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Article

Strategies and Tools for Eco-Efficient Local Food Supply Scenarios

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Abstract: Considering the wide demand for daily meals, the issue of the institutional food system has become very important in highly developed societies and, also, how it affects the flow of energy and matter within a territory. This research originates from a wide multi-disciplinary project aimed at developing a self-sufficient approach to improve the institutional food system in an area of Northern Italy. Thus, the aim of this research is to give some guidelines to implement ideal scenarios of food production, processing, consumption, and waste management at the local level. To that end, the organization of the supply and demand within the local institutional food system is inquired. A methodology has been developed to analyze the main energy flows and matter related to this catering, and to outline possible optimal scenarios. This methodology also allows to analyze case studies and to formulate improvements in order to reduce their energy consumption while exploring all the steps of the supply chain (considering the Life Cycle Assessment (LCA) approach). The use of quantitative indicators allows a comparison of the impacts related to the different steps characterizing the suggested scenarios. This paper presents results related to a test in the context of institutional catering in public schools.

Keywords: institutional food system sustainability; food supply chain; environmental impacts reduction; food waste management; bioregional approach; life cycle assessment

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1. Introduction

The research presented here is related to the first results of one work, which is part of a wider multidisciplinary project called "Bioregione".

Peter Berg was the first person to define the theory of bioregionalism. According to him, it can be defined as "a geographic area defined by natural characteristics, including watersheds, landforms, soils, geological qualities, native plants and animals, climate, and weather. These characteristics are continuous; in other words, when there are changes in these characteristics you've gone from one bioregion to another […]. A bioregion is a geographic terrain and a terrain of consciousness. It is a cultural idea based on characteristics usually associated with the natural sciences" [1]. The term "bioregionalism" is also described by him as proactive, based on forming a harmony between human culture and the natural environment.

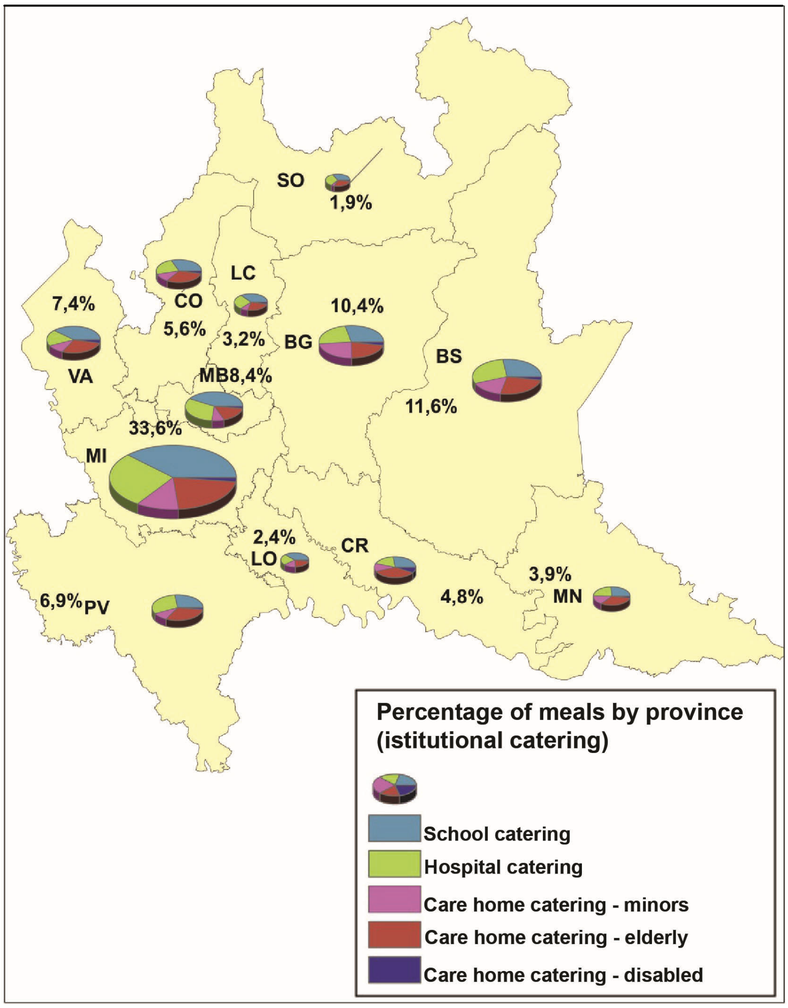
With these definitions in mind, in this research we consider a "bioregion" the area required to achieve the self-sufficiency in terms of food supply. In this specific case, the area includes Lombardia, a region of North Italy and the municipality of Novara (a town in Piemonte, the region bordering Lombardia to the west). Of course, our bioregion is not totally self-sufficiency in terms of food supply if, for example, the fish and citrus production are considered. The municipality of Novara was chosen due to the rice production, which is predominant in that area. In this paper when the term "local" is mentioned, it refers to this bioregion.

