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

Luca Benvenuti* Alberto De Santis* Fabio Santesarti
Luigino Tocca†

January 26, 2016

Abstract

Carbon and water footprints are definitely beyond the sustainable threshold levels and appropiate policies must be enforced to reduce them. A great deal of water consumption and greenhouse gas emissions is due to food production. This process is obviously driven by people's food consumption patterns so that their choices and lifestyles heavily impact on environmental sustainability of food production. In this paper we present a systematic procedure, based on an operation research approach, that finds a monthly schedule for a school lunch menu that requires either a minimal consumption of water or a minimal emission of greenhouse gases. The procedure is able to provide a varied and attractive menu for children whilst ensuring a proper amount of energy and nutrients intake. We then propose two different schedules over a given set of mediterranean cousine recipes. The optimal schedules save a significant amount of water consumption and greenhouse gas emissions with respect to menus usually defined by nutritionists via common sense heuristics. Moreover the proposed procedure is easy to implement, has no additional cost, and is scalable, that is the set of recipes among which select the schedule can be easily updated without changing the overall model.

Keywords: Carbon footprint; water footprint; food consumption pattern; environmental sustainability; nutrition.

1 Introduction

It takes a surprisingly large amount of water to make processed foods. For example, the production of one kilogram of beef requires 15 thousand litres of water [1](Mekonne and Hoekstra (2010)). The global water footprint, that is the total water consumed in the world, is quite large.

*Department of Computer, Control, and Management Engineering - Sapienza University of Rome, Via Ariosto 25, 00185 Roma, Italy.

†Department of Environmental Protection - Civil Protection, City of Rome, Circonvallazione Ostiense 191, 00154 Roma, Italy

[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.

For instance, in the period 1996-2005 it was 9087 Gm^3 per year and agricultural production contributed 92% to this total footprint (Mekonne and Hoekstra (2011)). Moreover, agriculture and food production releases annually up to 17000 megatonnes of greenhouse gases (Vermeulen, Campbell, and Ingram (2012)) into the atmosphere and agricultural production contributes 80% to this total footprint.

There is a general concern that carbon and water footprints are definitely beyond the sustainable threshold levels and that suitable policies must be enforced to reduce them. As a matter of fact if current population and consumption trends continue, humanity will need the equivalent of two Earths to support it by 2030 (United Nations Environment Programme (2012)). Furthermore, by 2050 the worlds population will reach 9,1 billion so that, in order to feed this larger population, food production must increase by 70 percent (Food and Agriculture Organization of the United Nations (2009)).

The global food system is a complex mix of production, processing, storage and transportation activities, that moves products from field-to-fork, through a traditionally resource-inefficient series of activities (United Nations Environment Programme (2015)) that are usually driven by firms short-term profit. These activities instead should be implemented balancing economic, environmental, and social issues in the present generation and for future ones. (Lozano, Carpenter, and Huisingh (2015)). In (Foster et al. (2006)) a detailed analysis and discussion about the environmental impacts that occur in the life cycles of a range of food products are provided. The study seeks to evaluate the environmental impact of certain patterns of food production, sourcing and distribution. Even though global environmental problems can not be solved by addressing them sector by sector (Deumling, Wackernagel, and Monfreda (2003)), increasing the efficiency in food production and delivery is a critical part of the solution for reducing carbon and water footprints. Indeed, food supply chain and consumption patterns carry an inherent dependence on energy and water. For example, the international character of many supply chains depend heavily on energy for transport, that can be reduced only if the supply chains are restructured such that less long-distance transport is 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, Lozano, Steinberger, Wright, and bin Ujang (2014)). On the other hand standard production patterns, inherently water-intensive, should be placed where it rains sufficiently, for a blue water saving. Moreover, 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)).

Consumption patterns are also of great concern since they largely dictate the shape of our global food production system. In fact supplying adequate human nutrition within ecosystem carrying capacities is a key element in the global environmental sustainability challenge. For instance, in (Lukas, Rohn, Lettenmeier, and C. Liedtke (in press)) and (Pairotti, Cerutti, Martini, Vesce, and D. Padovan (2015)) some methodologies to compute nutritional footprints are presented in order to let consumers able to evaluate their own choices for environmental sustainability of lifestyle and consumption practice. In (Heller, Keoleian, and Willett (2013)), the authors reviewed several studies (see the references therein) made to evaluate the impact of consumption patterns based on different diet choices. Such studies considered stereotyped meals or diets, diets constructed theoretically to meet nutritional goals, or diets based on national food availability statistics. 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 carbon or water 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 greenhouse gas emissions, calculated as carbon dioxide equivalent (CO_{2e}), resulting from the life cycle assessment at farm gate.

