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An optimal plan for food consumption with minimal environmental impact: the case of school lunch menus

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Food consumption patterns and lifestyles heavily affect the environmental sustainability of food production at least in terms of water consumption and greenhouse gases emission. In this paper, a systematic procedure based on an operation research approach is presented in order to define menus with low environmental impact. The procedure optimally allocates pre-specified recipes over the three courses of twenty lunches in a month. This approach is completely new in this field since it provides directly a realistic menu. The capabilities of the proposed method are proved through the planning of two monthly schedules for a school lunch menu requiring either a minimal consumption of water or a minimal emission of greenhouse gases. They provide varied and attractive menus for children over a given set of Mediterranean cuisine recipes, ensure a proper amount of energy and nutrients intake, and have an environmental impact significantly lower than menus usually defined by nutritionists via common sense heuristic. The proposed procedure is easy to implement, has no additional cost, and is scalable, that is the set of recipes can be easily updated without changing the overall model. The results appear to be encouraging so that it would be interesting to apply the proposed procedure to some other food service areas such as company service canteens, chain restaurants or other individual establishments.

1. Introduction

It takes a large amount of water to make processed foods. For example, the production of one kilogram of beef requires 15 thousand liters of water[1] (Mekonnen and Hoekstra, 2010). The global water footprint, that is the total water consumed in the world, is quite large. For instance, in the period 1996–2005 it was 9087 Gm^3 per year and agricultural production contributed 92% to this total footprint (Mekonnen and Hoekstra, 2011). Moreover, food production releases into the atmosphere up to 17,000 megatons of greenhouse gases (GHGs) every year (Vermeulen et al., 2012) and agricultural production contributes 80% to this total carbon footprint.

There is a general concern that water and carbon footprints are beyond the sustainable threshold levels (Hoekstra, 2014) and that suitable policies must be enforced to reduce them (Hoekstra and Wiedmann, 2014). In fact, if current population and consumption trends continue, humanity will need the equivalent of two Earths to support it by 2030 (Moore et al., 2012; UNEP, 2012). Furthermore, the world population will reach 9.1 billion by 2050 so that, in order to feed this larger population, food production must increase by 70% (FAO, 2009).

The global food system is a complex mix of production, processing, storage and transportation activities that move products from field-to-fork, through a traditionally resource-inefficient series of tasks (UNEP, 2015) that are usually driven by the firms' short-term profit. These activities should instead be implemented by balancing economic, environmental, and social issues in the present generation and for future ones (Lozano et al., 2015). Foster et al. (2006) provided a detailed analysis and discussion about the environmental impacts that occur in the life cycles of a range of food products. The study seeks to evaluate the environmental impact of certain patterns of food production, sourcing and distribution. Even though global environmental problems cannot be solved by addressing them sector-by-sector (Deumling et al., 2003), increasing the efficiency in food production and delivery is a critical

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[1] There is a huge variation around this global average. The precise footprint of a piece of beef depends on factors such as the type of production system and the composition and origin of the feed of the cow.

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part of the solution for reducing the water and carbon footprints. For example, the international character of many supply chains produces high levels of GHGs emission due to transport: this emission can be reduced only if the supply chains are restructured such that less long-distance transports are involved and electric vehicle technologies are employed for the last mile, i.e. deliveries in metropolitan areas (Ercin and Hoekstra, 2012). In short, locally grown ingredients should be preferred to imported ones. A sustainable production and consumption approach is a basic step also to tackle food surplus and waste throughout the global food supply chain (Papargyropoulou et al., 2014). On the other hand, standard production patterns, inherently water-intensive, should be placed where it rains sufficiently, for a blue water saving (Hoekstra and Mekonnen, 2012).

Consumption patterns are of great concern since they dictate the shape of the global food production system. For instance, replacement of a meat-heavy meal by a vegetarian, or a meat-light meal, will significantly help to lower the water footprint (Mekonnen and Hoekstra, 2012). Lukas et al. (in press) and Pairotti et al. (2015) presented some methodologies to compute nutritional footprints in order to let consumers able to evaluate their own choices for environmental sustainability of lifestyle and consumption practice. Heller et al. (2013) reviewed several studies made to evaluate the impact of consumption patterns based on different diet choices. Such studies considered stereotyped meals (Virtanen et al., 2011; Pathak et al., 2010) or diets (Saxe et al., 2013), diets constructed theoretically to meet nutritional goals (Baroni et al., 2007; Macdiarmid et al., 2012; Wilson et al., 2013), or diets based on national food availability statistics (Berners-Lee et al., 2012; Tukker et al., 2011; Fazeni and Steinmuller, 2011; Meier and Christen, 2012). In general, there is the need to comprehensively connect consumption patterns to production implications and quantitatively integrate environmental impact and nutritional health assessments.

This need stimulated the work presented in this paper that is aimed at defining a consumption pattern with reduced environmental impact – measured in terms of either water or carbon footprint[2] – whilst ensuring a proper intake of energy and nutrients. The water and carbon footprints here considered consist of the water consumption and the total set of GHG emissions, calculated as carbon dioxide equivalent (CO_{2e}), resulting from the life cycle assessment at farm gate. In particular, a systematic procedure based on an operation research approach is presented; it finds a monthly schedule for a school menu that requires either a minimal consumption of water or a minimal emission of GHGs. The typical meal is a composition of Mediterranean diet recipes and consists of a first course (pasta, soup, rice …), a second course (meat, fish, eggs …), a side dish (salad, vegetables …), fruit and bread. Hence, one has to decide the size of each meal to be served and the meals schedule throughout the month. However, for the schools in Rome, the local authority (City of Rome, 2013) fixes the total amount of ingredients in each recipe so that only the optimal monthly schedule of recipes needs to be defined. Some constraints are considered at different levels. The lunch must ensure a proper intake of energy and nutrients such as proteins, lipids, carbohydrates, fibers, sugars and sodium, according to legal nutritional requirements as suggested, for example, by the European Food Information Center (EUFIC, 2007). Moreover, in order to obtain a varied menu attractive for children, each day a different meal has to be provided and each dish may be served at most for a given number of times in a week and in the month. Therefore, the proposed procedure solves the problem of optimal allocation of prespecified recipes over the three courses (first, second and side course) of 20 lunches in a month. To the best of authors' knowledge, this approach is completely new in this field, while it is a well-established and validated practice in engineering problems related to supply or manufacturing chain management.[3] In these problems, variables are binary and denote the presence/absence of a resource in a given slot, see for example (Jain and Meeran, 1999). Indeed, Macdiarmid et al. (2012), Masset et al. (2009) and Wilson et al. (2013) applied linear programming techniques in order to obtain healthy diets with reduced environmental impact. They generally obtain food plans that best resemble current eating habits while meeting nutrition and/or cost constraints. Macdiarmid et al. (2012) are the only ones that propose a sample weekly menu to test whether the types and quantities of the optimal food plan could be combined into a realistic diet. This menu is obtained by supervised iterative attempts. The procedure proposed in this paper, instead, is completely unsupervised and directly provides realistic menus. It is applied twice in order to obtain a menu with minimal consumption of water and a menu with minimal emission of GHGs. These menus are particularly environmental friendly with respect to menus defined by nutritionists that take into account only the nutritional aspect and not the impact on the environment. In particular, the schedule obtained minimizing the emission of GHGs, saves more than 40% of CO_{2eq} emissions and more than 20% in water consumption; the schedule obtained minimizing the water consumption saves more than 35% in H_2O consumption and more than 20% of GHGs emission.