Thus, the project "Bioregione" aimed to develop sustainable policies and measures to optimize the issue of institutional catering in a bioregion. This optimization involves many aspects mainly related to economy, agriculture, and environment. At the same time it also involves academies, institutions, companies, *etc.* Hence, the research is not a Life Cycle Assessment but it is a study that suggests strategies to check the food self-sufficiency of a bioregion; we do not present the results of a Life Cycle Assessment (LCA) but we rather show the development of a tool to verify and improve the self-sufficiency. To reach this goal, we are developing a database to bring together a bioregion food demand and the food local supply. The model presented in this research (the Food Chain Model (FCM)) takes care of this aim, maximizing the economic benefits, and reducing environmental impacts. In this framework, our work package is devoted to the analysis and optimization of the main flows of matter and energy related to the several steps of the food chains of the institutional catering in Lombardia and Novara.

The impacts of institutional catering are not negligible. Considering the daily demand of meals, this activity significantly affects the energy and matter flows within a territory. In fact, it was estimated that during the last 30 years, in Italy, the outdoor food consumptions generated an increasing of the related costs of about 79% [2]. The same source also estimates that in 2020 Italians will increase, by 50%, their need for outdoor food consumption. Thus, the main aim is to understand how these meals can be supplied with the minimum consumption of energy and guarantee, at the same time, food quality and benefits for the local agricultural territory.

Figure 1 describes the importance of the demand for meals provided by the institutional food system Lombardia.

Figure 1. Percentage of meals by province.



In Lombardia, Milano is the town that requires the greatest amount of meals served by the institutional, representing a percentage of 33.6%. In all the provinces of Lombardia, the school sector is responsible for the highest percentage of meals compared to other public services. In particular, in Milano, the school sector requires about 35% of the total number of meals required by the institutional catering. The source of data on consumptions refers to a survey conducted in 2012 and 2013 by DiSAA (Department of Agricultural and Environmental Sciences-Production, Landscape, Agroenergy, University of Milan).

The supply chains related to school catering were analyzed in the framework of several national and international studies, such as the European project innovative Public Organic food Procurement for Youth (iPOPY) [3,4]. The latter underlines the necessity for major control by the stakeholders involved in supplying institutional catering on the overall food chains [5].

For these reasons, we decided to focus the experimental phase of the research presented in this paper on school catering. Nowadays, in this sector, there are no policies to encourage the use of local products: one of the aims of this research is, thus, to promote these actions.

The structure of the paper follows these main points:

- The development of a methodology to analyze the main energy flows and matters related to school catering;

- The application of the methodology to some case studies in order to reduce the energy consumption exploring all the steps of the supply chain (considering the LCA approach);
- The development of a methodology to quantify the food waste in some case studies;
- The outlining of possible optimal scenarios.

2. Methodology

To outline optimum scenarios of production, processing, consumption, and waste management, it has been necessary to streamline the food chains, retracing all the stages of the life cycle of each type of food.

Life Cycle Assessment is a method that provides analysis in line with the aim of this research. In the international scene, there is a great deal of research about the use of the Life Cycle methodology for the analysis of the food chains. The aims of these analyses could be the comparison between the overall impacts of different food chains, as well as the comparison between single phases.

Different researches have been investigated regarding the method used to verify the sustainability of the food system [6–17] and, in particular, about the school food systems [18–20].

An analysis of these researches reveals that the LCA approach is a useful method to analyze the environmental impacts of different stages of the food supply chains and that is the reason why the LCA approach has been chosen. Moreover, the LCA method has also been used in literature to quantify the flows of mass and energy [8], to suggest optimal scenario [6], and to compare different chains [11]: all of these kinds of analysis have been carried out in this research, using the same approach. In addition, the SimaPro tool (the leading LCA tool) is often used to quantify the environmental impacts in the food chains, as shown in [6,10,12,13]. As will be explained in the next section, SimaPro allows measuring the environmental impacts of different products or services across all life cycle stages.

Considering the Life Cycle Assessment, the methods and tools presented in this research support two general stages of evaluation, an inventory of inflows and outflows in the main stages of the supply chain, and the impact assessment starting from inventory data and indicators.