In particular we present a systematic procedure based on an operation research approach that finds a monthly school menu schedule that requires either a minimal consumption of water or a minimal greenhouse gas emissions. The typical meal is a composition of a mediterranean diet recipes and is composed 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 amount of ingredients for each recipe to be served and the meals schedule throughout the month. However, for the schools in Rome, the total amount of ingredients in each recipe is fixed by the local authority (City of Rome (2013)) 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, that is protein, lipids, carbohydrates, fiber, sugars and sodium, according to legal nutritional requirements (European Food Information Council (2007)). Moreover, in order to provide 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.

We applied the proposed procedure twice obtaining a menu with minimal consumption of water and a menu with minimal greenhouse gas emissions. 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 more detail, the schedule obtained minimizing total emission of greenhouse gases saves more than 40% of CO_{2eq} emissions and more than 20% in water consumption; the schedule obtained minimizing water consumption saves more than 35% in H_2O consumption and more than 20% of total emission of greenhouse gases.

The paper is organized as follows. Section 2 describes the nature of the data that are the inputs of the proposed model: the recipes defined by the local authorithy are collected along with their ingredients; then, for each ingredient, its energy and nutrients content and carbon/water footprints are collected; finally the constraints on each lunch and on the overall monthly meal schedule are presented.

In Section 3 the model defining the relationship between a monthly menu and its carbon/water cumulative footprint is developed.

The optimal menu is presented and discussed in Section 4 and conclusions are drawn in Section 5.

[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, ...) therefore it is in general not evaluable.

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 recipies along with the weight of their ingredients and the cooking procedure (City of Rome (2013)). From this guide we retrieved the set of dishes and the corresponding set of ingredients just for the primary school (children from 6 to 10 years old).

The set of possible recipies 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, vegetables, ...), fruit and bread. The list of the dishes can be found in Figure 1 at the end of the paper. For each recipe the municipality fixes the amount of ingredients needed to prepare it and all the given recipes require a total of 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. The column corresponding to the recipe of pasta with tomato sauce is given in Table 1 where only the nonzero ingredients are reported.

	Pasta with tomato sauce
Pasta (g)	50
Carrots (g)	5
Onion (g)	5
Celery (g)	2
Parmesan (g)	5
Peeled tomatoes (g)	80
Olive oil (g)	4

Table 1: Column of the table of dishes for pasta with tomato sauce.

In order to evaluate the water and carbon footprint as well as the energy and nutrients intake of each recipe is necessary to collect such data for each one of the 71 possible ingredients. Nutrients here considered are protein, lipids, carbohydrates, fiber, sugars and sodium as suggested in (European Food Information Council (2007)). The nutrition information on the ingredients was retrieved from the database of the Italian Research Institute on Food and Nutrition (INRAN Food Composition Database (2009)); carbon and water footprint values were retrieved from a database of the World Wide Fund for Nature (World Wide Fund for Nature, Italy (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 Food Database (2007), Vergé, Dyer, Desjardins, and Worth (2009), Global Footprint Network (2008). 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 carbon and water footprints for 100 g of each ingredient. Note that nutritional contents and footprints of fruit have been determined as average of the footprints of the following different fruits: oranges, apples, pears, grape, peaches, cerries, tangerines, apricoats and plums. A section of this table is given in Table 2 for the ingredients of the recipe of pasta with tomato sauce.

	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
Fiber (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
Water (ℓ)	192,4	19,5	19,5	23,7	506	42,8	1334
CO_{2e} (Kg)	0,181	0,006	0,006	0,066	0,267	0,138	0,209

Table 2: Columns of the table of ingredients to prepare pasta with tomato sauce. Values refer to 100 g of each ingredient.

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 less accepted among children such as legumes, vegetables, fish and fruit (see Estruch et al. (2013)). In particular, it must ensure an appropriate intake of energy and nutrients. 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, we considered the daily dietary reference values of food energy and nutrients for 5–10 years children found in (Committee on Medical Aspects of Food Policy (1991)). The lunch portion of energy and nutrients intake corresponds to about 35% of the daily amount as suggested in (Estruch et al. (2013)). However, dietary recommendations for children vary depending on the age. Energy and nutrients requirements during childhood and adolescence change in fact as the child grows. So, 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. Therefore, following the suggestion of the European Food Information Center (European Food Information Council (2007)), the dietary recommendations should not be regarded as strict individual targets. For these reasons, rather than a reference single value for each item, we consider a range of possible values. These ranges are reported in Table 3. Note that, according to (Estruch et al. (2013)), the mediterranean diet is rich in proteins so that the range values for protein are higher than the reference value retrieved in (Committee on Medical Aspects of Food Policy (1991)). These ranges constrain the choice of the recipes to be considered in the schedule.