The paper is organized as follows. Section 2 describes the data that are the inputs of the proposed model: the recipes defined by the local authority are collected along with their ingredients; then, for each ingredient, its energy and nutrients content and water/carbon footprints are collected; finally the constraints on each lunch and on the overall monthly schedule are presented. Moreover, the model defining the relationship between a monthly menu and its water/carbon cumulative footprint is also developed. The optimal menus are presented and discussed in Section 3 and conclusions are drawn in Section 4.

2. Material and methods

In the Italian infant primary and secondary school (children from 3 to 13 years old), schools with canteen service are in charge to prepare the meals according to a guide of health and nutritional practices established by municipalities. The guide provides requirements to ensure food safety and hygiene as well as proper nutritional intakes. In more detail, the municipality of Rome provides a set of possible recipes along with the weight of their ingredients and the cooking procedure (City of Rome, 2013). The set of dishes and the corresponding set of ingredients, just for the primary school (children from 6 to 10 years old), are retrieved from this guide.

The set of possible recipes given by the municipality of Rome for the primary school consists of 106 different dishes of the Mediterranean cuisine divided into 33 first courses (pasta, soup, rice, …), 48 second courses (meat, fish, eggs, …), 23 side dishes (salad,

[2] The footprints here considered are determined only by the production process; packaging is not considered in the calculation of footprints. Indeed, packaging can contribute up to about 10% for carbon footprint while is negligible when considering water consumption. However, packaging contribution greatly depends on packaging characteristics (materials, size …) and therefore it is in general not evaluable.

[3] Job shop scheduling, for example, is the problem of sequencing a given number of jobs over a given set of machines in order to minimize the time needed to complete all the jobs.

Table 1
Columns of the table of the ingredients to prepare pasta with tomato sauce (values refer to 100 g of each ingredient).

	Pasta	Carrots	Onion	Celery	Parmesan	Peeled tomatoes	Olive oil
Energy (kcal)	137	35	26	20	387	21	899
Proteins (g)	4.7	1.1	1	2.3	33.5	1.2	0
Lipids (g)	0.5	0.2	0.1	0.2	28.1	0.5	99.9
Carbs (g)	30.3	7.6	5.7	2.4	0	3	0
Fibers (g)	1.5	3.1	1	1.6	0	0.9	0
Sugars (g)	1.3	7.6	5.7	2.2	0	3	0
Sodium (mg)	1	95	10	140	600	9	0
H_2O (L)	192.4	19.5	19.5	23.7	506	42.8	1334
CO_{2e} (g)	181	6	6	66	267	138	209

vegetables, …), fruit and bread. The list of the dishes can be found in Table 8 at the end of the paper. The municipality fixes the amount of ingredients needed to prepare each recipe and all the given recipes require 71 different ingredients. The recipes are then stored in a table of 106 columns and 71 rows. Each column corresponds to a recipe and each row to an ingredient. Therefore, in each column, the nonzero entries represent the amount of ingredients required for the recipe corresponding to that column.

In order to evaluate the water and carbon footprint as well as the energy and nutrients intake of each recipe, it is necessary to collect such data for each one of the 71 possible ingredients. Nutrients here considered, as suggested by the European Food Information Center (EUFIC, 2007), are proteins, lipids, carbohydrates, fibers, sugars and sodium. The nutrition information on the ingredients was retrieved from the database of the Italian Research Institute on Food and Nutrition (INRAN, 2009). Water and carbon footprint values were retrieved from a database of the World Wide Fund for Nature (WWF, 2009), made in collaboration with the University of Tuscia at Viterbo (Italy), the Second University of Naples (Italy) and Mutti S.p.A., on the basis of the following databases and research reports: Eurispes (2013), LCA (2007) and Vergé et al. (2009). All these data are stored in a table of 71 columns and 9 rows. Each column corresponds to an ingredient. The rows of the table contain the amount of energy, nutrients and the water and carbon footprints for 100 g of each ingredient.[4] A section of this table is given in Table 1 for the ingredients of the recipe of pasta with tomato sauce.

2.1. Energy, nutrients and dishes schedule constraints

A school menu should be adequate, balanced, varied and adapted to the characteristics and needs of children through the variety of food preparations and textures. It should be a diet that enhances and respects both the products and the culinary traditions of the area, taking into account those foods less accepted among children such as legumes, vegetables, fish and fruit (Estruch et al., 2013). In particular, it must ensure an appropriate intake of energy and nutrients. The Guideline Daily Amounts (GDA) indicate the total amount of energy and nutrients that a typical healthy person should intake in a day. In order to determine dietary recommendations for primary school children, the daily dietary reference values of food energy and nutrients for 5–10 years children found in COMA Report (1991) is considered. The lunch portion of energy and nutrients intake corresponds to about 35% of the daily amount, as suggested by Estruch et al. (2013). However, dietary recommendations for children vary depending on the age. In fact, energy and nutrients requirements during childhood and adolescence change as the child grows. Therefore, food must not only provide energy to maintain bodily functions and to perform daily physical activity, but also to meet the nutritional needs involving the child's growth and maturation (formation of tissues, bones, muscles, etc.). Hence, when talking about intake recommendations, each child's individual characteristics should be taken into account, such as sex, age, degree of maturity, growth rate and amount of physical activity (Estruch et al., 2013). Therefore, following the suggestion of the European Food Information Center (EUFIC, 2007), the dietary recommendations should not be regarded as strict individual targets. For these reasons, rather than a reference single value for each item, a range of possible values is considered. These ranges are reported in Table 2. Note that, according to Estruch et al. (2013) and Garcia-Meseguera et al. (2014), the Mediterranean diet is rich in proteins so that the range of possible values for proteins are higher than the reference value retrieved in COMA Report (1991). These ranges constrain the choice of the recipes to be considered in the schedule.