The methodology suggested in this paper is articulated in the following stages:

- Identification of a sample of case studies served by institutional food systems and inventory of the main foods in the menu. The case studies have been chosen in Lombardia, as well as the institutional food systems. The sample includes three kinds of schools: two kindergarten classes (in Italy, for children ages 3 to 6), two primary school classes (in Italy, for children ages 6 to 11), and two secondary school classes (in Italy, for boys and girls ages 11 to 14). In Section 3.1, all the details about the choice of these case studies will be shown;
- Individuation of the main steps of the overall chain (such as production phase, transformation, processing, and so on) for some foods of the menu. In this research, only the foods that could be produced at the local scale have been taken into account. In fact, one of the main aims of the research is to give some guidelines to implement ideal scenarios of food production, processing, consumption, and waste management at the local level;
- Data integration: if there is no data available for some steps of the food chain, it is necessary to complete the information with data coming from monitoring/surveys. The approach adopted in this research provides surveys and monitoring in case of missing data about some steps of the food supply chain. For example, during the test of the methodology in the framework of schools

catering, it has been necessary to quantify the waste of food by an on-site survey. The waste survey has been developed in order to calibrate data found in technical literature with specific information concerning the local context and the peculiarity of the case studies;

- Elaboration of a Food Chain Model (called FCM in the following) and environmental impact assessment: elaboration of a database able to quantitatively describe all the steps of the food chains and to evaluate the environmental impacts of each step by some impact indicators. FCM is based on the LCA approach and its development has been supported by the software for the life cycle analysis SimaPro [21] and by other databases connected to it [22,23];
- Elaboration of different scenarios (using the FCM database) in order to optimize the relationship between the local demand and supply, reducing energy and matter waste. The FCM model has been developed and applied to suggest optimal scenarios starting from a quantitative assessment of the environmental impacts of each step of the foods supply chain. In this research, the foods contained in the menu of the case studies have been taken into account and analyzed.

Life Cycle Assessment (LCA) is globally recognized as the leading method to measure product sustainability, as it can evaluate a wide range of metrics and provide a deeper understanding of impacts, from cradle to grave. SimaPro enables to analyze and monitor the sustainability performance of products or services. It is easily possible to analyze life cycles in an organized and transparent way. Using SimaPro, it is also possible to measure the environmental impacts of different products and services across all life cycle stages. It shows different environmental impacts in all aspects of the supply chains, from extraction of raw materials to manufacturing, distribution, use, and disposal [21].

Further details about the stages of the methodology will be given in Section 3. The following Section also describes methods and tools adopted in our research.

3. Application of the Methodology

The points listed in the Section 2 are better described and applied to case studies.

3.1. Identification of a Sample of Case Studies Served by Institutional Food System and Inventory of the Main Foods in the Menu

On the basis of the consideration explained in the previous Sections 1 and 2, a sample of case studies has been identified. The sample is necessary because of the need to have specific data (menu and foods) in order to verify the applicability of the FCM and to test the methodology for the waste quantification (see Section 3.3). Up to now, we worked on a small sample of schools, postponing the enlargement of the sample to the near future.

As already stated, the case studies have been chosen in Lombardia, as well as the institutional food system. The case studies are located in Milano, as it is the town that provides in absolute the most out-of-home eating throughout the bioregion considered. In addition, the menu is the same in all the schools of the city because the company that manages the meals is always the same, as well as the portions depending on the age. For these reasons, although not numerically representative, the sample may represent a reasonable average reference. At a later stage of the research a major number of case studies will be analyzed.

The sample includes a kindergarten (in Italy, for children ages 3 to 6), a primary school (in Italy, for children ages 6 to 11), and a secondary school (in Italy, for boys and girls ages 11 to 14). The total number of students is about 132 (the number is not exact because, during the survey, from day to day, there were some absent students). The case studies have been chosen considering subsequent classes every 2 years.

During the survey, an analysis of the weekly menu was carried out and all the foods were classified as described in Table 1, in descending order considering the weekly amount, in grams, per child.

Table 1. Weekly amount of food per child in the school menu. The lines in gray indicate foods that could be produced at the local scale (inside Lombardia).

Food	Weekly Amount (grams per child)
Bread	250
Apple	200
Orange	200
Pasta	100
Tomato sauce	100
Courgettes	80
Ravioli	70
Chicken breast	65
Beef	65
Carrots	55
Parboiled rice	50
Codfish	50
Extra virgin olive oil (*)	41
Cheese	40
Peas	40
Fennel	40
Corn meal	35
Salad	25

(*) olive oil production is present in region Lombardia, but in small quantity. For this reason, conservatively it is not taken into account.

The foods not locally producible will not be considered (in the specific case: oranges and oil) as one of the main aims of the research is to give some guidelines to implement ideal scenarios of food production, processing, consumption, and waste management at the local level. Thus, considering the context of bioregionalism, foods that can be produced only in other regions are not interesting for the purpose of research. In the school menu of Table 1, only about the 30% of the foods that could be produced in Lombardia were really produced there, as there are no policies that encourage local products. That is why one of the aims of the research is to promote actions able to improve the self-sufficiency of the bioregion and, consequently, to reduce the environmental impacts. Moreover, the foods with several transformation steps have also not been taken into account due to the necessary level of approximation in the chain assessment (in the specific case: ravioli).