	Miminum	*Maximum*
Energy ($Kcal$)	500	700
Proteins (g)	0	28
Lipids (g)	0	40
Carbs (g)	60	80
Fiber (g)	5	15
Sugars (g)	0	40
Sodium (mg)	300	500

Table 3: Energy and nutrients range values for primary school children's lunch.

Some further constraints on monthly meal schedule are considered. They correspond 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 dishes like "lasagne" have to be present at least once in the menu monthly schedule, since they are particularly tasty for children.

A first constraint consists of 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 constraint refers to the weekly and monthly allowed repetition for dishes. 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 and each row corresponds to a recipe. In more detail, any dish (except "lasagne") may not be served at all in a week or in the month and may be served at most once in a week and twice in the month. On the contrary, "lasagne" has to be served exactly once in the month. An example of some rows of this table is reported in Table 4.

	Weekly min	*Weekly max*	*Monthly min*	*Monthly max*
Pasta with tomato sauce	0	1	0	2
Lasagne	0	1	1	1

Table 4: Weekly and monthly repetition constraints for pasta with tomato sauce and lasagne.

A third constraint regards some food categories repetition on weekly scale. Examples of such constraints can be found in (see Estruch et al. (2013)). We consider constraints on the following 11 food categories: *Pastas*, *Tomato pastas*, *No tomato pastas*, *Rice*, *Meat*, *Fish*, *Eggs*, *Dairy*, *Potatoes*, *Legumes*, *Salads*. As above, such constraints are built in a table of 2 columns and 11 rows, see Table 5. For example, meat has to be served at least once in a week but no

	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

Table 5: Weekly repetition constraints for some food categories.

more than 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.

3 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 Section 2, the schedule must be composed by choosing within a given set of recipes whose composition and serving size is fixed; moreover the schedule must satisfy some contraints related to a proper energy and nutrients intake and variety of food. Therefore, the problem consists of an optimal allocation of recipes over the 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 manufactoring 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))) .

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 menu that minimizes either the associated carbon or water footprint. The schedule is subject to several constraints related to the total amount of energy and nutrients ranges and 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 index, $j = 1, \ldots, 5$ 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,

[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.

- the first seven rows of Table 2 are stored in 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 Table 2 are stored in array A_F of size 2×71, so that the element $A_F(1, c)$ is the amount of water consumption to produce 100 g of ingredient c and the element $A_F(2, c)$ is the corresponding amount of greenhouse gas emissions;
- Table 1 is stored in 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 3 is stored in 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 daily intake, respectively;
- the first two columns of Table 4 are stored in 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 last two columns of Table 4 are stored in 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 5 is stored in 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.

On the basis of the above arrays it is easy to compute the amount of energy, nutrients and footprints associated to any recipe. The vector[4]

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

has size 7×1 and contains the total amount of energy and nutrients in the i-th recipe. For example, $i = 10$ corresponds to the recipe of pasta with tomato sauce as reported in the list of the dishes in Figure 1 at the end of the paper. Therefore

$$\frac{1}{100} \cdot A_I \cdot A_R(:, 10) = \begin{bmatrix} 171,46 \\ 6,17 \\ 24,32 \\ 4,02 \\ 6,08 \\ 2,01 \\ 45,95 \end{bmatrix}$$

These values are reported in the 10th row of the table given in Figure 1 at the end of the paper and similarly for each of the other recipes.

As well, the vector

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

[4]The notation $A_R(:, i)$ means the i-th column of array A_R.

has size 2×1 and contains the total amount of water consumption and greenhouse gas emissions needed to serve the i-th recipe. Again, for pasta with tomato sauce

$$\frac{1}{100} \cdot A_F \cdot A_R(:,10) = \begin{bmatrix} 250 \\ 261 \end{bmatrix}$$

Also these values are reported in the 10th row of the table given in Figure 1 at the end of the paper and similarly for each of the other recipes.

In order to formalize the model we need also to label any recipe as a first course (*First*), a second course (*Second*) or a side dish (*Side*). Moreover, each recipe has to be labeled according to the categories defined in Table 5 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 assignign to each label a proper subset of the dish indices.

The objective function for water consumpion or greenhouse gas emissions minimization is finally obtained as follows[5]

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

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

respectively.

Constraints on the k-th energy/nutrient must be satisfied for each day j of every week h and are expressed as follows

$$V_R(k,1) \leq \sum_{i=1}^{106} x(i,j,h) \cdot \frac{1}{100} \cdot A_I(k,:) \cdot A_R(:,i) \leq V_R(k,2)$$

for $k = 1, \ldots, 7$, $j = 1, \ldots, 5$ and $h = 1, \ldots, 4$.

