# Energy Services for Food Industry

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## Abstract

The gastronomy industry implements a number of various measures to contribute to the energy transition. This research investigates the feasibility and market potential of combining two energy services for professional espresso machines: an increase in the energy efficiency and a simultaneous provision of Frequency Containment Reserve (FCR) services.

Three quantitative investigations were carried out to estimate the market potential for the selected energy services: the estimation of (1) coffee machines' stock size (based on statistical data), (2) potential energy savings and (3) disposable power for FCR services. Both (2) and (3) focused on data analysis from a three group *La Marzocco* coffee machine (60 days; seconds resolution).

Four scenarios for stock size quantity were prepared for 12 countries (total results in thousands of units:141, 180, 517, 616) covering 95% of EU population. The total potential energy saving of a coffee machine was estimated to be around 25%. Furthermore, the following values of FCR disposable power for aggregation of 100 machines were estimated: night-time- 33,17kW, 8:00-10:00 – 39,33 kW, 10:00-18:00 - 42,65 kW, 18:00-20:00 – 36,9 kW, 20:00-21:00- 35,69 kW.

## Introduction

Despite the size and ubiquity of catering industry, its role in the global quest for sustainable energy systems is still widely under-explored. In fact, a very recent work[1] surveying the literature on sustainable restaurants between 1991 and 2015 claims that the majority of studies engage only partly with sustainability, focusing particularly on the ecological one rather than treating the problem holistically.

KOENA tec GmbH, a German start-up, proposed an initiative to combine traditional energy efficiency measures with an innovative approach to the provision of balancing services for the electrical grid security. The company has identified professional espresso machines as gastronomy appliances characterized with a specific load structure which not only have a high potential to reduce the energy use, but also are capable of contributing to the grid frequency restoration.

A typical professional espresso brews coffee by forcing a hot (above 90 °C) pressurized water through grounded beans, whereas for some kind of drinks additional production of steam ($P \approx 1.5$ bar; $T \approx 115°C$) is required. In order to guarantee stable service of high quality products throughout Café's operating hours, these high thermodynamic parameters are maintained by controlling devices (PID, thermostat). A set of hot water and steam boilers together with a pump can cause a temporary power consumption of above 8kW, which not only indicates the potential of energy savings, but also highlights a probable capability of providing Frequency Containment Reserve (FCR) services.

The aim of this work is to examine the feasibility of this solution and the estimation of its potential market. The study consists of three main parts regarding major areas of interest: (1) an estimation of coffee machine stock size, (2) an examination of energy efficiency improvement and (3) an analysis of supplying FCR services. Then, in section 4, the entire research is consolidated and discussed. At the end of the work, the conclusions are drawn and future work opportunities are indicated.

## Stock market estimation

### Introduction and Objectives

A study prepared as a part of Eco-Design Working Plan (EWP) 3 2016-2019 and other research conducted by Eric Bush[2], [3] claim that there is no database with accurate quantities of professional coffee machines neither worldwide nor in Europe. Eric Bush in his "Preliminary Study on Tertiary Hot Beverage Equipment"[2], where he estimates the number of units, follows the same methodology as Eco-Design Working Plan 2016-2019. This methodology assumes that each of the existing restaurants owns its one machine. The number of restaurants is based on Eurostat statistics beginning in 2010 and projected until 2018, for which the quantity is equal to 1.680.000 units.