Thus, the analysis is carried out on the most relevant foods considering the weekly amount, in grams, per child. This choice was made to verify the environmental impacts of some of the most common food in a menu of an institutional food system.

3.2. Food Chain Stages

For each food on the menu, different stages of the supply chain have been identified considering the main steps of all the life cycle, starting from the production phase up to the end of life (waste management). The main stages common to almost all foods are:

- Production phase;
- Transportation phase (from the production site to the processing one);
- Processing phase;
- Storage phase;
- Transportation phase (from the storage site to the cooking one);
- Cooking phase;
- Packaging phase;
- Transportation phase (from the packaging site to the consumption one);
- Consumption phase;
- Waste production and management.

In this first phase of the research, we decided to identify the most significant phases of the supply chain of each food of the menu (see Table 3) by their energy impacts.

The compilation of the FCM model includes, also, the knowledge of the amount of waste. In order to be able to retrieve these data, a methodology has been implemented and tested (see Section 3.3).

3.3. Data Integration: The Survey for Food Waste

In the first application, we referred to data from technical literature [8,23–29], to the software SimaPro [21], and to databases connected to it [22,23]. The only exception was that related to waste production after food consumption, as it strictly depends on users' behavior and habits. These data were collected by a survey aimed to estimate the ratio between the food provided and the food rejected. This survey was necessary due to the specificity of the users considered (students). Starting from data found in literature about the amount of waste, the survey aims to better calibrate the general data and to get specific information about the waste concerning the case studies. In this way it has been possible to complete our FCM with specific data related to the case of studies. The results of the survey are in line with other recent and similar research, which revealed that about 40% of the food goes straight into the garbage [30]. In this case, the analysis takes into account ten primary schools for three weeks. The catering company weighed the leftover food that remained in the dishes of the students and it estimated, in three weeks, a food waste amounts up to 143 tons (equal to about 40%).

In our case a visual survey of the food left in the dishes for each portion (first course, main course, and dessert) by each student was done for a certain period. As will be stated in the next paragraph, the method has been tested on a sample served by an institutional food system for a specific period of time:

- Kindergarten: from 21 to 25 January, 2013 (2 classes of about 22 students, 5 lunches);
- Primary school: from 26 to 30 November, 2012 (2 classes of about 22 students, 5 lunches);
- Secondary school: 26 and 28 November, 2012 (2 classes of about 22 students, 2 lunches);

The quantification has been done considering these indicators:

- 0, if in the dish there is no waste;
- 1/3 or 2/3, if there is some waste (the indicator depends on the visual quantification of the food in the dish);
- 1, if, in the dish, there is the whole meal.

Following is a part of the table used during the survey (Table 2).

Table 2. Part of the table used during the survey.

Week Day 1																
Student	**First Course**				**Second Course**				**Side Dish**				**Fruit**			
	0	**1/3**	**2/3**	**1**	**0**	**1/3**	**2/3**	**1**	**0**	**1/3**	**2/3**	**1**	**0**	**1/3**	**2/3**	**1**
student 1			X					X				X				X
student 2	X							X		X					X	
student 3	X					X			X							X
student 4				X			X				X				X	
student 5	X				X							X				X
…																

This first qualitative evaluation was translated in a quantitative one. Each whole portion of cooked food was weighed during the survey and, then, the waste was quantified in grams proportionally.

In summary, the final evaluation of the waste follows these steps:

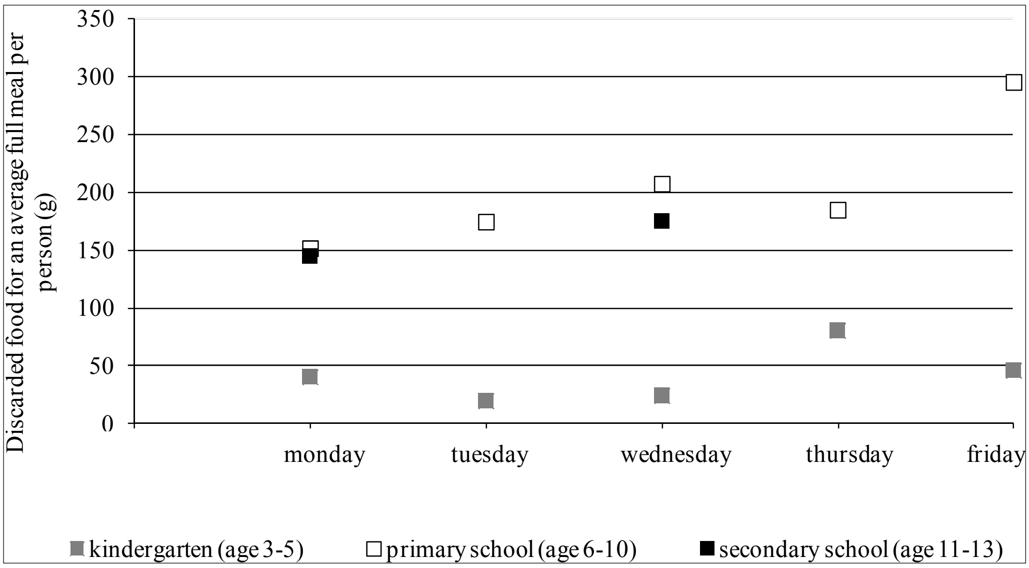
- Visual assessment of waste and quantification in fractions (Table 2);
- Estimation of the weight of waste in terms of mass (in grams).