Constraints on meal composition are considered for each day of every week and can be written as follows

$$\sum_{i \in I} x(i,j,h) = 1$$

for $j = 1, \ldots, 5$ and $h = 1, \ldots, 4$. The constraints are repeated six times for different subsets I, that is *First*, *Second*, *Side*, *Fruit*, *Bread* and *Vegs* subset of indices.

Constraints on weekly repetition are written for each recipe i and week h as follows

$$V_W(i,1) \leq \sum_{j=1}^{5} x(i,j,h) \leq V_W(i,2)$$

for $i = 1, \ldots, 106$ and $h = 1, \ldots, 4$.

Constraints on monthly repetition are written for each recipe i as follows

$$V_M(i,1) \leq \sum_{j=1}^{5}\sum_{h=1}^{4} x(i,j,h) \leq V_M(i,2)$$

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

for $i = 1, \ldots, 106$.

Constraints on weekly repetition for the 11 food categories are written for each category and week h as follows (constraints are written as an example for *Rice* category)

$$V_C(4,1) \leq \sum_{i \in Rice} \sum_{j=1}^{5} x(i,j,h) \leq V_C(4,2)$$

for $h = 1, \ldots, 4$.

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 contraints, the optimal monthly schedule problem can be formalized as

$$\min_{x \in F} f_{H_20}(x)$$

for a menu minimizing water consumption, and

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

for a menu minimizing greenhouse gas emissions.

4 Results and discussion

The solution of the optimization problem defined in the previous section has 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 6 while the one minimizing water footprint is given in Table 7. Fresh fruit and bread are served every lunch and are not indicated in the tables.

The total emission of greenhouse gases for serving recipes in Table 6 is $7,81$ Kg while the water consumed is equal to $16,50$ m^3. The total emission of greenhouse gases for serving recipes in Table 7 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 8 and 9.

The first and last columns of the tables report just the energy and nutrients ranges for children's school lunch as in Table 3. In the second and fourth columns the minimum and maximum value of energy and nutrients of daily intake within the monthly schedule are given. In the third column the monthly average value of energy and nutrients are provided. 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.

To stress the effectiveness of our result we make some further remarks. Schools of Rome with canteen service usually choose, independently of one another, their monthly schedule from the list of recipes indicated by the municipality. They use some common sense heuristics in order to obtain a varied menu. They do not evaluate the energy and nutrients content of each meal

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

Table 6: Monthly schedule that minimizes the total greenhouse gas emissions.

since the average intake over the month is somewhat ensured by the set of recipies indicated by the municipality. Moreover, since the mediterranean diet is known to be environmentally friendly (Estruch et al. (2013)), they do not consider the footprints as a discriminating factor when defining the monthly schedule. Therefore, the environmental impact of the monthly lunch 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 different schedules are considered, and this is the case of Rome. The average total emission of greenhouse gases of the monthly school lunch 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 of the school lunch monthly schedule, along with the strict ensuring of a proper intake of nutrients and energy according to scientific

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

Table 7: Monthly schedule that minimizes the water consumption.

recommendations. In more detail, the schedule proposed in Table 6 saves more than 40% of total emission of greenhouse gases and more than 20% in water consumption. On the other hand, the schedule proposed in Table 7 saves more than 20% of total emission of greenhouse gases and more than 35% in water consumption. It is remarkable that both footprints decrease with a significant reduction of the one that is optimized. Since the number of students in the primary school in Rome are about equal to 2800 as indicated by the National Institute of Statistics (Istituto nazionale di statistica, Italy (n.d.)) and the school year is about 9 month

	lower bound	*min*	*average*	*max*	*upper bound*
Energy ($Kcal$)	500	500,71	548,51	635,01	700
Proteins (g)	0	17,90	24,10	27,90	28
Fats (g)	0	16,52	22,59	29,83	40
Carbs (g)	60	60,45	66,79	79,15	80
Fiber (g)	5	6,12	8,33	12,56	15
Sugars (g)	0	17,83	22,59	27,15	40
Salt (mg)	300	300,35	337,30	472,42	500

Table 8: Daily minimum, average and maximum values of energy and nutrients for the monthly schedule that minimizes the total of greenhouse gas emissions.

	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
Fats (g)	0	15,83	20,55	32,19	40
Carbs (g)	60	63,66	68,97	79,15	80
Fiber (g)	5	6,12	8,05	12,12	15
Sugars (g)	0	18,06	22,43	27,79	40
Salt (mg)	300	300,48	361,95	467,67	500

Table 9: Daily minimum, average and maximum values of energy and nutrients for the monthly schedule that minimizes the water consumption.

long, if all the school in Rome would adopt the schedule proposed in Table 7, the total water saved in one year would be nearly 200000 m^3. On the other hand, if all the school would adopt the schedule proposed in Table 6,t he amount of gas emissions avoided would be about equal to 150000 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 recipies and new cookware.

