ON THE ROLE OF INDUSTRIAL KITCHENS IN SUSTAINABLE ENERGY SYSTEMS: THE NEXIK VISION

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ABSTRACT

Often overlooked by the research community, industrial kitchens (IKs) are among the main consumers of electric energy and water. This paper presents the nexIK research vision, which intends to turn IKs into active players in the quest for sustainable energy systems. More precisely, we first describe the five pilar of the vision: resource monitoring, users, data-driven modeling, energy efficiency and flexibility, and scale-up potential. Then, we present some initial results, namely, the definition of a taxonomy to classify IKs, and the assessment of the most common IK appliances in terms of their energy flexibility potential.

CONTEXT AND MOTIVATION

Industrial kitchens (IKs) use between 5 and 7 times more energy per square meter than other commercial building spaces like office buildings and retail stores [1]. Furthermore, studies indicate that in the EU, UK, and the US, 30% of the energy consumed in industrial kitchens is used in purely commercial establishments, e.g., restaurants and snack bars [2]. EU-27 has around 1.5 million food and beverage businesses [3].

Despite the size and ubiquity of this industry, its role in the global quest for sustainable energy systems is still widely under-explored. In fact, in a recent work that surveyed the literature on sustainable restaurants between 1991 and 2015, the authors claim that most of the works only engage with parts of sustainability, particularly ecological, rather than holistic sustainability [4].

Additionally, restaurants are significantly changing their activity and global business model due to the food-delivery ecosystem. According to [5], food delivery is already a global market worth more than $150 billion, having tripled since 2017. The same document mentions that the main factors for this increase are the population growth but mainly the millennials and Gen Zers preferring the convenience of prepared meals.

From the point of view of restaurants, food delivery is seen as an opportunity where the driver replaces the waiter, and the orders are placed on platforms as an additional table. As a consequence, the use of kitchens increases, and energy consumption follows the same trend. The concept of virtual kitchens is introduced in [6], [7]. A virtual kitchen, also known as a ghost kitchen, can be defined as "*a restaurant that eliminates the eat-in option for diners and focuses purely on off-premises sales channels. A virtual kitchen operates as delivery only, with some offering take-out options*" [7].

These changes in food and beverage businesses open an opportunity to increase the efficiency of the IKs' operation, the better coordination between the use of IKs appliances, and the integration of small production and storage technologies [8]–[10]. Using these technologies is vital to reduce the carbon footprint of IKs through the decarbonization and electrification of the global system. The electrification of IKs has a significant potential to contribute to the energy transition targets by enabling the participation of smaller consumers in electricity markets [11] and reducing the waste of electricity and water [12].

Despite their potential, research in IKs is still in its infancy, and several challenges remain underexplored. These include: 1) the lack of real-world datasets, 2) poor understanding of how water and electricity and consumed in IKs and their relation to food, 3) almost total absence of research towards the understanding of how IKs can promote to increase the amount of RES in the energy mix, and 4) lack of interaction with the leading IKs players, namely restaurant owners, and IKs staff.

Against this background, the Exploring the Human-Water-Energy Nexus in Industrial Kitchens (nexIK – https://nexik.tecnico.ulisboa.pt) project aims to set itself as a unique real-world test-bed for conducting exploratory research in IKs to understand how the Water-Energy-Food (WEF) Nexus can be leveraged to promote responsible resource consumption, cleaner energy, and industry innovations.

The remaining of this paper is organized as follows. First, the nexIK research framework is presented. Then, some preliminary results of the project are provided. This paper concludes with a summary and overview of future work.

NEXIK RESEARCH FRAMEWORK

The nexIK project has five specific objectives to target the challenges mentioned above.

1. Collect year-long water and electricity consumption data from IKs in actual operational conditions;
2. Engage with the major IK stakeholders, and understand their perceptions and motivations towards the WEFN and energy efficiency and flexibility opportunities;
3. Develop data-driven methods to model and understand resource consumption in IKs;
4. Assess the potential of IKs to contribute to increasing the penetration of RES in the energy mix by participating in demand-side flexibility markets;
5. Explore potential opportunities to scale up the project findings to other regions of Portugal, Europe, and the World.

Each of the objectives and the research plan is briefly described next.