Some further constraints are considered. A first set of constraints deals with the composition of the meal: each meal must be composed of a first course (pasta, soup, rice …), a second course (meat, fish, eggs …), a side dish (salad, vegetables …), fresh fruit and bread. Moreover, vegetables must be served every lunch.

A second set of constraints refers to the weekly and monthly-allowed repetition for dishes. It corresponds to the need of serving a varied menu attractive for children. For example, a dish cannot be served too frequently within a week and totally in a month. Moreover, “lasagna” has to be present at least once in the monthly schedule, since it is particularly tasty for children. Such constraints are built in a table of 4 columns and 106 rows where the columns represent the minimum and maximum weekly repetition and the minimum and maximum monthly repetition for each recipe. In more detail, “lasagna” has to be served exactly once in the month while all the other dishes may be served at most once in a week and twice in the month.

A third set of constraints regards some food categories repetition on weekly scale. Examples of such constraints can be found in Estruch et al. (2013). The following 11 food categories are considered: *Pastas*, *Tomato pastas*, *No tomato pastas*, *Rice*, *Meat*, *Fish*, *Eggs*, *Dairy*, *Potatoes*, *Legumes* and *Salads*. As above, the constraints are built in a table of 2 columns and 11 rows, see Table 3. For example, meat has to be served at least once in a week but no more than

Table 2
Energy and nutrients range values for primary school children's lunch.

	Lower bound	Upper bound
Energy (kcal)	500	700
Proteins (g)	0	28
Lipids (g)	0	40
Carbs (g)	60	80
Fibers (g)	5	15
Sugars (g)	0	40
Sodium (mg)	300	500

[4] Nutritional contents and footprints of fruit have been determined as average of the footprints of the following different fruits: oranges, apples, pears, grape, peaches, cherries, tangerines, apricots and plums.

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Table 3
Weekly repetition constraints for some food categories.

	Weekly min	Weekly max
Pastas	1	3
Tomato pastas	1	2
No tomato pastas	0	1
Rice	1	2
Meat	1	2
Fish	1	2
Eggs	1	1
Dairy	1	1
Potatoes	0	2
Legumes	0	3
Salads	1	3

twice. Eggs have to be served exactly once in a week while legumes may not be served at all in a week but can be served up to three times.

2.2. Mathematical modeling and optimization method

The main goal of the paper is to determine the monthly schedule for the primary school lunch with minimum footprint for water or carbon. Summarizing, the schedule must be organized by choosing within a given set of recipes whose composition and serving size is fixed and must satisfy some constraints related to a proper energy and nutrients intake and variety of food.

In this Section the data structures used to set up the optimization problem are described. The optimization problem consists in determining the monthly schedule of recipes for a school lunch menu that minimizes either the associated water or carbon footprint. The schedule is subject to several constraints related to the composition of the meal, the total amount of energy and nutrients ranges, weekly and monthly-allowed repetition for recipes and food categories.

The unknowns are binary valued variables $x(i,j,h)$ where $i = 1, \ldots, 106$ denotes the recipe, $j = 1, \ldots, 5$ the day of the week, and $h = 1, \ldots, 4$ the week in the month. Therefore, $x(i,j,h) = 1$ means that the i-th recipe is served in the school meal of the j-th day of the h-th week. Then, the total number of unknowns is $N = 106 \times 4 \times 5 = 2120$.

To model the objective function and constraints, the tables defined in the previous section are stored in arrays of proper sizes. In more detail.

- the first seven rows of the table of the ingredients are stored in an array A_I of size 7×71, so that the element $A_I(r,c)$ is the amount of the r-th energy/nutrient in 100 g of the c-th ingredient;
- the last two rows of the table of the ingredients are stored in an array A_F of size 2×71, so that the element $A_F(1,c)$ is the water consumed to produce 100 g of ingredient c and the element $A_F(2,c)$ is the corresponding amount of GHGs emission;
- the table of the recipes is stored in an array A_R of size 71×106, so that the element $A_R(r,c)$ is the amount of the r-th ingredient in the c-th recipe;
- Table 2 is stored in an array V_R of size 7×2, so that the elements $V_R(r,1)$ and $V_R(r,2)$ are the minimum and maximum amount of the r-th energy/nutrient for lunch intake, respectively;
- the minimum and maximum number of times that recipes can be served in a week are stored in an array V_W of size 106×2, so that the elements $V_W(r,1)$ and $V_W(r,2)$ are the minimum and maximum number of times that recipe r can be served in a week, respectively;
- the minimum and maximum number of times that recipes can be served in a month are stored in an array V_M of size 106×2, so that the elements $V_M(r,1)$ and $V_M(r,2)$ are the minimum and maximum number of times that recipe r can be served in a month, respectively;
- Table 3 is stored in an array V_C of size 11×2, so that the elements $V_C(r,1)$ and $V_C(r,2)$ are the minimum and maximum number of times that recipes belonging to the r-th category can be served in a week, respectively.

It is easy to compute the amount of energy, nutrients and footprints associated to any recipe using the above arrays. The vector in expression (1) has size 7×1 and contains the total amount of energy and nutrients in the i-th recipe[5]

$$\frac{1}{100} \cdot A_I \cdot A_R(\,:, i). \tag{1}$$

For example, $i = 10$ corresponds to the recipe of pasta with tomato sauce; hence the vector in expression (2) contains the amount of energy and nutrients in the recipe of pasta with tomato sauce. These values are reported in the 10th row of Table 8 at the end of the paper and similarly for each one of the other recipes.

$$\frac{1}{100} \cdot A_I \cdot A_R(:, 10) = \begin{bmatrix} 171.46 \\ 6.08 \\ 6.17 \\ 24.32 \\ 2.01 \\ 4.02 \\ 45.95 \end{bmatrix}. \tag{2}$$

The vector in expression (3) has size 2×1 and contains the total amount of water consumption and GHGs emission needed to serve the i-th recipe.

$$\frac{1}{100} \cdot A_F \cdot A_R(\,:, i). \tag{3}$$

Again, the vector in expression (4) contains the amount of water consumption and GHGs emission for the recipe of pasta with tomato sauce.

$$\frac{1}{100} \cdot A_F \cdot A_R(:, 10) = \begin{bmatrix} 250.00 \\ 260.73 \end{bmatrix}. \tag{4}$$

These values are reported in the 10th row of the table given in Table 8 at the end of the paper and similarly for each one of the other recipes.