The proposed method has some key features quite significant from a technical point of view. First of all, 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 repetions for recipes and food categories. 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 foodsystem from field to fork. Finally, the time span of the schedule can also be easily changed; for example one can consider weekly schedules as well as quarterly schedules.

It's worth noting that scalability of the model impacts on the number of variables and costraints 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 minutes. A key issue is instead the number of constraints that can make the problem unfeasible when unadvisedly chosen.

5 Conclusions

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

The goal of this work is to define a consumption pattern with reduced environmental impact. In more detail, a monthly school meal schedule requiring either a minimal consumption of water or greenhouse gas emissions is defined. The schedule has to provide a varied menu attractive for children with a proper intake of energy and nutrients. To this end, an optimization model is developed that selects, among a given set of mediterranean recipes, the monthly menu schedule that minimizes either the associated carbon or water footprint.

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

References

City of Rome. (2013). *Procedura per l'affidamento del servizio di ristorazione scolastica in autogestione: Allegato tecnico n. 2.* Retrieved from www.icgoffredopetrassi.gov.it/files/allegato_tecnico_2.pdf

Committee on Medical Aspects of Food Policy. (1991). *Dietary reference values for food energy and nutrients for the united kingdom* (Tech. Rep. No. 41). Department of Health, HMSO.

Deumling, D., Wackernagel, M., and Monfreda, C. (2003, July). *Eating up the earth: how sustainable food systems shrink our ecological footprint.* Retrieved 2015-09-17, from http://rprogress.org/publications/2003/ag_food_0703.pdf

Ercin, A. E., and Hoekstra, A. Y. (2012). *Carbon and water footprints: Concepts, methodologies and policy responses* (Vol. 4; Tech. Rep.). UNESCO World Water Assessment Programme.

Estruch, R., Bach-Faig, A., Kussman, M., Y. Yasmine Kandil, T. K., Vlachos, I., Koulochera, A., ... Ati, J. E. (2013). *Guidelines for mediterranean diet education in schools* (Tech. Rep.). European Union.

Eurispes. (2013). *Scheda cibo ed energia: un approccio sostenibile* (Vol. 4; Tech. Rep.).

European Food Information Council. (2007, March). *Making sense of guideline daily amounts.* Retrieved 2015-09-17, from http://www.eufic.org/article/en/artid/Making_Sense_of_Guideline_Daily_Amounts/

Food and Agriculture Organization of the United Nations. (2009).

Foster, C., Green, K., Bleda, M., Dewick, P., Flynn, A., and Mylan, J. (2006). *Environmental impacts of food production and consumption: a report to the department for food and rural affairs* (Tech. Rep.). Manchester Business School, Defra, UK.

Global Footprint Network. (2008). *2008 edition of the national footprint accounts for italy* (Tech. Rep.).

Heller, M. C., Keoleian, G. A., and Willett, W. C. (2013). Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: A critical review. *Environmental Science & Technology*, *47*, 12632 - 12647.

INRAN Food Composition Database. (2009). *Tabelle di composizione degli alimenti.* Retrieved 2015-09-17, from http://nut.entecra.it/646/tabelle_di_composizione_degli_alimenti.html

Istituto nazionale di statistica, Italy. (n.d.). *Istruzione, istruzione scolastica.* Retrieved from http://seriestoriche.istat.it

Jain, A., and Meeran, S. (1999). Deterministic job-shop scheduling: Past, present and future. *European Journal of Operational Research*, *113*(2), 390 - 434.

LCA Food Database. (2007). Retrieved 2015-09-17, from http://www.lcafood.dk/

Lozano, R., Carpenter, A., and Huisingh, D. (2015). A review of theories of the firm and their contributions to corporate sustainability. *Journal of Cleaner Production*, *106*, 430–442.

Lukas, M., Rohn, H., Lettenmeier, M., and C. Liedtke, K. W. (in press). The nutritional footprint e integrated methodology using environmental and health indicators to indicate potential for absolute reduction of natural resource use in the field of food and nutrition. *Journal of Cleaner Production.*

Mekonne, M. M., and Hoekstra, A. Y. (2010, December). *The green, blue and grey water footprint of farm animals and animal products* (Vol. 1; Tech. Rep. No. 48). Unesco-IHE Institute for Water Education.

Mekonne, M. M., and Hoekstra, A. Y. (2011, May). *National water footprint accounts: the green, blue and grey water footprint of production and consumption* (Vol. 1; Tech. Rep. No. 50). Unesco-IHE Institute for Water Education.

Mekonnen, M. M., and Hoekstra, A. Y. (2012). A global assessment of the water footprint of farm animal products. *Ecosystems*, *15*, 401-415.