T1. Electricity and Water Monitoring

Given the overarching objectives of nexIK, the data collection activities will focus on two main areas of the IK: the kitchen itself (where food is prepared, cooked, and delivered) and the ware-washing zone. These are the two areas of higher energy intensity during the IK operation since they cover all the cooking and cleaning appliances, short-term refrigeration, and hot/cold water needs.

To this end, we developed two non-intrusive electricity and water monitoring solutions. The energy monitoring device used is the eGaugePro (https://www.egauge.net/), which allows up to 30 current circuits to be monitored simultaneously (see Figure 1, left) [13]. The water monitoring system is the TUF2000M (https://www.libe.net/en-flowmeter), which is a non-invasive ultrasonic flow meter (Figure 2, right) [14].

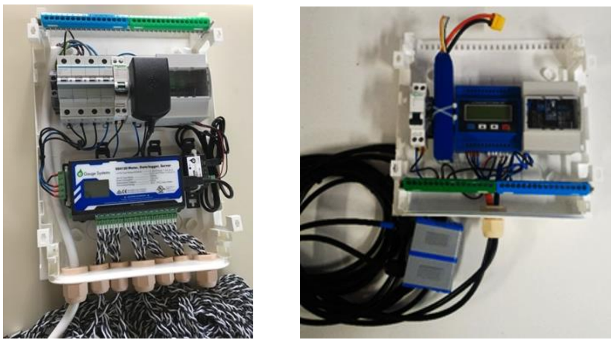
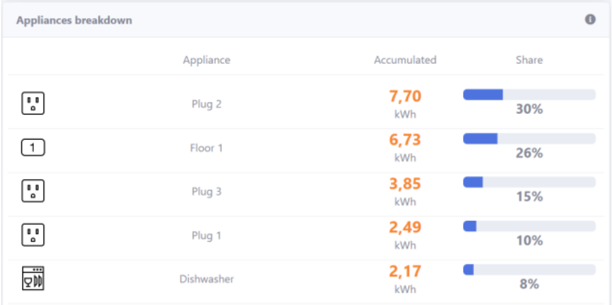


Figure 1: Monitoring Hardware: electricity (left); water (right).

T2. User-Centered Research

This task will focus on understanding the perceptions of the main IKs stakeholders concerning energy efficiency and flexibility opportunities in IKs solutions. This task will also explore how the IK Stakeholders perceive different eco-feedback visualizations. To this end, different visualizations will be implemented and delivered to the IKs participating in this project using a dedicated APP. Figure 2 shows a screenshot of the individual appliances widget that will be part of the nexIK front-end web application.



Appliances breakdown

Appliance	Accumulated	Share
Plug 2	7,70 kWh	30%
Floor 1	6,73 kWh	26%
Plug 3	3,85 kWh	15%
Plug 1	2,49 kWh	10%
Dishwasher	2,17 kWh	8%

Figure 2: Screenshot of the individual appliance consumption breakdown widget.

T3. Data-Driven Modeling

This task will focus on developing data-driven models for gaining a better understanding of resource consumption in IKs. In this regard, four main research avenues will be explored: 1) forecasting of aggregated and individual appliance consumption (e.g., [15]); 2) identification of appliance usage patterns and appliance interactions; 3) disaggregation of electricity and water consumption; and 4) appliance load profile modeling by combining physics-based and data-driven techniques.

T4. Energy Efficiency and Flexibility Management

This task will focus on analyzing the potential of IKs to increase energy use efficiency and provide flexibility to the system operators. To this end, the nexIK project will develop and evaluate different strategies to optimize appliance usage for providing demand-side flexibility considering scenarios with and without the presence of Distributed Energy Resources (DERs) such as micro-generation and battery energy storage. In this task, the appliance models developed in T3 will be integrated into a co-simulation platform, enabling a bottom-up simulation of different types of IKs.

T5: Scale-up and Generalization

The objective of this task is to leverage the results from the previous tasks to create abstract models and simulations of different types of IKs. The IK taxonomy defined in T2 and the appliance models and co-simulation tool developed in T4 will be used to simulate the demand for water and electricity in different categories of IKs according to the appliance usage patterns and interactions identified in T3. Then, the simulated IKs will be categorized according to their flexibility potential based on the methodology proposed in T4.

PRELIMINARY RESULTS

This section unveils some of the results already obtained in the nexIK project.