The following points are stressed:

- The company that provides the food service gave the net and raw weight of the foods of the menus for each case of studies;
- The portion of each food depends on the age of the students (secondary school > primary school > kindergarten);
- Each whole portion of cooked food was weighed during the survey;
- The food waste was visually evaluated in third parts (0; 1/3; 2/3; and 1) and, then, was proportionally quantified in grams during the survey;
- The menu monitored during the survey was the same in each case studies (and, thus, also the food);
- The menu is fixed and there is not the possibility of choice of alternative dishes excluding special diets that were not considered in this survey;
- In the kindergarten fruit is served as an appetizer (snack), while in the other schools is served at the end of the meal.

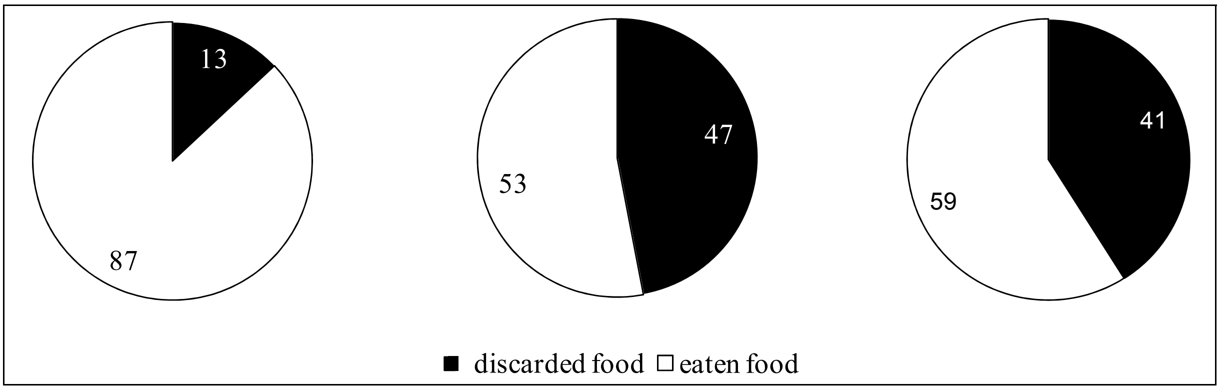
Figure 2 shows the overall results of the survey in the three monitored schools during the week under review; the food waste in grams per person for each day are represented as the average value between the two classes monitored for each school.

Figure 2. Monitoring results (kindergarten, primary school, and secondary school).



The survey also shows the percentage of discarded food and eaten food in the three schools (Figure 3).

Figure 3. Percentage of discarded food and eaten food in the kindergarten (left), primary school (middle), and secondary school (right).



These results demonstrate that a significant amount of food is wasted at the end of the school food service. Further research related to its reduction and to its correct and efficient management is recommended.

3.4. Food Chain Model (FCM) and Environmental Impacts Assessment

The following paragraphs illustrate the last two points of the methodology described in Section 2. The first one (Section 3.4) shows in detail the FCM and its application to an experimental case study. The second (Section 3.5) regards the use of FCM to define scenarios for improvement.

As already mentioned, FCM is a database able to quantitatively describe all the steps of the food chains and to evaluate the environmental impacts of each steps using some impact indicators. It also allows the development of optimal scenarios starting from a quantitative assessment of the environmental impacts of the foods supply chain.

The final results of this paper report the application of FCM in its actual state of advancement. The analysis of the food of the menu of the case studies has been carried out. The aim of this analysis is, thus, to test the effectiveness of the FCM model. As the preliminary phase of data collection has not been completed yet, the numerical data reported a partial value. It is helpful, in any case, in the evaluation of the applicability of the model to develop improving scenarios. In particular, information about the practices of cooking in the cooking centers has not been collected yet and data relating to domestic cooking has been used [9]. Regarding the transportation phase, a hypothetical distance between the nodes of the supply chain, equal to 250 km, has been adopted.

Future insights will cover the complete knowledge of the entire supply chain, including the actual distance between nodes, the energy costs of cooking, the managing (management) of the spaces in which foods are consumed, and the processing related to the waste management system.