In order to formalize the model, the labeling of any recipe as a first course (*First*), a second course (*Second*) or a side dish (*Side*) is needed. Moreover, each recipe has to be labeled according to the categories defined in Table 3 and the category *Vegs* generally indicating vegetables. For example, saffron rice is a *First* belonging to *Rice* food category, while Ricotta cheese with cooked ham is a *Second* and belongs to both *Dairy* and *Meat* food categories. Labeling is implemented by assigning to each label a proper subset of the dish indices.

Expressions (5) and (6) define the objective function for the minimization of water consumption and GHGs emission, respectively[5]

$$f_{H_2O}(x) = \sum_{i=1}^{106} \sum_{j=1}^{5} \sum_{h=1}^{4} x(i,j,h) \cdot \frac{1}{100} \cdot A_F(1,:) \cdot A_R(:,i), \tag{5}$$

[5] The notation $A_R(:,i)$ means the i-th column of array A_R and the notation $A_F(i,:)$ means the i-th row of array A_F.

$$f_{CO_2}(x) = \sum_{i=1}^{106}\sum_{j=1}^{5}\sum_{h=1}^{4} x(i,j,h)\cdot\frac{1}{100}\cdot A_F(2,:)\cdot A_R(:,i). \quad (6)$$

Inequalities in (7) define the constraints on the k-th energy/nutrient ($k = 1, \ldots, 7$) that must be satisfied for each day j of every week h:

$$V_R(k,1) \le \sum_{i=1}^{106} x(i,j,h)\cdot\frac{1}{100}\cdot A_I(k,:)\cdot A_R(:,i) \le V_R(k,2), \quad j = 1,\ldots,5, \quad h = 1,\ldots,4. \quad (7)$$

Constraints on meal composition are considered for each day of every week and are expressed by equalities (8):

$$\sum_{i\in I} x(i,j,h) = 1, \quad j = 1,\ldots,5, \quad h = 1,\ldots,4. \quad (8)$$

The constraints are repeated six times for different subsets I, that is the subsets of indices associated to the labels *First*, *Second*, *Side*, *Fruit*, *Bread* and *Vegs*.

Inequalities in (9) define the constraints on weekly repetition and are written for each recipe i and week h:

$$V_W(i,1) \le \sum_{j=1}^{5} x(i,j,h) \le V_W(i,2), \quad i = 1,\ldots,106, \quad h = 1,\ldots,4. \quad (9)$$

Inequalities in (10) define the constraints on monthly repetition and are written for each recipe i:

$$V_M(i,1) \le \sum_{j=1}^{5}\sum_{h=1}^{4} x(i,j,h) \le V_M(i,2), \quad i = 1,\ldots,106. \quad (10)$$

Constraints on weekly repetition for the 11 food categories are expressed by inequalities (11) for each category and week h (constraints in (11) are written for the fourth category, i.e. *Rice*):

$$V_C(4,1) \le \sum_{i\in Rice}\sum_{j=1}^{5} x(i,j,h) \le V_C(4,2), \quad h = 1,\ldots,4. \quad (11)$$

In conclusion, the total number of unknowns is 2120 subject to 1428 inequality constraints and 120 equality constraints. Denoting by $F \subseteq \{0,1\}^{2120}$ the set of feasible values for the unknowns, that is all the possible combinations of unknowns values that satisfy the constraints, the optimal monthly schedule problem can be formalized as in expressions (12) and (13) for a menu minimizing the water consumption or the GHGs emission, respectively:

$$\min_{x\in F} f_{H_2O}(x), \quad (12)$$

$$\min_{x\in F} f_{CO_2}(x). \quad (13)$$

3. Results and discussion

The solutions of the optimization problems defined in (12) and (13) have been found using AMPL, an algebraic modeling language for describing and solving large-scale optimization and scheduling-type problems. The optimal monthly schedule of recipes for a school menu that minimizes the associated carbon footprint is given in Table 4 while the one minimizing water footprint is given in Table 5.

Fresh fruit and bread are served every lunch and are not indicated in the tables. The emission of GHGs for serving recipes in Table 4 is 7.77 kg while the water consumed is equal to 16.64 m^3. The emission of GHGs for serving recipes in Table 5 is instead 10.85 kg while the water consumed is equal to 13.72 m^3. Some statistics on the energy and nutrients for each of the two solutions are provided in Tables 6 and 7. The first and last columns of Tables 6 and 7 report just the energy and nutrients reference ranges for children's school lunch as in Table 2. In the second and fourth columns the minimum and maximum value of energy and nutrients of lunch intake within the optimal monthly schedule are given. The average of energy and nutrients over the optimal monthly schedule, are provided in the third column. As one can see, the two schedules are equivalent from a nutritional point of view since the average values of energy and nutrients contents are practically the same. Moreover, both schedules provide indeed a varied menu since they make use of the largest possible number of recipes. This is the case since the values of energy and nutrients span over almost all the allowable ranges.

Some further remarks are in order to stress the effectiveness of the proposed result. Nutritionists chose generally the monthly schedule from the list of recipes indicated by the municipality using some common sense heuristic in order to obtain a varied menu. Energy and nutrients content of each meal is not considered since the average intake over the month is somewhat ensured by the set of recipes indicated by the municipality. Moreover, since the Mediterranean diet is known to be environmentally friendly (Estruch et al., 2013), footprints are not considered as a discriminating factor when defining the monthly schedule. Therefore, the environmental impact of the monthly schedules of the schools of Rome can be evaluated by considering the sum of the average water and carbon footprint of first courses, second courses, side dishes, fruit and bread over the set of recipes given by the municipality. This is especially true as more schedules that are different are considered, and this is the case of Rome over different months. The average emission of GHGs of the monthly schedules is 13.81 kg while the average water consumed is equal to 21.61 m^3. It is clear now that the proposed optimal procedure provides many advantages in terms of a significant reduction of the environmental impact, along with the strict ensuring of a proper intake of nutrients and energy according to scientific recommendations. In more detail, the schedule proposed in Table 4 saves more than 40% of the GHGs emission and more than 20% of the water consumed. On the other hand, the schedule proposed in Table 5 saves more than 20% of the GHGs emission and more than 35% of the water consumed. These results are summarized in Fig. 1. It is remarkable that both footprints decrease with a significant reduction of the one that is optimized.