Thus, one can argue that previous research suffers from a possible bias and a new methodology has to be formulated. The herein approach will proceed in two stages. Based on The Statistical Classification of Economic Activities in the European Community (NACE) for selected 12 countries covering 95% of EU population, a number of gastronomy points and, consequently, a quantity of coffee machines, will be approximated. Next, a so-called correction factor $CF$ will be defined to identify the segment of the stock which contains the most relevant appliances in terms of power and energy consumption, based on sales data. $CF$ is then defined as a ratio of sales of target subset of coffee machines to the total sales for each country and year.

$$CF_{i,j}^{3,4} = \frac{S_{i,j}^{3,4}}{S_{i,j}^{total}} \qquad (1)$$

$S_{i,j}^{3,4}$- sales of 3rd and 4th group of traditional coffee machines per i country and j year
$S_{i,j}^{total}$ – total sales of coffee machines per I country and j year

For the purpose of this research, it was assumed that sales distribution of espresso coffee units corresponds to the distribution of espresso machines in the restaurants. Consequently,

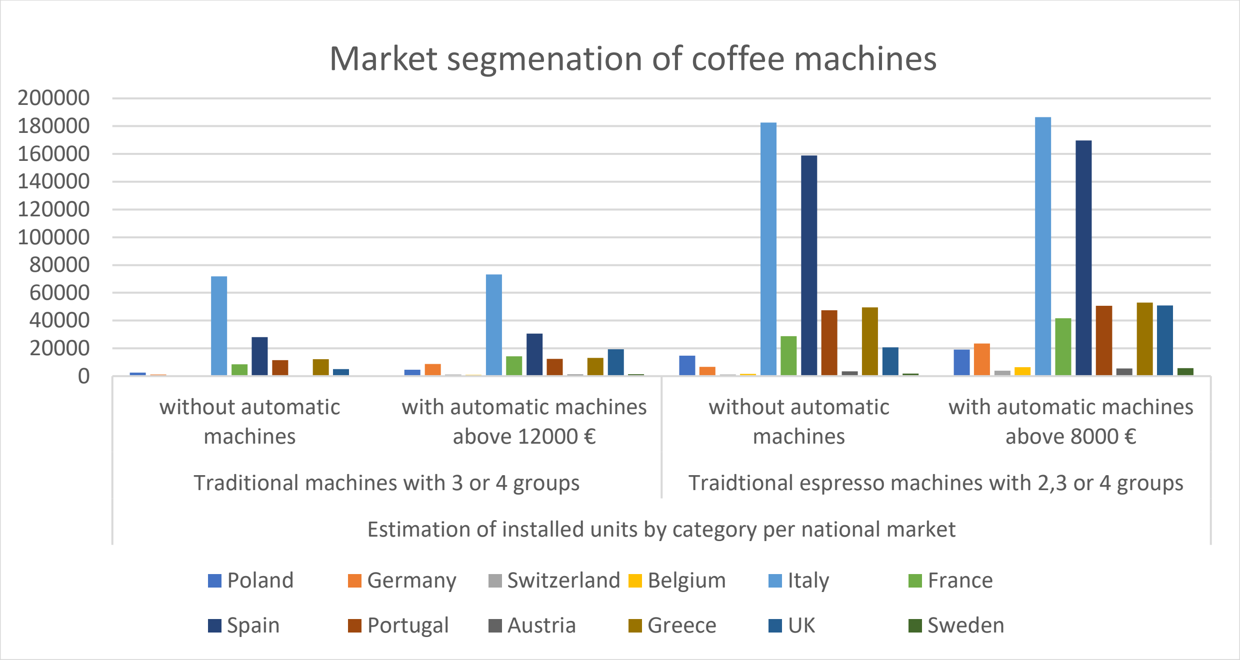

Figure 1 Market segmenation of coffee machines

$$Espresso\_units_{i,j}^{3,4} = CF_{i,j}^{3,4} \cdot GL_{i,j} \qquad (2)$$

Where *GL* – number of gastronomy locals.

**Available data**

NACE is a standardized industrial classification, which follows a UN ISIC classification and provides a structured framework of economic activities. Each branch consists of up four hierarchical levels. Five categories of NACE were analyzed and a combination of two 3-digit NACE code subsets: 561 (Restaurants) and 563 (Beverages establishments) was considered to most effectively describe relevant gastronomy locals. Data were collected from national statistical offices from 12 countries: Poland, Germany, Switzerland, Belgium, Italy, France, Spain, Portugal, Austria, Greece, UK and Sweden.