The FCM also gives the possibility to study the different steps of the supply chain through some impact indicators. Considering the aims of the overall project, in this first phase of our work package we adopted the following energy-environment indicators:

- The main indicator used to quantify the environmental impacts refers to the accounting of renewable and non-renewable primary energy, as CED (Cumulative Energy Demand). This indicator allows to quantify the energy input in each stage;
- The other indicator adopted in the FCM model is the Global Warming Potential in a range of permanence in the atmosphere of 100 years (GWP_{100}). It expresses the amount of greenhouse gases emitted in the processes of the supply chain (kg CO_2 equivalent), from production to consumption.

The choice of these two indicators comes from the awareness of some agro-ecological indicators adopted in previous researches, such as the ones of the project called Agro-ecological indicators for organic agriculture (INDIA) [5], in which an analysis of a representative number of organic farms in Lombardia has been carried out.

The aim of our study needs to choose indicators able to allow the quantification of the environmental impacts related to all the stages, such as the primary energy accounting and the nitrogen flow accounting. The current state of development of the FCM takes into account the two mentioned indicators; future developments will concern the renewable component and the integration of the nitrogen balance in the accounting of greenhouse gas emissions.

In order to evaluate and compare the environmental impacts of each food on the menu of the case studies, it has been also necessary to define functional units. The data collected in the database has been organized in such a way to easily move from a functional unit to another one. The kg of food product has been used as reference value to analyze the menus of the case studies. While a more suitable functional unit, able to describe the nutritional values of foods, could be adopted to outline optimal scenarios in order to guide the local supply and demand of food (for example, the protein content in grams could be considered as functional unit if chicken and veal are compared (see Figure 6).

The development of the FCM has been supported by SimaPro [21], by databases connected to it [22,23], and by data collected in the scientific literature. In particular, the analysis of the embodied energy in products used as nutrients refers to the Swiss data bank, Ecoinvent [22], as well as the analysis of the transportation phase. Field production storage and food processing refer to the database LCAfood [23] and to other scientific publications and reports about environmental product declarations [28,29].

LCAfood collects information related to Danish companies and local productions in the context of Northern Europe. The data are suitable for this preliminary evaluation phase of the FCM in order to verify the correct operation of the model. The data will be updated about the on-field production, by adapting the yields and energy/material budgets with characteristic values of Northern Italy.

All the information of the database is associated with the amount of mass of the foodstuff adopted in the menu. The energy required to the transport phase and storage is expressed in unitary value ("energy per km" for transport, "energy per day of permanence" for storage). In this way, during the filling out of the model, it is possible to enter the distance between the different nodes of the supply chain and the time interval of food storage. The database collects information about different types of cultivation in order to assess the environmental impacts of different modes of agricultural production according to the period of the year (in open field or in a greenhouse).

3.4.1. Database Compilation

The model is made up of a spreadsheet linked to a database.

The information in the database is structured in such a way to allow the user to perform the compilation of the model through the following activities:

- Identification of the foods listed on the menu and indication of the weekly amount, per person, and the amount of waste;
- Identification of the processing stages related to the food chain, for instance in field production, transportation, processing, storage, meal preparation/cooking, waste management;
- Identification of the distance between the nodes of the supply chain (blue boxes in Table 3);
- Formulation of optimal scenarios by choosing alternative procedures related to the supply chain activities (e.g., by reducing the distance between the nodes of the supply chain, by changing the transportation system, by changing the infield cultivation mode and storage time).

3.4.2. Identification of the Environmental Impacts

Table 3 shows the results of the application of the FCM considering the main foods selected from the menu of the case studies. The colors associated to the different steps of the supply chain give some indications on the main variables that need to be considered.

In light blue are marked the fields in which the cultivation mode could change (convectional or organic farming, cultivation in greenhouse or in open field, *etc.*).

Areas highlighted in blue are related to the transportation stages. Editing the model, the transportation system and the distance must be specified (in the case study, a distance of 250 km between all nodes of the supply chain has been considered).

Highlighted in green are those processes in which the time of storage is relevant.

After entering the information about the menu (weekly amount of food, methods of production, processing, and transportation system), FCM processes the environmental burden of the relevant steps of the supply chain in terms of the indicators adopted (CED non-renewable, GWP_{100}).