Pairotti, M. B., Cerutti, A. K., Martini, F., Vesce, E., and D. Padovan, R. B. (2015). Energy consumption and ghg emission of the mediterranean diet: a systemic assessment using a hybrid lca-io method. *Journal of Cleaner Production*(103), 507-516.

Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., and bin Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, *76*, 106–115.

United Nations Environment Programme. (2012). *The critical role of global food consumption patterns in achieving sustainable food systems and food for all* (Tech. Rep.).

United Nations Environment Programme. (2015). *Agriculture & food.* Retrieved 2015-09-17, from http://www.unep.org/resourceefficiency/Default.aspx?tabid=78943

Vergé, X., Dyer, J., Desjardins, R., and Worth, D. (2009). Greenhouse gas emissions from the canadian pork industry. *Livestock Science*, *121*(1), 92 - 101.

Vermeulen, S. J., Campbell, B. M., and Ingram, J. S. I. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, *37*, 195-222.

World Wide Fund for Nature, Italy. (2009). *Footprint calculator.* Retrieved 2015-09-17, from `http://www.improntawwf.it/`

		Energy (Kcal)	Proteins (g)	Lipids (g)	Carbs (g)	Fibers (g)	Sugar (g)	Sodium (mg)	Water (liters)	CO2e (Kg)
1	Agnolotti with tomato sauce	426,71	16,98	15,57	58,16	2,80	5,69	410,20	423,60	0,313
2	Cream of chickpea soup with pasta	125,71	3,96	4,95	17,46	2,65	1,83	11,45	242,30	0,101
3	Cream of bean soup with pasta	117,31	4,11	4,35	16,50	3,16	1,68	10,55	242,30	0,101
4	Cream of lentil soup with pasta	117,31	3,93	4,35	16,68	3,39	1,65	10,55	242,30	0,101
5	Vegetable soup with pasta (summer)	144,56	5,99	5,85	18,12	2,73	6,05	77,35	172,58	0,132
6	Vegetable soup with pasta (winter)	142,26	5,61	5,83	17,99	2,81	5,63	76,15	172,58	0,132
7	Lasagna	302,01	14,78	16,51	24,97	1,76	6,13	111,90	699,98	0,349
8	Pasta with butter and parmesan	202,66	6,05	10,94	21,32	1,05	1,02	49,40	230,69	0,182
9	Pasta with pesto	187,40	4,92	8,60	23,71	1,70	1,89	1,33	319,87	0,183
10	Pasta with tomato sauce	171,46	6,08	6,17	24,32	2,01	4,02	45,95	250,00	0,261
11	Pasta with tomato and basil	169,31	5,98	6,16	23,90	1,82	3,60	38,40	248,56	0,259
12	Pasta with meat sauce	191,41	9,12	7,03	24,32	2,01	4,02	53,90	482,50	0,353
13	Pasta with vegetable ragout	175,16	6,21	6,19	25,11	2,33	4,80	56,85	252,19	0,262
14	Pasta with trout	169,66	8,33	5,27	23,61	1,77	3,31	17,50	222,28	0,309
15	Pasta with tuna	196,66	10,55	7,27	23,61	1,77	3,31	86,90	372,36	0,286
16	Pasta with vegetables	176,86	6,72	6,21	25,00	2,27	4,66	50,35	256,44	0,266
17	Pasta all'Amatriciana	220,53	9,41	10,31	23,90	1,82	3,60	321,30	325,62	0,331
18	Pasta with marinara sauce	148,66	4,25	4,75	23,61	1,77	3,31	7,90	222,28	0,245
19	Pasta tomato sauce and oregano	148,66	4,25	4,75	23,61	1,77	3,31	7,90	222,28	0,245
20	Fettuccine with tomato sauce	148,76	5,37	6,30	18,65	1,62	3,53	45,85	257,81	0,184
21	Pasta with zucchini	163,31	6,30	5,84	22,86	1,62	2,48	40,00	227,20	0,159
22	Pasta and potatoes soup	130,36	4,08	5,66	16,86	1,30	1,56	42,05	154,56	0,097
23	Pasta with mediterranean sauce	164,11	6,19	5,59	23,63	1,77	3,33	43,90	267,30	0,258
24	Pasta with ricotta and tomato sauce	181,31	6,16	6,95	25,02	2,01	4,72	31,55	288,26	0,281