Electricity Monitoring

The electricity and water monitoring system were already installed in two IKs. The first one in open for lunch and dinner from Monday to Saturday. The second is only open for lunch from Monday to Friday. Figure 3 depicts the load demand for the same day days in the two IKs, where it is possible to observe the working hours of each establishment.

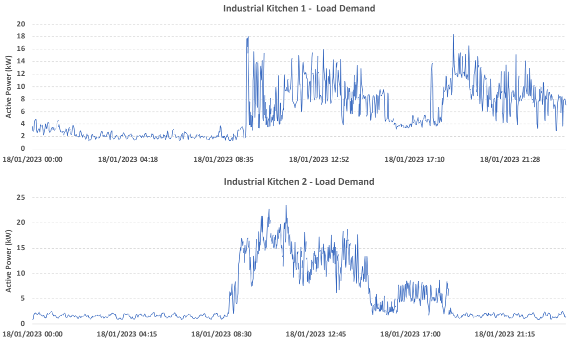


Figure 3: Load demand of the two IKs that are being monitored in the scope of the nexIK project.

IKs Taxonomy

A taxonomy is a structure of hierarchical categories that enables the classification of similar things according to some pre-established criteria. The groups or classes obtained through this classification must share at least one characteristics that the members of another class do not share [16], [17].

Since there is no systemized set of consolidated knowledge on how to develop a taxonomy for restaurants (or any other similar subject), it was necessary to define our own methodology based on an extensive literature review of existing methodologies. The stages of the proposed methodology are depicted in Figure 4.

The first stage is the **definition of the knowledge domain**. i.e., the environment where the taxonomy will be implemented and presented such that the abstraction mechanisms are elaborated to think first in the context, independently of the elements and their relationships. For example, in the concrete case of the nexIK project, the primary target audience is the managers and operators of IKs.

The second stage involves **extracting the terms and concepts** that compose the taxonomy. In this case, this was carried out through an in-depth characterization of IKs concerning their infrastructure and processes. The following terms were extracted: type and quantity of equipment, number of employees, types of food served, period of operation, services provided (eat-in, take-away, take-out, deliveries), meals served (breakfast, lunch, dinner), the importance given to saving water and electricity and the main challenges concerning these aspects.

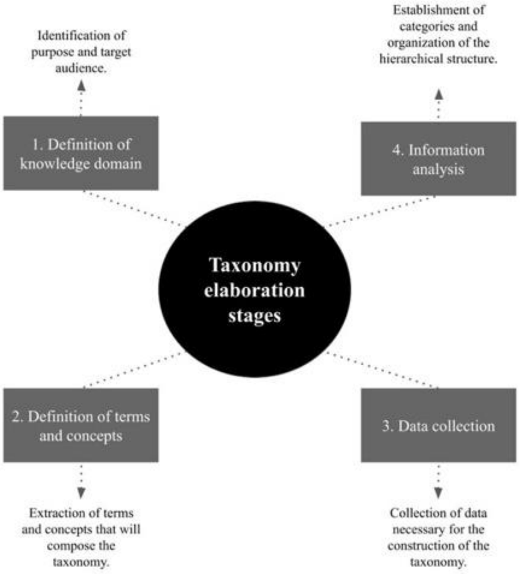


Figure 4: Stages of the proposed methodology for the taxonomy establishment.

The third stage consists of **data collection**, which in this case, was initially carried out through an email marketing campaign to restaurants in Lisbon. However, due to the low turnaround rate of responses, it was opted to hire a professional company to perform the data collection.

The last stage consists of the **information analysis** that will result in the taxonomy creation. In this particular case, quantitative and qualitative methods will be explored, for example, using software like NVivo (see https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home) and Minitab (see https://www.minitab.com/en-us/) for qualitative and quantitative data analysis, respectively. Finally, the taxonomy structure will be generated using concept maps using tools such as the cmap software (see https://cmap.ihmc.us/).

Classification of Appliance Flexibility in IKs

To date, there is still no formal definition of appliance flexibility [18]. Instead, several definitions have been proposed in recent years. For example, according to [19], flexibility corresponds to "*the amount of energy and the duration of time to which the device energy profile (energy flexibility) and/or activation time (time flexibility) can be the change.*" According to [20], it is the capacity to adjust the energy demand to support the grid, considering the ambient conditions and the quality of users. On the other hand, according to [21], energy flexibility is related to the time when power consumption can be increased or decreased at a specific time.