The sales data (2019, HKI) includes the sales of automatic professional coffee machines and the traditional professional coffee machines with an additional segmentation by group number and price respectively.

**Results and discussion**

The number of gastronomy locals for each country is presented in Figure 2. As it can be seen in the pie chart, more than 50% of GLs are located within three countries: Spain, France and Italy. Furthermore, one can point out a strong regional differences between particular nations: for example Greece and Portugal have ca. 3.5 times more espresso machines per capita than Germany, which aligns well with Nobly's Europe's Biggest and Smallest Coffees Cultures report. In the Figure 1 a categorization of coffee machines in terms of relevance for KOENA tec is presented. The left part of the graph depicts the less optimistic scenario. In this case only three and four group machines are counted. On the other hand, the right part of the figure shows the inclusion of additional 2 group coffee machines.

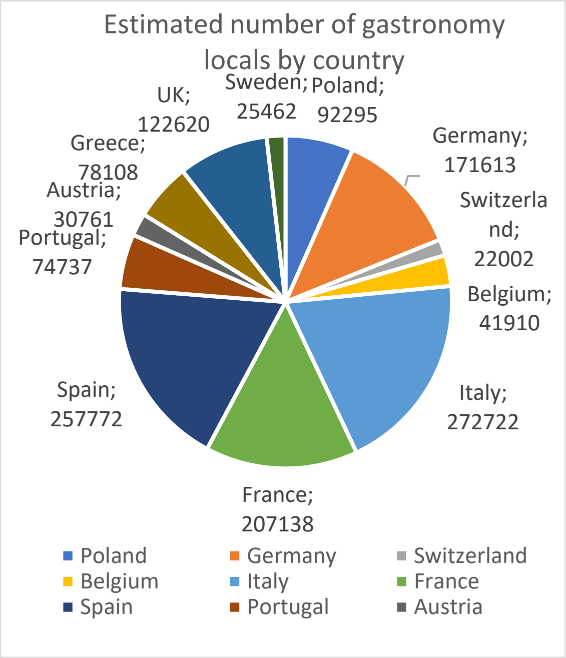

Figure 2 Approximated quantity of gastronomy locals

Both alternative approaches are then divided in two subsections, one with automatic machines and one without.

## Energy efficiency

### Introduction and Objectives

The main goal of this analysis is to investigate possible areas where energy consumption can be reduced. Since saving the opportunity should not impact the quality of the product, it cannot include the energy required by the process of making a proper coffee. Instead, they should focus on the energy loses between boilers and the environment. The respective thermal flux can be described with simplified formula:

$$q = a\Delta T \qquad (3)$$

Where a – convection parameter $[Wm^{-1}K^{-1}]$, $\Delta T$[°C] – temperature difference between boiler and environment.

Consequently, it can be concluded that, in order to preserve the boiler's temperature in periods when coffee is not brewed, the energy is unnecessarily dissipated. It is then relevant to examine the corresponding energy reduction.

### Methodology

The applied algorithm focuses on the investigation of thermal flux between boilers and the environment. First, the heat cycle is divided into (a) coffee boiler cycle and (b) steam boiler cycle. Due to the complexity of the heat exchange for the steam boiler (phase transition regime), only the coffee boiler is considered. In the second step an idle mode power consumption (when no coffee is brewed; nighttime, Figure 3.) is calculated. This value is projected for a day time and, consequently, $heat\ loses_{day}$ characterize how much energy is dissipated for heat during the day [8:00 AM to 9:00 PM] with current heating algorithms (not including coffee brewing). Thus, $heat\ loses_{day}$ represent the energy loss and depend on temperature difference (equitation 3). Theoretically, a perfect heating cycle could instantly heat up the boiler before brewing coffees so that a longer interval between particular heatings would decrease an average thermodynamic temperature of a boiler and, in consequence, decrease energy loss. Hence, this theoretical energy loss- $heat_{theoretical}$ - is iteratively calculated (equitation 3) and subtracted from

$heat\ loses_{day}$. The outcome represents a potential energy saving.