25	Parmesan risotto	174,66	4,23	10,66	16,42	0,21	0,25	51,50	334,01	0,088
26	Rice and potatoes porridge	118,36	3,30	5,54	14,76	0,94	1,23	42,95	198,84	0,056
27	Tomato risotto	143,46	4,26	5,89	19,42	1,17	3,25	48,05	353,32	0,167
28	Saffron rice	124,51	3,20	5,48	16,60	0,26	0,43	33,30	317,64	0,055
29	Creamy pea risotto	134,11	4,28	5,54	17,88	1,52	1,83	81,70	324,08	0,111
30	Endive risotto	129,31	3,47	5,57	17,41	0,74	1,24	36,30	324,75	0,075
31	Pumpkin risotto	129,91	3,53	5,51	17,65	0,65	1,18	39,90	327,30	0,063
32	Zucchini risotto	132,61	4,16	5,54	17,62	0,65	1,39	39,90	327,30	0,063
33	Tortellini with butter and parmesan	456,86	16,89	20,31	55,01	1,80	2,54	413,20	402,14	0,227
34	Braised lamb with potatoes	545,91	36,39	28,52	38,55	2,70	0,90	157,50	715,98	0,194
35	Lamb cacciatore	278,96	32,04	16,78	0,00	0,00	0,00	144,00	606,23	0,166
36	Roast beef	133,86	19,83	5,65	1,09	0,39	1,09	49,70	1451,76	0,567
37	Roast pork	190,76	18,72	12,91	0,00	0,00	0,00	53,10	485,36	0,215
38	Roast turkey	159,06	26,85	5,29	1,09	0,39	1,09	74,00	407,76	0,178
39	Balsamic beef stew	157,42	18,28	9,13	0,34	0,00	0,30	48,16	1564,80	0,810
40	Roasted chicken leg	350,96	43,50	19,75	0,00	0,00	0,00	177,00	638,36	0,287
41	Breaded pork cutlet	237,71	21,12	14,14	7,00	0,34	0,45	105,54	544,06	0,225
42	Cod fillet croquettes	151,17	18,79	5,21	7,71	0,34	0,36	103,06	84,20	0,369
43	Hake fillet croquettes	151,17	18,79	5,21	7,71	0,34	0,36	103,06	84,20	0,369
44	Roasted turkey breast with lemon	167,50	27,10	5,30	3,05	0,12	0,07	61,28	409,75	0,181
45	Fried turkey breast	153,86	26,64	5,26	0,00	0,00	0,00	61,20	404,36	0,176
46	Dab fillets au gratin	140,86	19,48	5,52	3,61	0,17	0,34	150,00	59,21	0,362
47	Breaded dab fillets	190,22	22,47	7,24	9,45	0,46	0,71	204,66	139,46	0,372
48	Cod fillets au gratin	126,56	17,61	4,75	3,50	0,17	0,23	92,80	59,21	0,362
49	Hake fillets au gratin	126,56	17,61	4,75	3,50	0,17	0,23	92,80	59,21	0,362
50	Breaded bass fillets	190,22	22,47	7,24	9,45	0,46	0,71	204,66	139,46	0,372
51	Asiago cheese	178,00	15,70	12,80	1,00	0,00	1,00	380,00	253,00	0,230
52	Caciotta cheese	192,00	12,25	15,50	0,90	0,00	0,90	257,00	158,90	0,084
53	Crescenza cheese	196,70	11,27	16,31	1,33	0,00	1,33	245,00	222,46	0,118
54	Montasio cheese	205,50	15,15	16,10	1,00	0,00	1,00	378,50	253,00	0,230
55	Provolone cheese	187,00	14,05	14,10	1,00	0,00	1,00	430,00	253,00	0,230
56	Omelets	99,96	6,20	8,35	0,00	0,00	0,00	68,50	249,19	0,017
57	Beef burger	175,30	19,10	9,48	3,50	0,17	0,23	69,81	1465,96	0,569
58	Pork burger	196,00	17,93	12,36	3,50	0,17	0,23	87,81	502,96	0,220
59	Cod fillet burger	135,83	18,27	5,16	4,28	0,21	0,28	102,97	78,14	0,364
60	Hake fillet burger	135,83	18,27	5,16	4,28	0,21	0,28	102,97	78,14	0,364
61	Bass fillet burger	150,13	20,14	5,93	4,39	0,21	0,39	160,17	78,14	0,364
62	Mozzarella cheese	187,20	10,86	15,86	0,26	0,00	0,26	130,00	206,57	0,046
63	Fried chicken breast	152,06	27,18	4,81	0,00	0,00	0,00	41,40	404,36	0,176
64	Bread crumbed chicken breast	199,01	29,58	6,04	7,00	0,34	0,45	93,84	463,06	0,186
65	Beef meatballs with tomato sauce	182,90	19,51	9,64	4,69	0,49	1,41	73,01	1479,78	0,611