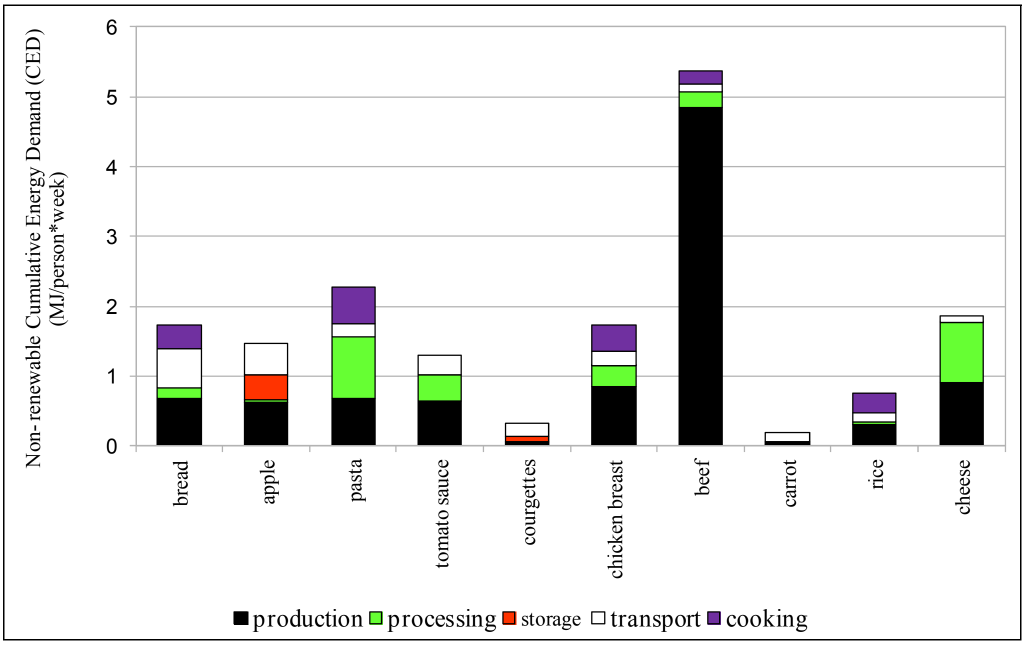
Table 3. Some of the results extracted from the Food Chain Model (FCM). The table shows the impacts related to the main stages of the supply chain related to some of the foods of the case study menu (the distances between the nodes is 250 km/node). The sources used to compile the database are associated with individual numerical values for the Cumulative Energy Demand (CED) and the Global Warming Potential (GWP_{100}): a [23], b [28], c [29], d [8], e [25].

Foods	Weekly Amount (kg)	Chain Stages	CED (MJ)	GWP_{100} ($kgCO_2eq$)
Bread	0.25	Wheat production (conventional)	0.68(a)	0.179(a)
		Grain transport	0.219(a)	0.014(a)
		Meal production	0.149(a)	0.028(a)
		Bread production	0.331(a)	0.020(a)
		Transport to the catering site	0.341(a)	0.023(a)
		Total	1.72	0.27
Apples	0.2	Field production (conventional)	0.627(b)	0.040(b)
		Transport to the factory (km)	0.273(a)	0.018(a)
		Cold storage (200 days)	0.358(b)	0.023(b)
		Packaging	0.031(b)	0.002(b)
		Transport to the catering site (km)	0.176(a)	0.011(a)
		Total	0.15	0.1
Pasta	0.1	Field production (conventional)	0.680(c)	0.084(c)
		Grain transport	0.088(a)	0.006(a)
		Meal production	0.310(c)	0.022(c)
		Pasta production	0.430(c)	0.,027(c)
		Packaging	0.150(c)	0.010(c)
		Transport to the catering site	0.088(a)	0.01(a)
		Cooking	0.530(a)	0.030(a)
		Total	2.28	0.18
Tomato Sauce	0.1	Field production (conventional)	0.651(e)	0.063(e)
		Transport to the factory	0.19(a)	0.003(a)
		Production in the factory	0.367(e)	0.033(e)
		Transport to the catering site	0.088(a)	0.006(a)
		Total	1.29	0.1
Courgettes	0.08	Field production (conventional)	0.046(a)	0.005(a)
		Transport to the factory	0.070(a)	0.004(a)
		Stationing in factory	0.068(a)	0.005(a)
		Washing and packaging	0.020(a)	0.00004(a)
		Transport to the catering site (km)	0.109(a)	0.007(a)
		Total	0.31	0.02
Chicken Breast	0.065	Farm production (conventional)	0.850(a)	0.158(a)
		Transport to the slaughterhouse	0.057(a)	0.004(a)
		Processing in the slaughterhouse	0.288(a)	0.037(a)
		Transport to the wholesale	0.057(a)	0.004(a)
		Stationing in the wholesale	0.002(a)	0.001(a)
		Transport to the catering site	0.088(a)	0.006(a)
		Stationing in the cooking place	0.003(a)	0.0002(a)
		Cooking	0.377(d)	0.076(d)
		Total	1.72	0.29

The application of the FCM to the weekly menu allows the calculation of the environmental impacts of the different foods. The supply chains with the highest impact and the relative impacts of each step can be identified.