### Results

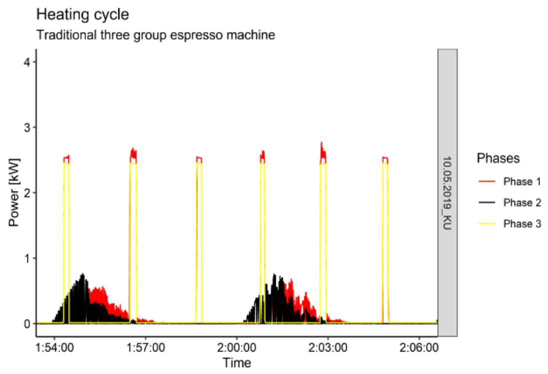

Figure 3 Heating cycle of coffee machine.

In this particular case energy savings are due to (1) switching off the appliance for night time and (2) applying theoretical heating cycle for a coffee boiler. Energy savings for the night time, reduced by the morning heating up phase, are equal to 4,51 kWh. The average value of energy savings from a coffee boiler is 0,73 kWh per day. Their combined value is equal to 5,24 kWh per day (1912 kWh per year) and corresponds to 25% of the total energy consumption.

## FCR service provision

### Introduction

The FCR services aim to stabilize the grid by injecting the power or increasing its consumption. In the case of coffee machines' FCR provision, two main constraints are relevant: (a) the impact on the product's quality (b) the identification of the positive balancing with decreasing power consumption, i.e. the availability of positive balancing only while consuming power. Since factor (a) refers to both directions of balancing services and (b) only to injecting power (decreasing power use), the factor (b) is considered a bottle-neck for this study and will be further investigated.

### Methodology

In the first part of this section the impact of a particular weekday and hour on the load will be analysed to determine possible patterns for the availability of FCR. It will be conducted basing on a *coffee list* (a list containing coffee timestamp and the length of corresponding pump's working time) from 60 days of observation. A coffee will be considered to be brewed when the pump's operating time is at least 16 seconds. In the second part, the disposable power for FCR is estimated. In order to guarantee a stable provision of FCR, it is assumed that appliances are aggregated in groups of 100 units. The load profiles of aggregation are generated accordingly to the working profile of a single machine *La Marzocco.*

The vital characteristics of a coffee machine is to be able to deliver its product on-demand despite extended periods of zero-demand. A combination of irregular demand arrivals with different demand sizes has been examined in previous studies. J.D. Croston in his article "Forecasting and Stock Control for Intermittent Demand" [4] suggests a decomposition of the data into two independent series: the first one to be associated with inter-demand intervals (IDI) whereas the second one to focus on the value of non-zero demand. This technique was improved by K. Nikolopoulos and alumni[5] who suggested an aggregate-disaggregate approach. It is then possible to cut down the frequency of our data (seconds resolution) and divide demand series into non-overlapping consecutive block of length equal to 10 or 20 minutes.

However, it is still significant to select a proper distribution for the forecasting model. Syntetos and Boylan in their research[6] managed to develop a classification of demand distribution based on two parameters: inter-demand interval (IDI) and squared coefficient of variation ($C_v^2$). The non-zero demands are forecasted using Bernouli distribution In our case the probability of failure p is equal to the inverse of inter-demand interval:

The actual size of the demand (number of coffees made when demand is non-zero) is calculated using the negative binomial distribution [7], [8], with the given probability density function:

$$P(X = k) = \binom{k + r - 1}{k} p^r (1 - p)^k \quad (4)$$

Where k is the number of failures, r is equal to the number of successes and p equals to the probability of success.

In our case:

$$n = \frac{\mu p}{1 - p} \quad (5)$$

where n is the number of successes, p is the probability of success and μ is the mean number of coffees per interval. And:

$$p = \frac{\mu}{C_v^2 (1 + \mu)^2} \quad (6)$$

where $C_v^2$ is the squared coefficient of variation.

