Xu, M.G. Chung, J. Sun, S. Li, Nexus approaches to global sustainable development, Nat. Sustain. 1 (9) (2018) 466–476, http://dx.doi.org/10.1038/s41893-018-0135-8.

[38] T. von Wirth, L. Fuenfschilling, N. Frantzeskaki, L. Coenen, Impacts of urban living labs on sustainability transitions: mechanisms and strategies for systemic change t-hrough experimentation, Eur. Plan. Stud. 27 (2) (2019) 229–257, http://dx.doi.org/10.1080/09654313.2018.1504895.

[39] A. Crétot, La Boulangerie Solaire – Un Exemple Pour Un Futur Radieux, Terre vivante, 2023.

[40] T. Yang, W. Liu, G.J. Kramer, Q. Sun, Seasonal thermal energy storage: A techno-economic literature review, Renew. Sustain. Energy Rev. 139 (2021) 110732, http://dx.doi.org/10.1016/j.rser.2021.110732.

[41] F.F. Nerini, C. Ray, Y. Boulkaid, The cost of cooking a meal. the case of Nyeri county, Kenya, Environ. Res. Lett. 12 (2017) http://dx.doi.org/10.1088/1748-9326/aa6fd0.

[42] A.J. Tatem, WorldPop, open data for spatial demography, Sci. Data 4 (2017) 2–5, http://dx.doi.org/10.1038/sdata.2017.4.

[43] P. Deville, C. Linard, S. Martin, M. Gilbert, F.R. Stevens, A.E. Gaughan, V.D. Blondel, A.J. Tatem, Dynamic population mapping using mobile phone data, Proc. Natl. Acad. Sci. USA 111 (2014) 15888–15893, http://dx.doi.org/10.1073/pnas.1408439111.

[44] M. Wentzel, A. Pouris, The development impact of solar cookers: A review of solar cooking impact research in South Africa, Energy Policy 35 (3) (2007) 1909–1919, http://dx.doi.org/10.1016/j.enpol.2006.06.002.

[45] G. Salazar, C. Gueymard, J.B. Galdino, O. de Castro Vilela, N. Fraidenraich, Solar irradiance time series derived from high-quality measurements, satellite-based models, and reanalyses at a near-equatorial site in Brazil, Renew. Sustain. Energy Rev. 117 (2020) http://dx.doi.org/10.1016/j.rser.2019.109478.

[46] M. Sengupta, Y. Xie, A. Lopez, A. Habte, G. Maclaurin, J. Shelby, The national solar radiation data base (NSRDB), Renew. Sustain. Energy Rev. 89 (September 2017) (2018) 51–60, http://dx.doi.org/10.1016/j.rser.2018.03.003.

[47] D. Kenny, S. Fiedler, Which gridded irradiance data is best for modelling photovoltaic power production in Germany? Sol. Energy 232 (July 2021) (2022) 444–458, http://dx.doi.org/10.1016/j.solener.2021.12.044.

[48] D. Yang, J.M. Bright, Worldwide validation of 8 satellite-derived and reanalysis solar radiation products: A preliminary evaluation and overall metrics for hourly data over 27 years, Sol. Energy 210 (February) (2020) 3–19, http://dx.doi.org/10.1016/j.solener.2020.04.016.

[49] J. Trentmann, U. Pfeifroth, J. Drücke, R. Cremer, Quality assessment of SARAH-3: The new regional satellite-based surface solar radiation data set from the CM SAF, in: EGU General Assembly, Vienna, Austria, 2022, http://dx.doi.org/10.5194/egusphere-egu22-5605.

[50] T. Chatelain, D. Mauree, S. Taylor, O. Bouvard, J. Fleury, L. Burnier, A. Schüler, Solar cooking potential in Switzerland: Nodal modelling and optimization, Sol. Energy 194 (October) (2019) 788–803, http://dx.doi.org/10.1016/j.solener.2019.10.071.

[51] C. Zhou, Y. Wang, J. Li, X. Ma, Q. Li, M. Yang, X. Zhao, Y. Zhu, Simulation and economic analysis of an innovative indoor solar cooking system with energy storage, Sol. Energy 263 (2023) 111816, http://dx.doi.org/10.1016/j.solener.2023.111816.

[52] Lytefire, Lytefire deluxe big solar oven + roaster, 2024, URL https://lytefire.com/deluxe-big-oven-roaster (Accessed 02 February 2024).

[53] A. Eglite, D. Kunkulberga, Bread choice and consumption trends, in: 11th Baltic Conference on Food Science and Technology, 2017, pp. 178–182, http://dx.doi.org/10.22616/foodbalt.2017.005.

[54] AFHES, Bakery: European Market, Consumer Trends, and Innovation, Tech rep, 2021, pp. 1–46, URL https://www.ahfesproject.com/app/uploads/2021/12/AHFES-A6.2_Bakery-report_20211203-1.pdf.

[55] P. Sandvik, I. Kihlberg, A.K. Lindroos, I. Marklinder, M. Nydahl, Bread consumption patterns in a Swedish national dietary survey focusing particularly on whole-grain and rye bread, Food Nutr. Res. 58 (2014) http://dx.doi.org/10.3402/fnr.v58.24024.

[56] L. An, V. Grimm, A. Sullivan, B.T. II, N. Malleson, A. Heppenstall, C. Vincenot, D. Robinson, X. Ye, J. Liu, E. Lindkvist, W. Tang, Challenges, tasks, and opportunities in modeling agent-based complex systems, Ecol. Model. 457 (2021) 109685, http://dx.doi.org/10.1016/j.ecolmodel.2021.109685.

[57] T. Deng, K. Zhang, Z.-J.M. Shen, A systematic review of a digital twin city: A new pattern of urban governance toward smart cities, J. Manag. Sci. Eng. 6 (2) (2021) 125–134, http://dx.doi.org/10.1016/j.jmse.2021.03.003.

[58] Meta, High Resolution Population Density Maps + Demographic Estimates, 2023, https://dataforgood.facebook.com/dfg/docs/methodology-high-resolution-population-density-maps (Accessed 11 March 2023).