If all the school in Rome would adopt the schedule proposed in Table 5, the water saved in one year would be nearly 200,000 m^3. This can be computed considering that the number of students in the primary school in Rome is about equal to 2800, as indicated by the National Institute of Statistics (ISTAT, 2015), and the school year is about 9 month long. On the other hand, if all the school would adopt the schedule proposed in Table 4, the amount of gas emissions avoided would be about equal to 150,000 kg.

Note that, all these advantages would be achieved at no cost since they are obtained only by a smart selection of the schedule of meals without requiring modification of the allowable recipes and new cookware. The results appear to be encouraging so that it would be interesting to apply the proposed procedure to some other food service areas such as company service canteens, chain restaurants or other individual establishments.

Table 4
Monthly schedule that minimizes the GHGs emission.

Monday	Tuesday	Wednesday	Thursday	Friday
First week				
Fettuccine with tomato sauce	Cream of lentil soup with pasta	Cream of bean soup with pasta	Creamy pea risotto	Saffron rice
Tuna in olive oil	Caciotta cheese	Cooked ham	Omelets	Pork cacciatore
Sauteed courgettes	Tomatoes salad	Boiled broccoli with olive oil	Courgettes au gratin	Sliced carrots
Second week				
Pasta and potatoes soup	Saffron rice	Cream of lentil soup with pasta	Creamy pea risotto	Lasagna
Baked meatballs of cod fillet[a]	Mozzarella cheese	Pork burger	Pork cacciatore	Scrambled eggs
Mixed salad with cucumbers	Sauteed courgettes	Sliced carrots	Mixed salad	Fennel salad
Third week				
Parmesan risotto	Pasta with tuna	Pasta and potatoes soup	Rice and potatoes porridge	Cream of chickpea soup with pasta
Pork burger	Omelets	Hake fillet burger[a]	Cooked ham (half portion)	Caciotta cheese
Mixed salad	Fennels au gratin	Mixed salad with cucumbers	Fried courgette flowers	Fennel salad
Fourth week				
Rice and potatoes porridge	Parmesan risotto	Pasta with tuna	Cream of chickpea soup with pasta	Cream of bean soup with pasta
Cooked ham (half portion)	Tuna in olive oil	Scrambled eggs	Mozzarella cheese	Cooked ham
Fried courgette flowers	Tomatoes salad	Fennels au gratin	Courgettes au gratin	Boiled broccoli with olive oil

[a] Some recipes are equivalent in terms of nutrients and energy content and of environmental impact. Therefore, they can be substituted one to another in the schedule provided that the constraints on weekly and monthly repetition remain satisfied. The equivalent recipes are: Pasta with marinara sauce—Pasta with tomato sauce and oregano; Cod fillet croquettes—Hake fillet croquettes; Breaded dab fillets—Breaded bass fillets; Cod fillets au gratin—Hake fillets au gratin; Beef burger—Beef meatloaf; Cod fillet burger—Hake fillet burger—Baked meatballs of cod fillet; Backed potatoes—Roast potatoes; Boiled potatoes with olive oil—Sauteed potatoes.

Table 5
Monthly schedule that minimizes the water consumption.

Monday	Tuesday	Wednesday	Thursday	Friday
First week				
Pasta with trout	Pasta with butter and parmesan	Saffron rice	Creamy pea risotto	Pasta with marinara sauce[a]
Cooked ham	Mozzarella cheese	Dab fillets au gratin	Hake fillets au gratin[a]	Scrambled eggs
Green salad	Fennel salad	Sliced carrots	Mix of potatoes, carrots and string beans	Spinach with butter and parmesan
Second week				
Cream of vegetable soup with pasta (winter)	Pasta and potatoes soup	Rice and potatoes porridge	Pasta with tomato sauce and oregano[a]	Parmesan risotto
Omelets	Cod fillet burger[a]	Cooked ham (half portion)	Caciotta cheese	Cod fillets au gratin[a]
Stewed peas	Mixed salad with cucumbers	Fried courgette flowers	Fennel salad	Mixed salad
Third week				
Cream of vegetable soup with pasta (winter)	Parmesan risotto	Creamy pea risotto	Pasta with marinara sauce[a]	Pasta with trout
Omelets	Cod fillets au gratin[a]	Hake fillets au gratin[a]	Mozzarella cheese	Cooked ham
Stewed peas	Mixed salad	Mix of potatoes, carrots and string beans	Spinach with butter and parmesan	Tomatoes salad
Fourth week				
Rice and potatoes porridge	Pasta with tomato sauce and oregano[a]	Pasta and potatoes soup	Saffron rice	Lasagna
Cooked ham (half portion)	Caciotta cheese	Cod fillet burger[a]	Dab fillets au gratin	Scrambled eggs
Fried courgette flowers	Green salad	Mixed salad with cucumbers	Sliced carrots	Tomatoes salad

[a] Some recipes are equivalent in terms of nutrients and energy content and of environmental impact. Therefore, they can be substituted one to another in the schedule provided that the constraints on weekly and monthly repetition remain satisfied. The equivalent recipes are: Pasta with marinara sauce—Pasta with tomato sauce and oregano; Cod fillet croquettes—Hake fillet croquettes; Breaded dab fillets—Breaded bass fillets; Cod fillets au gratin—Hake fillets au gratin; Beef burger—Beef meatloaf; Cod fillet burger—Hake fillet burger—Baked meatballs of cod fillet; Backed potatoes—Roast potatoes; Boiled potatoes with olive oil—Sauteed potatoes.

Table 6
Lunch minimum, average and maximum values of energy and nutrients for the monthly schedule that minimizes the emission of GHGs.