Consequently, basing on the *coffee list*, 60 values (from 60 observation days; 10 minutes length of temporal aggregation) of IDI, $C_v^2$ and mean (μ) will be calculated. Next, following the equations (4-(6 new IDI, $C_v^2$ and μ are generated for each of 100 machines. The disaggregation procedure will assume a uniform distribution within 10 minutes intervals.

It is then necessary to assign power consumption to each cup of coffee. In order to do that, each coffee is described with corresponding $P_t$. Secondly, the algorithm searches for all identical $P_t$ within *La Marzocco* dataset and randomly selects one of them. Then, a corresponding load profile from historical data is copied to new generated dataset.

The disposable power is considered a maximum load power, which is available for 98% of time.

## Results

In the Figure 4, all weekdays are depicted in a single grid using various colours. On the Y axis there is an amount of time for which the pump was switched on in a given time interval. The X axis represents day time. A strong similarity between weekdays can be observed. Thus, it is only relevant to consider the daytime for differentiating the size of FCR service. Five day periods can be recognized: nighttime (no coffees are brewed), morning time (8:00AM to 10:00AM), midday time (10:00 AM to 18:00 AM), evening time (6:00 PM to 8:00 PM), closing time (8:00 PM to 9:00 PM)

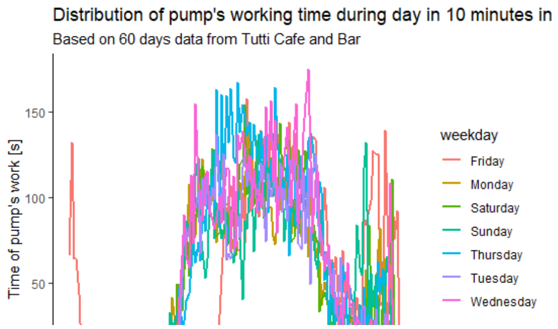

Figure 4 Coffee consumption behaviour at cafe.

For all these five time periods, a disposable power for FCR services was calculated. The results are presented in Figure 5 to Figure 9. Interestingly, the curve has a similar shape in all graphs, which can be divided into three separate groups. The initial, horizontal part of the curve describes the time needed to establish a non-zero power distribution within at least 98% of the forecasted 8-hour long dataset. When this condition is met, the first incremental amount of disposable power appears in the graph. Next, the curve turns out to obtain a more convex, polynomial shape. It can play a role of a transition to its third, most relevant regime.

Consequently, when aggregation level is around 25-30, the curve becomes linear. Following this assumption of linearity, it is then possible to estimate relatively easily the achievable power for any quantity of devices. The results turn out to follow the distributions of coffees and the pump's operational time from the periods in Figure 4. Consequently, as it was assumed, the highest obtainable power corresponds to midday, whereas the closing time is the bottleneck of our estimation. The disposable powers per 100 machines are presented in Table 1. The values presented in the graph are the averages of 100 different machine aggregations (100 repetitions). The confidence interval covers 95% of the results.

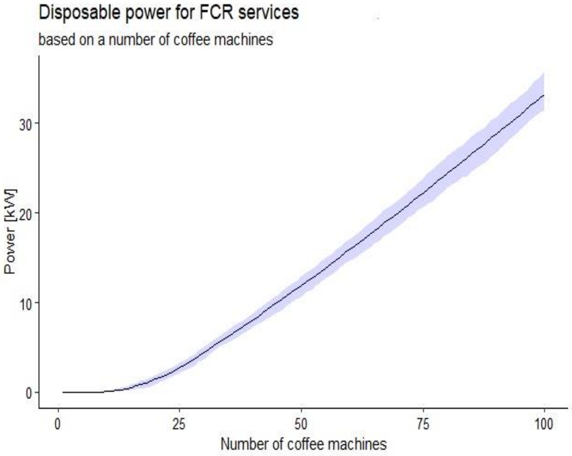

Figure 5 Disposable power per number of aggregated coffee machines when no coffees are brewed.