66	Meatballs with tomato sauce	206,96	20,05	11,97	4,99	0,58	1,71	100,91	1017,74	0,458
67	Baked meatballs of cod fillet	135,83	18,27	5,16	4,28	0,21	0,28	102,97	78,14	0,364
68	Beef meatloaf	175,30	19,10	9,48	3,50	0,17	0,23	69,81	1465,96	0,569
69	Cooked ham	107,50	9,90	7,35	0,45	0,00	0,45	324,00	240,00	0,218
70	Cooked ham (half portion)	53,75	4,95	3,68	0,23	0,00	0,23	162,00	120,00	0,109
71	Ham	134,00	12,75	9,20	0,00	0,00	0,00	1289,00	240,00	0,218
72	Ham (half portion)	67,00	6,38	4,60	0,00	0,00	0,00	644,50	120,00	0,109
73	Ricotta cheese with cooked ham	154,60	11,66	11,14	2,10	0,00	2,10	691,30	310,68	0,210
74	Escalope with ham and sage	152,64	22,19	7,13	0,02	0,00	0,02	294,84	1480,79	0,611
75	Beef escalope	139,48	20,10	5,33	3,07	0,12	0,09	37,12	1438,17	0,57
76	Pork cacciatore	176,36	17,10	12,01	0,00	0,00	0,00	65,70	485,36	0,215
77	Chicken breast strips	165,70	27,64	4,85	3,05	0,12	0,07	41,48	409,75	0,181
78	Beef strips	131,36	19,17	6,07	0,00	0,00	0,00	36,00	1448,36	0,565
79	Tuna in olive oil	96,00	12,60	5,05	0,00	0,00	0,00	158,00	300,15	0,081
80	Potato mould	321,60	16,41	15,82	30,46	2,12	2,44	277,39	383,73	0,166
81	Scrambled eggs	94,32	6,23	7,69	0,04	0,00	0,04	68,78	218,05	0,022
82	Sautéed chard	98,95	4,20	5,30	9,00	2,40	9,00	30,00	102,25	0,109
83	Boiled broccoli with olive oil	103,45	6,45	5,75	6,75	4,95	6,75	18,00	102,25	0,109
84	Stewed artichokes	77,95	4,05	5,30	3,75	7,50	2,85	199,50	115,00	0,429
85	Sliced carrots	80,25	1,11	5,20	7,67	3,10	7,67	95,10	92,60	0,020
86	Boiled string beans with olive oil	82,45	2,55	5,15	6,90	4,35	3,15	12,00	115,00	0,429
87	Fennels au gratin	76,72	2,77	5,62	3,83	3,41	1,65	30,00	109,97	0,027
88	Fried zucchini flowers	200,00	5,92	9,04	23,28	0,96	0,32	2,16	70,01	0,037
89	Fennel salad	55,75	1,44	5,00	1,20	2,64	1,20	4,80	90,10	0,018
90	Tomatoes salad	65,35	1,44	5,24	3,36	1,20	3,36	3,60	90,58	0,016
91	Mixed salad with cucumbers	70,95	1,43	5,30	4,68	1,91	4,68	35,60	94,44	0,045
92	Mixed salad	71,15	1,55	5,18	4,84	2,55	4,84	43,70	92,20	0,048
93	Green salad	58,25	1,05	5,14	2,10	0,91	2,10	6,30	83,29	0,057
94	Potatoes, carrots and string beans	100,95	1,91	5,15	12,57	2,74	3,32	35,20	99,78	0,130
95	Backed potatoes	266,95	4,35	11,75	38,55	2,70	0,90	13,50	109,75	0,028
96	Boiled potatoes with olive oil	151,45	2,70	5,15	25,35	1,95	0,60	10,50	109,75	0,028
97	Roast potatoes	266,95	4,35	11,75	38,55	2,70	0,90	13,50	109,75	0,028
98	Sautéed potatoes	151,45	2,70	5,15	25,35	1,95	0,60	10,50	109,75	0,028
99	Stewed peas	84,65	4,37	5,24	5,41	5,09	5,89	194,10	93,44	0,234
100	Mashed potatoes	210,97	5,59	9,57	27,55	1,95	2,80	57,56	152,71	0,063
101	Spinach with butter and parmesan	87,88	5,58	5,29	4,56	2,70	0,73	109,85	96,31	0,446
102	Boiled spinaches with olive oil	79,45	4,20	5,00	4,50	2,70	0,68	85,50	115,00	0,429
103	Zucchini au gratin	99,49	5,20	5,38	8,21	2,10	5,00	49,00	120,20	0,053
104	Sautéed zucchini	85,45	4,80	5,30	5,10	1,95	4,80	33,00	115,00	0,049
105	Bread	110,00	3,24	0,20	25,40	1,52	0,80	117,20	52,00	0,035
106	Fruit	63,33	0,88	0,20	15,48	2,70	15,48	2,67	135,60	0,047

Figure 1: List of recipes considered in the paper along with nutrients content, water consumption and greenhouse gases emission for their production.