	Lower bound	Min	Average	Max	Upper bound
Energy (kcal)	500	501.59	544.52	625.41	700
Proteins (g)	0	18.29	24.13	27.90	28
Lipids (g)	0	16.52	21.92	29.59	40
Carbs (g)	60	60.45	66.60	79.15	80
Fibers (g)	5	5.63	8.42	12.33	15
Sugars (g)	0	18.06	22.41	25.83	40
Sodium (mg)	300	300.48	338.82	472.42	500

Table 7
Lunch minimum, average and maximum values of energy and nutrients for the monthly schedule that minimizes the water consumption.

	Lower bound	Min	Average	Max	Upper bound
Energy (kcal)	500	500.20	541.66	635.01	700
Proteins (g)	0	18.29	24.23	27.92	28
Lipids (g)	0	15.83	20.55	32.19	40
Carbs (g)	60	63.66	68.97	79.15	80
Fibers (g)	5	6.12	8.05	12.12	15
Sugars (g)	0	18.06	22.43	27.79	40
Sodium (mg)	300	300.48	361.95	467.67	500

Table 8
List of recipes considered in the paper along with nutrients content, water consumption and GHGs emission for their production.

		Energy (kcal)	Proteins (g)	Lipids (g)	Carbs (g)	Fibers (g)	Sugars (g)	Sodium (mg)	H_2O (L)	CO_{2eq} (g)
1	Agnolotti with tomato sauce	426.71	16.98	15.57	58.16	2.80	5.69	410.20	423.60	313.03
2	Cream of chickpea soup with pasta	125.71	3.96	4.95	17.46	2.65	1.83	11.45	242.30	100.58
3	Cream of bean soup with pasta	117.31	4.11	4.35	16.50	3.16	1.68	10.55	242.30	100.58
4	Cream of lentil soup with pasta	117.31	3.93	4.35	16.68	3.39	1.65	10.55	242.30	100.58
5	Cream of vegetable soup with pasta (summer)	144.56	5.99	5.85	18.12	2.73	6.05	77.35	172.58	131.51
6	Cream of vegetable soup with pasta (winter)	142.26	5.61	5.83	17.99	2.81	5.63	76.15	172.58	131.51
7	Lasagna	302.01	14.78	16.51	24.97	1.76	6.13	111.90	699.98	349.46
8	Pasta with butter and parmesan	202.66	6.05	10.94	21.32	1.05	1.02	49.40	230.69	181.66
9	Pasta with pesto	187.40	4.92	8.60	23.71	1.70	1.89	1.33	319.87	183.39
10	Pasta with tomato sauce	171.46	6.08	6.17	24.32	2.01	4.02	45.95	250.00	260.73
11	Pasta with tomato and basil	169.31	5.98	6.16	23.90	1.82	3.60	38.40	248.56	259.11
12	Pasta with meat sauce	191.41	9.12	7.03	24.32	2.01	4.02	53.90	482.50	353.43
13	Pasta with vegetable ragu	175.16	6.21	6.19	25.11	2.33	4.80	56.85	252.19	261.99
14	Pasta with trout	169.66	8.33	5.27	23.61	1.77	3.31	17.50	222.28	309.06
15	Pasta with tuna	196.66	10.55	7.27	23.61	1.77	3.31	86.90	372.36	285.75
16	Pasta with vegetables	176.86	6.72	6.21	25.00	2.27	4.66	50.35	256.44	265.93
17	Pasta all'Amatriciana	220.53	9.41	10.31	23.90	1.82	3.60	321.30	325.62	331.04
18	Pasta with marinara sauce	148.66	4.25	4.75	23.61	1.77	3.31	7.90	222.28	245.46
19	Pasta with tomato sauce and oregano	148.66	4.25	4.75	23.61	1.77	3.31	7.90	222.28	245.46
20	Fettuccine with tomato sauce	148.76	5.37	6.30	18.65	1.62	3.53	45.85	257.81	183.72
21	Pasta with zucchini	163.31	6.30	5.84	22.86	1.62	2.48	40.00	227.20	159.11
22	Pasta and potatoes soup	130.36	4.08	5.66	16.86	1.30	1.56	42.05	154.56	96.53
23	Pasta with Mediterranean sauce	164.11	6.19	5.59	23.63	1.77	3.33	43.90	267.30	257.55
24	Pasta with ricotta and tomato sauce	181.31	6.16	6.95	25.02	2.01	4.72	31.55	288.26	280.98
25	Parmesan risotto	174.66	4.23	10.66	16.42	0.21	0.25	51.50	334.01	87.86
26	Rice and potatoes porridge	118.36	3.30	5.54	14.76	0.94	1.23	42.95	198.84	56.33
27	Tomato risotto	143.46	4.26	5.89	19.42	1.17	3.25	48.05	353.32	166.93
28	Saffron rice	124.51	3.20	5.48	16.60	0.26	0.43	33.30	317.64	54.91
29	Creamy pea risotto	134.11	4.28	5.54	17.88	1.52	1.83	81.70	324.08	110.71
30	Endive risotto	129.31	3.47	5.57	17.41	0.74	1.24	36.30	324.75	74.71
31	Pumpkin risotto	129.91	3.53	5.51	17.65	0.65	1.18	39.90	327.30	62.71
32	Zucchini risotto	132.61	4.16	5.54	17.62	0.65	1.39	39.90	327.30	62.71
33	Tortellini with butter and parmesan	456.86	16.89	20.31	55.01	1.80	2.54	413.20	402.14	227.06
34	Braised lamb with potatoes	545.91	36.39	28.52	38.55	2.70	0.90	157.50	715.98	194.31
35	Lamb cacciatore	278.96	32.04	16.78	0.00	0.00	0.00	144.00	606.23	165.86
36	Roast beef	133.86	19.83	5.65	1.09	0.39	1.09	49.70	1451.76	566.78
37	Roast pork	190.76	18.72	12.91	0.00	0.00	0.00	53.10	485.36	215.36
38	Roast turkey	159.06	26.85	5.29	1.09	0.39	1.09	74.00	407.76	177.98
39	Balsamic beef stew	157.42	18.28	9.13	0.34	0.00	0.30	48.16	1564.80	810.08
40	Roasted chicken leg	350.96	43.50	19.75	0.00	0.00	0.00	177.00	638.36	287.36
41	Breaded pork cutlet	237.71	21.12	14.14	7.00	0.34	0.45	105.54	544.06	225.32
42	Cod fillet croquettes	151.17	18.79	5.21	7.71	0.34	0.36	103.06	84.20	369.47
43	Hake fillet croquettes	151.17	18.79	5.21	7.71	0.34	0.36	103.06	84.20	369.47
44	Roasted turkey breast with lemon	167.50	27.10	5.30	3.05	0.12	0.07	61.28	409.75	180.83
45	Fried turkey breast	153.86	26.64	5.26	0.00	0.00	0.00	61.20	404.36	175.76
46	Dab fillets au gratin	140.86	19.48	5.52	3.61	0.17	0.34	150.00	59.21	362.12
47	Breaded dab fillets	190.22	22.47	7.24	9.45	0.46	0.71	204.66	139.46	371.78
48	Cod fillets au gratin	126.56	17.61	4.75	3.50	0.17	0.23	92.80	59.21	362.12
49	Hake fillets au gratin	126.56	17.61	4.75	3.50	0.17	0.23	92.80	59.21	362.12
50	Breaded bass fillets	190.22	22.47	7.24	9.45	0.46	0.71	204.66	139.46	371.78
51	Asiago cheese	178.00	15.70	12.80	1.00	0.00	1.00	380.00	253.00	230.00
52	Caciotta cheese	192.00	12.25	15.50	0.90	0.00	0.90	257.00	158.90	84.00
53	Crescenza cheese	196.70	11.27	16.31	1.33	0.00	1.33	245.00	222.46	117.60
54	Montasio cheese	205.50	15.15	16.10	1.00	0.00	1.00	378.50	253.00	230.00
55	Provolone cheese	187.00	14.05	14.10	1.00	0.00	1.00	430.00	253.00	230.00
56	Omelets	99.96	6.20	8.35	0.00	0.00	0.00	68.50	249.19	16.86
57	Beef burger	175.30	19.10	9.48	3.50	0.17	0.23	69.81	1465.96	569.03
58	Pork burger	196.00	17.93	12.36	3.50	0.17	0.23	87.81	502.96	219.83
59	Cod fillet burger	135.83	18.27	5.16	4.28	0.21	0.28	102.97	78.14	363.77
60	Hake fillet burger	135.83	18.27	5.16	4.28	0.21	0.28	102.97	78.14	363.77
61	Bass fillet burger	150.13	20.14	5.93	4.39	0.21	0.39	160.17	78.14	363.77
62	Mozzarella cheese	187.20	10.86	15.86	0.26	0.00	0.26	130.00	206.57	45.50
63	Fried chicken breast	152.06	27.18	4.81	0.00	0.00	0.00	41.40	404.36	175.76
64	Bread crumbed chicken breast	199.01	29.58	6.04	7.00	0.34	0.45	93.84	463.06	185.72
65	Beef meatballs with tomato sauce	182.90	19.51	9.64	4.69	0.49	1.41	73.01	1479.78	610.73
66	Meatballs with tomato sauce	206.96	20.05	11.97	4.99	0.58	1.71	100.91	1017.74	457.94
67	Baked meatballs of cod fillet	135.83	18.27	5.16	4.28	0.21	0.28	102.97	78.14	363.77
68	Beef meatloaf	175.30	19.10	9.48	3.50	0.17	0.23	69.81	1465.96	569.03
69	Cooked ham	107.50	9.90	7.35	0.45	0.00	0.45	324.00	240.00	218.00
70	Cooked ham (half portion)	53.75	4.95	3.68	0.23	0.00	0.23	162.00	120.00	109.00
71	Ham	134.00	12.75	9.20	0.00	0.00	0.00	1289.00	240.00	218.00
72	Ham (half portion)	67.00	6.38	4.60	0.00	0.00	0.00	644.50	120.00	109.00
73	Ricotta cheese with cooked ham	154.60	11.66	11.14	2.10	0.00	2.10	691.30	310.68	209.80