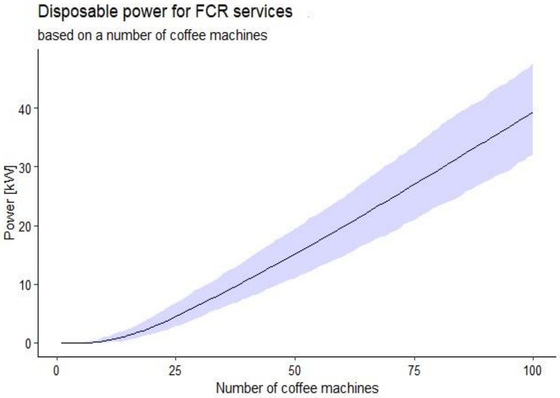

Figure 6 Disposable power per number of aggregated coffee machines between 8:00 and 10:00

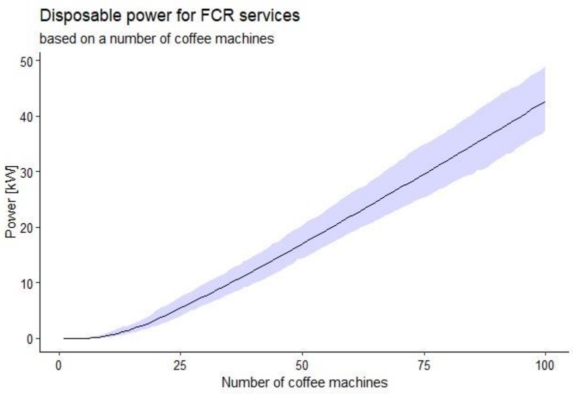

Figure 7 Disposable power per number of aggregated coffee machines between 10:00 and 18:00.

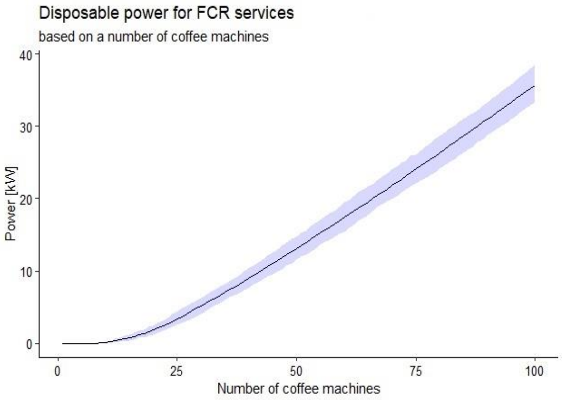

Figure 8 Disposable power per number of aggregated coffee machines between 18:00 and 20:00.

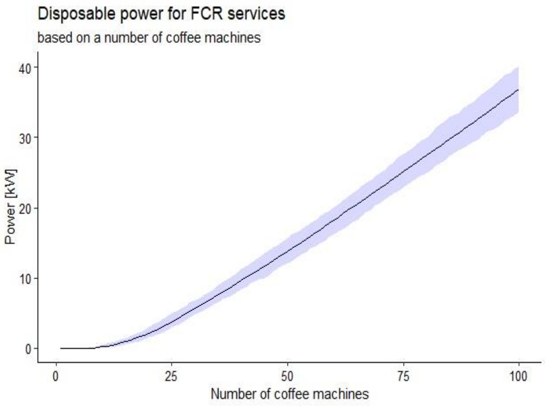

Figure 9 Disposable power per number of aggregated coffee machines between 20:00 and 21:00.