As such, the first task was to establish the definition of flexibility in the nexIK project. More precisely, flexibility refers to the capacity of electric devices to adjust their energy consumption to support the electric grid and keep the user comfort. Three parameters are considered when classifying the flexibility of a particular appliance: load shift, load reduction, and user comfort.

IK Appliances

Industrial kitchens are equipped with professional appliances, many of which have the same end as their domestic counterparts. In such cases, the main difference is the size of the device and the intensity of use, which are naturally much higher in IKs. In the context of this work, IK appliances can be classified into five distinct groups:

1. **Cooling:** appliances for ingredients and food preservation. Includes appliances such as *garde-manger*, refrigerators, freezers, blast chillers, and ice machines;
2. **Food preparation:** it is common to find appliances as varied as induction plates, convection ovens, cooking posts, sous-vide machines, microwaves, deep fryers, electric grills, hot houses, hot plate stoves, salamanders and smoke extractors;
3. **Service:** appliances used during service, including infrared shelves, heating lamps, and stove of dishes;
4. **Cleaning:** appliances used for cleaning, mainly dish, and glass washers;
5. **Heating and Cooling:** appliances responsible for heating, ventilation, and air conditioning (HVAC).

The flexibility of IK Appliances

Based on our definition of flexibility and the appliances commonly found in IKs, we developed the classification presented in Table 1.

The dishwasher (and glass washer) is considered a shiftable load since it presents flexibility in time. It is possible to postpone its operation without losing user comfort. All the surveyed articles comply with this classification.

The freezer and refrigerator have flexibility in time and power. Since the compressor can be ON or OFF, it is possible to postpone the operation of the freezer/refrigerator during some periods.

Table 1: Classification of IK appliances according to their flexibility potential per this paper's definition of flexibility.

Appliance	Not Flexible	Flexibility	
		Time	Power
Dishwasher		X	
Freezer		X	X
Refrigerator		X	X
Microwave	X		
Stove	X		
Oven	X		
HVAC / AC		X	X
Lighting			X

The dishwasher (and glass washer) is considered a shiftable load since it presents flexibility in time. It is possible to postpone its operation without losing user comfort. All the surveyed articles comply with this classification.

Although the authors in [19] consider loads like microwaves, stoves, and ovens to be semi-flexible, in the context of IKs, they are classified as non-flexible. It is essential to notice that [19] focuses on residential loads. Hence, it is possible to reduce the power and increase the operation's time with just some comfort loss. However, IKs do not have this flexibility since it is necessary to prepare the orders as they arrive. In this situation, shifting will likely result in a loss of comfort in the dinners at the restaurant. Furthermore, if the shifting period is too long, it can result in a total loss of quality perceived by the customers that could opt to leave the restaurant.

Since the operation principle of HVAC units is similar to the refrigerator, this appliance is also classified as flexible in time and power.

Finally, lighting has flexibility in power but not in time. It is not possible to postpone its operation without completely losing comfort. However, the power can be decreased if a dimmer switch is used. This device reduces the amount of electricity flowing to the bulbs, which means it will use less electricity. Hence, short variations of power in the kitchen and outside should not be a problem. However, reducing the power of lighting in restaurants is not convenient since it would represent a loss of quality perceived by customers.

CONCLUSIONS

This paper presented the vision of the nexIK research project, that aims to turn IKs into players in the transition towards sustainable energy systems. As the grid moves towards the new distributed model, the role of IKs will become even more important since due to their systematic way of operating, they can be more easily predicted and with that help to compensate for the unpredictability of the domestic sector. As such, a future work direction will be to study how IKs can be integrated into Energy Communities (EC), either by forming ECs based only in IKs, or by introducing them into existing ECs that in the present are mainly residential.

ACKNOWLEDGMENTS

This work is partially funded by the nexIK project, which is funded by the Portuguese Foundation for Science and Technology (FCT) under the grant (EXPL/CCI-COM/1234/2021) through national funds. The authors are also supported by Portuguese Foundation for Science and Technology (FCT) under the grant UIDB/50009/2020, UIDB/50021/2020 and CEECIND/01179/2017.

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