(*continued on next page*)

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Table 8 (*continued*)

		Energy (kcal)	Proteins (g)	Lipids (g)	Carbs (g)	Fibers (g)	Sugars (g)	Sodium (mg)	H_2O (L)	CO_{2eq} (g)
74	Escalope with ham and sage	152.64	22.19	7.13	0.02	0.00	0.02	294.84	1480.79	610.70
75	Beef escalope	139.48	20.10	5.33	3.07	0.12	0.09	37.12	1438.17	572.17
76	Pork cacciatore	176.36	17.10	12.01	0.00	0.00	0.00	65.70	485.36	215.36
77	Chicken breast strips	165.70	27.64	4.85	3.05	0.12	0.07	41.48	409.75	180.83
78	Beef strips	131.36	19.17	6.07	0.00	0.00	0.00	36.00	1448.36	564.56
79	Tuna in olive oil	96.00	12.60	5.05	0.00	0.00	0.00	158.00	300.15	80.58
80	Potato mould	321.60	16.41	15.82	30.46	2.12	2.44	277.39	383.73	166.36
81	Scrambled eggs	94.32	6.23	7.69	0.04	0.00	0.04	68.78	218.05	21.94
82	Sauteed chard	98.95	4.20	5.30	9.00	2.40	9.00	30.00	102.25	109.45
83	Boiled broccoli with olive oil	103.45	6.45	5.75	6.75	4.95	6.75	18.00	102.25	109.45
84	Stewed artichokes	77.95	4.05	5.30	3.75	7.50	2.85	199.50	115.00	428.95
85	Sliced carrots	80.25	1.11	5.20	7.67	3.10	7.67	95.10	92.60	20.10
86	Boiled string beans with olive oil	82.45	2.55	5.15	6.90	4.35	3.15	12.00	115.00	428.95
87	Fennels au gratin	76.72	2.77	5.62	3.83	3.41	1.65	30.00	109.97	27.43
88	Fried courgette flowers	200.00	5.92	9.04	23.28	0.96	0.32	2.16	70.01	36.99
89	Fennel salad	55.75	1.44	5.00	1.20	2.64	1.20	4.80	90.10	17.65
90	Tomatoes salad	65.35	1.44	5.24	3.36	1.20	3.36	3.60	90.58	16.45
91	Mixed salad with cucumbers	70.95	1.43	5.30	4.68	1.91	4.68	35.60	94.44	45.35
92	Mixed salad	71.15	1.55	5.18	4.84	2.55	4.84	43.70	92.20	47.65
93	Green salad	58.25	1.05	5.14	2.10	0.91	2.10	6.30	83.29	56.65
94	Mix of potatoes. carrots and string beans	100.95	1.91	5.15	12.57	2.74	3.32	35.20	99.78	129.85
95	Backed potatoes	266.95	4.35	11.75	38.55	2.70	0.90	13.50	109.75	28.45
96	Boiled potatoes with olive oil	151.45	2.70	5.15	25.35	1.95	0.60	10.50	109.75	28.45
97	Roast potatoes	266.95	4.35	11.75	38.55	2.70	0.90	13.50	109.75	28.45
98	Sauteed potatoes	151.45	2.70	5.15	25.35	1.95	0.60	10.50	109.75	28.45
99	Stewed peas	84.65	4.37	5.24	5.41	5.09	5.89	194.10	93.44	233.95
100	Mashed potatoes	210.97	5.59	9.57	27.55	1.95	2.80	57.56	152.71	63.21
101	Spinach with butter and parmesan	87.88	5.58	5.29	4.56	2.70	0.73	109.85	96.31	445.98
102	Boiled spinaches with olive oil	79.45	4.20	5.00	4.50	2.70	0.68	85.50	115.00	428.95
103	Courgettes au gratin	99.49	5.20	5.38	8.21	2.10	5.00	49.00	120.20	52.97
104	Sauteed courgettes	85.45	4.80	5.30	5.10	1.95	4.80	33.00	115.00	49.45
105	Bread	110.00	3.24	0.20	25.40	1.52	0.80	117.20	52.00	35.20
106	Fruit	63.33	0.88	0.20	15.48	2.70	15.48	2.67	135.60	47.40