Table 1 Values of disposable power per 100 coffee machines in given day periods.

| **Day period** | **Disposable power per 100 coffee machines** |
|---|---|
| Night time | 33,17 kW |
| 8:00 – 10:00 | 39,33 kW |
| 10:00 -18:00 | 42,65 kW |
| 18:00 -20:00 | 36,90 kW |
| 20:00 -21:00 | 35,69 kW |

## Results Consolidation

In this section a recapitulation of the results concluded in previous chapters is presented. The study includes four various scenarios and two variants of coffee machines' market estimation:

- Scenario I – Traditional professional espresso machines (group 3 and 4)
- Scenario II – Scenario I extended by professional automatic machines (price above 12000 €)
- Scenario III – Traditional professional espresso machines (group 2,3 and 4)
- Scenario IV – Scenario III extended by professional automatic machines (price above 8000 €)

Variant a) When a coffee machine is in idle mode during night

Variant b) When a coffee machine is switched off during night

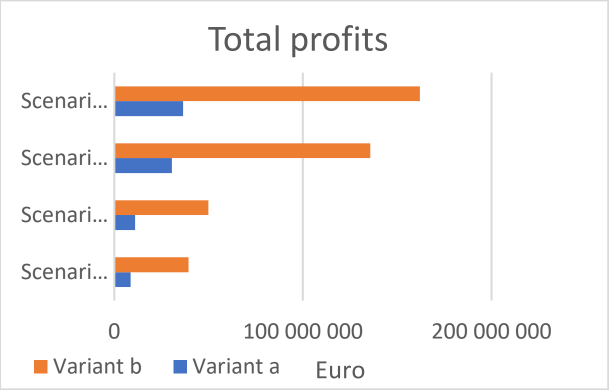

Figure 10 Total profits from aggregation of 100 coffee machines

The detailed aggregated results for scenario I variant a) is presented in Table 2, whereas a profit comparison between alternatives is depicted in figure Figure 10. It turns out that profits are much higher when the coffee machine is switched off during nights. Consequently, energy efficiency is considered to be more beneficial than providing FCR services. However, a combination of both energy services might be the optimal solution.

## Discussions

It is relevant to compare our results with other studies. For instance, S. Mudie and M. Vadhati in “Low energy catering insights from a nove”, similarly to the author of the thesis, follow a bottom-up approach to investigate energy behavior of an “average” restaurant and forecast potential savings. The total yearly energy consumption of a kitchen use phase (excluding house operation – lightening, heating, entertainment etc.) is estimated to 335 187 kWh (53 268 kWh of electricity[9]). The potential savings of 1912 kWh per espresso machine would be equal to 0,5% of total energy use of a kitchen (3,5% of electricity use).

On the other hand, the above mentioned 1912 kWh of savings correspond to 25% of energy reduction a coffee machine itself. The saving of 25% is similar to the result of S. Mudie for the whole restaurant: it is consistent with the first energy saving strategy – 29 % of saving potential – and is relatively lower than the outcome of second strategy (46,24%).

## Conclusion and future work

This research confirms feasibility of using professional coffee machines to provide both a) frequency containment reserve for the grid and b) improvement of the energy efficiency simultaneously while estimating its market potential. In spite of a number of difficulties and limitations (single source of data, simplification of thermodynamic phenomena, various assumptions in methodology), it was possible to estimate a stock size of espresso machines in 12 EU countries (four scenarios). Furthermore, the analysis of potential energy savings of espresso machine was carried out basing on a field test. In addition, a new methodology for estimating FCR services was established and, consequently, disposable power for FCR was estimated for five periods of the day.

Eventual forthcoming studies could further develop and confirm these initial findings by increasing the scope of available dataset to a larger and more dispersed set of coffee machines and gastronomy points. In addition, the investigation of delivering FCR in the direction from the grid and its impact on product quality should be conducted