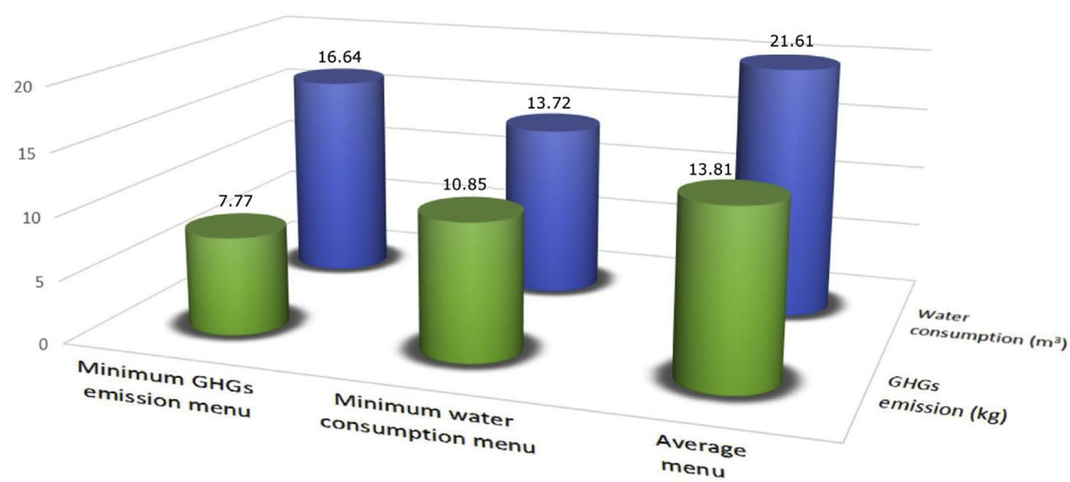

Fig. 1. Comparison of water consumption and GHGs emission for the schedules in Tables 4 and 5 with respect to menus usually defined by nutritionists.

The proposed method has some key features quite significant from a technical point of view. First, the model is scalable, i.e. it is capable to cope with an increased data size. In other words, one can easily consider more recipes, ingredients, food categories as well as different constraints without affecting the structure of the model. To do this, one has just to update the tables storing recipes, energy and nutrients contents of ingredients, weekly and monthly allowable repetitions for recipes and food categories. Other constraints can be also easily included to take into account issues such as palatability, for example by defining new labels to specify recipes pairing. This can also be extended to food and wine pairing. Moreover, one can think to have a set of tables for any regional cuisine, so taking into account food availability and trade, varying climates, cooking traditions and practices, and cultural differences. This might boost the use of locally grown ingredients and reduce the footprints due to goods transport. Hence, this method is an effective way to enforce those consumption patterns able to drive a significant change in the global food system from field to fork. Further, the time span of the schedule can also be easily changed; for example, one can consider weekly schedules as well as quarterly schedules. Summarizing, this line of research can be extended in order to comply with different food service application fields and different and more sophisticated constraints related to specific nutritional requirements (diets for diabetes, celiac disease …) or food pairing. A more general method can be studied by allowing variable serving size for the recipes but this would turn the optimization problem from a problem with only binary valued variables to a more complex problem with both binary and real valued variables.

It is worth noting that scalability of the model impacts on the number of variables and constraints, thus delivering optimization problems with increasing size. This does not affect the chance to find the optimal solution (with a computer having 4GB of memory and running a 64-bit operating system AMPL can typically accommodate over a million variables and/or constraints) but impacts on the computation time of the optimal schedule. For example, the optimization problem solved in this paper required at most a computation time of about 15 min. A key issue is instead the number of constraints that can make the problem unfeasible when unadvisedly chosen.

4. Conclusions

The global food system is a complex production process demanding water consumption and producing GHGs emission responsible for global warming and climate change. Indeed, water and carbon footprints are beyond the sustainable threshold levels so that suitable policies are encouraged in order to reduce them.

The goal of this work is to define realistic menus over a pre-specified set of recipes, with reduced environmental impact — measured in terms of either water or carbon footprint. The menus have to be varied and attractive for children, with a proper intake of energy and nutrients. To this end, an optimization model that selects, among a given set of Mediterranean recipes, the monthly schedule for a school lunch that minimizes either water or carbon footprint, is developed.

The menus obtained using the proposed model are particularly environmental friendly with respect to menus usually defined by nutritionists via common sense heuristic. As a matter of fact, the schedule obtained minimizing the GHGs emission, saves more than 40% of CO_{2eq} and more than 20% in the water consumption; the schedule obtained minimizing the water consumed, saves more than 35% in H_2O consumption and more than 20% of the GHGs emission.

The proposed procedure can be easily applied to some other food service areas such as company service canteens, chain restaurants or other individual establishments. The model is completely scalable and can be easily updated.

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