Table 2 The detailed quantitative results for scenario 2, variant a

**Traditional professional espresso machines (group 3 and 4)**

| Country | Number of espresso machines | Percentage of the FCR market | Energy savings [GWh] | CO2 reduction [t] | Savings due to energy efficiency [€] | Savings due to providing FCR services [€] | Total profits [€] |
|---|---|---|---|---|---|---|---|
| **Poland** | 2.543 | 0,00 | 678 | 200 | 56.101 | 62.015 | 118.116 |
| **Germany** | 1.072 | 0,00 | 286 | 84 | 45.125 | 25.876 | 71.001 |
| **Switzerland** | 198 | 0,00 | 53 | 16 | 6.848 | 4.400 | 11.248 |
| **Belgium** | 197 | 0,00 | 52 | 15 | 6.045 | 4.381 | 10.426 |
| **Italy** | 71.794 | 0,07 | 19.130 | 5.643 | 3.091.335 | 1.763.338 | 4.854.673 |
| **France** | 8.523 | 0,01 | 2.271 | 670 | 215.731 | 208.921 | 424.652 |
| **Spain** | 28.205 | 0,04 | 7.515 | 2.217 | 829.674 | 692.461 | 1.522.135 |
| **Portugal** | 11.586 | 0,07 | 3.087 | 911 | 353.457 | 284.168 | 637.625 |
| **Austria** | 337 | 0,00 | 90 | 27 | 9.782 | 7.832 | 17.614 |
| **Greece** | 12.108 | 0,07 | 3.226 | 952 | 349.720 | 297.006 | 646.726 |
| **UK** | 5.123 | 0,00 | 1.365 | 403 | 212.937 | 125.398 | 338.335 |
| **Sweden** | 89 | 0,00 | 24 | 7 | 1.646 | 1.730 | 3.376 |
| **Total** | 141.774 | 0,02 | 37.776 | 11.144 | 5.178.402 | 3.477.526 | 8.655.928 |

## Bibliography

[1] F. Higgins-Desbiolles, E. Moskwa, and G. Wijesinghe, “How sustainable is sustainable hospitality research? A review of sustainable restaurant literature from 1991 to 2015,” *Curr. Issues Tour.*, vol. 22, no. 13, pp. 1551–1580, Aug. 2019, doi: 10.1080/13683500.2017.1383368.

[2] E. Bush and I. Rothwell, “Preliminary Study on Hot Beverages Equipment.” Jul. 2016.

[3] E. Bush, J. Nipkow, B. Josephy, and S. Heutling, “Strategies to Enhance Energy Efficiency of Coffee Machines,” p. 8.

[4] J. D. Croston, “Forecasting and Stock Control for Intermittent Demand,” *Oper. Res. Q. 23 289-303*, 1972, [Online]. Available: https://www.tandfonline.com/doi/abs/10.1057/jors.1972.50#:~:text=Exponential%20smoothing%20is%20frequently%20used%20for%20the%20forecasts%20in%20stock%20control%20systems.&text=Demand%20for%20constant%20quantities%20at,double%20the%20quantity%20really%20needed.

[5] K. Nikolopoulos, A. A. Syntetos, J. E. Boylan, F. Petropoulos, and V. Assimakopoulos, “An aggregate–disaggregate intermittent demand approach (ADIDA) to forecasting: an empirical proposition and analysis,” *J. Oper. Res. Soc.*, vol. 62, no. 3, pp. 544–554, Mar. 2011, doi: 10.1057/jors.2010.32.

[6] A. A. Syntetos and J. E. Boylan, “The accuracy of intermittent demand estimates,” *Int. J. Forecast.*, vol. 21, no. 2, pp. 303–314, Apr. 2005, doi: 10.1016/j.ijforecast.2004.10.001.

[7] A. A. Syntetos *et al.*, *Service Parts Management*. London: Springer London, 2011.

[8] F. Petropoulos, S. Makridakis, V. Assimakopoulos, and K. Nikolopoulos, “‘Horses for Courses’ in demand forecasting,” *Eur. J. Oper. Res.*, vol. 237, no. 1, pp. 152–163, Aug. 2014, doi: 10.1016/j.ejor.2014.02.036.

[9] S. Mudie, E. A. Essah, A. Grandison, and R. Felgate, “Electricity use in the commercial kitchen,” *Int. J. Low-Carbon Technol.*, p. ctt068, Sep. 2013.