Figure 4 shows the value of non-renewable CED of some foods on the menu of the case studies. The data is aggregated for food, considering part of the supply chain (from the production stage to the cooking stage). In particular, data has been aggregated into the following macro-activities: production, processing, transport, and storage. The figure clearly shows the high environmental impacts due to the beef consumption.

Figure 4. Non-renewable CED (Cumulative Energy Demand) of some foods on the menu of the case studies.



Considering the processing phase, the largest environmental impact in terms of non-renewable energy is due to cheese and pasta consumption.

Considering storage, the only relevant value is in the supply chain of apples, as a storage time in the company of 200 days has been assumed.

About the transportation phase, the data is not representative of the real situation. As already stated, the distance between nodes was fixed hypothetically to 250 kilometers.

3.5. Elaboration of Different Scenarios by Using the FCM

Starting from the results of the previous assessment, it is possible to identify the steps of the supply chain in charge of the greatest environmental impacts and to propose different scenarios.

The potential improvements (according to the major impacts recorded) could affect different areas (the stage of production, transport, processing, food preparation, consumption and waste management).

For example, suggested improving interventions could include:

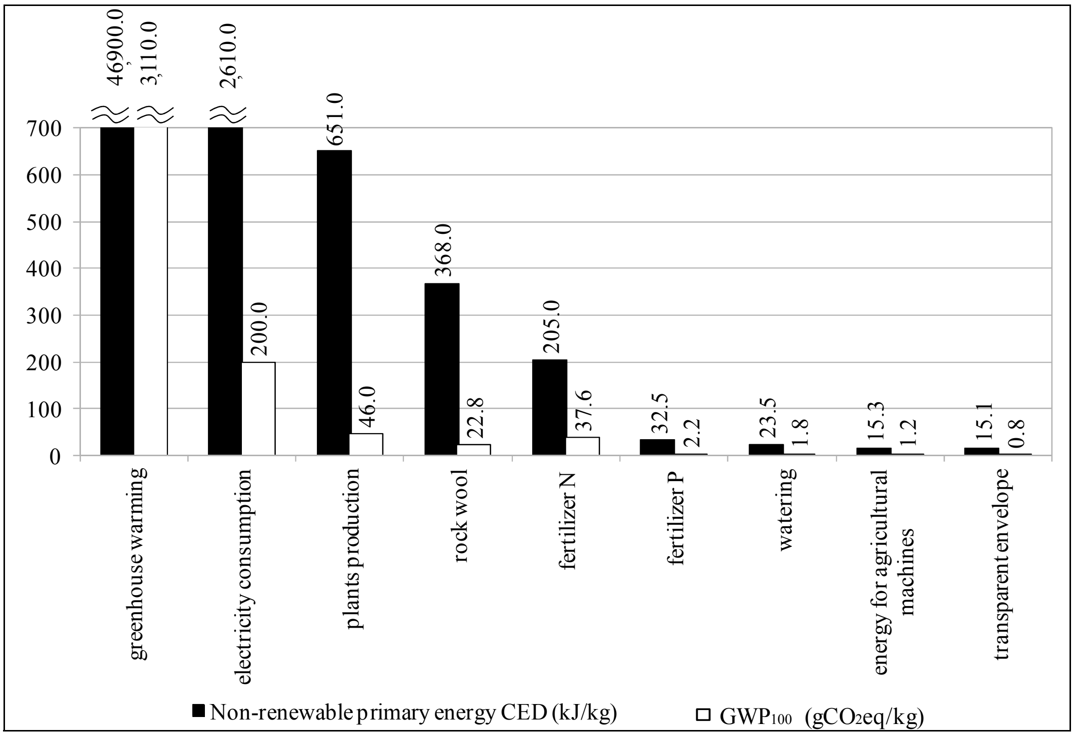
- A greater use of seasonal products;
- The choice of different types of production, conventional or organic;

- The choice of different foods with the same nutritional contents;
- The reduction of the distance between the different steps of the supply chain;
- The choice of different systems of waste management.

As example, some of the items just listed are described below.

In regards to the first point, a greater attention to the seasonality of the products would be possible, for example, using FCM to quantify the different amount of energy used for cultivation in greenhouses and in open field. The foods more sensitive to seasons are especially fruits and vegetables. In the case of tomatoes, for example, in greenhouses the cultivations can lead to a greater increase in energy consumption (40,000 tons of tomatoes are annually imported from Holland to Italy out of season). Figure 5 shows the breakdown of energy consumption related to the production in greenhouse of tomatoes (Northern Europe, Denmark). The non-renewable primary energy used to produce 1 kg of tomatoes in a greenhouse would amount to 50.82 MJ (46.9 MJ are due to electricity consumption and greenhouse heating [23]), while an open field crop in Southern Europe registers values of about 3 MJ/kg [24].

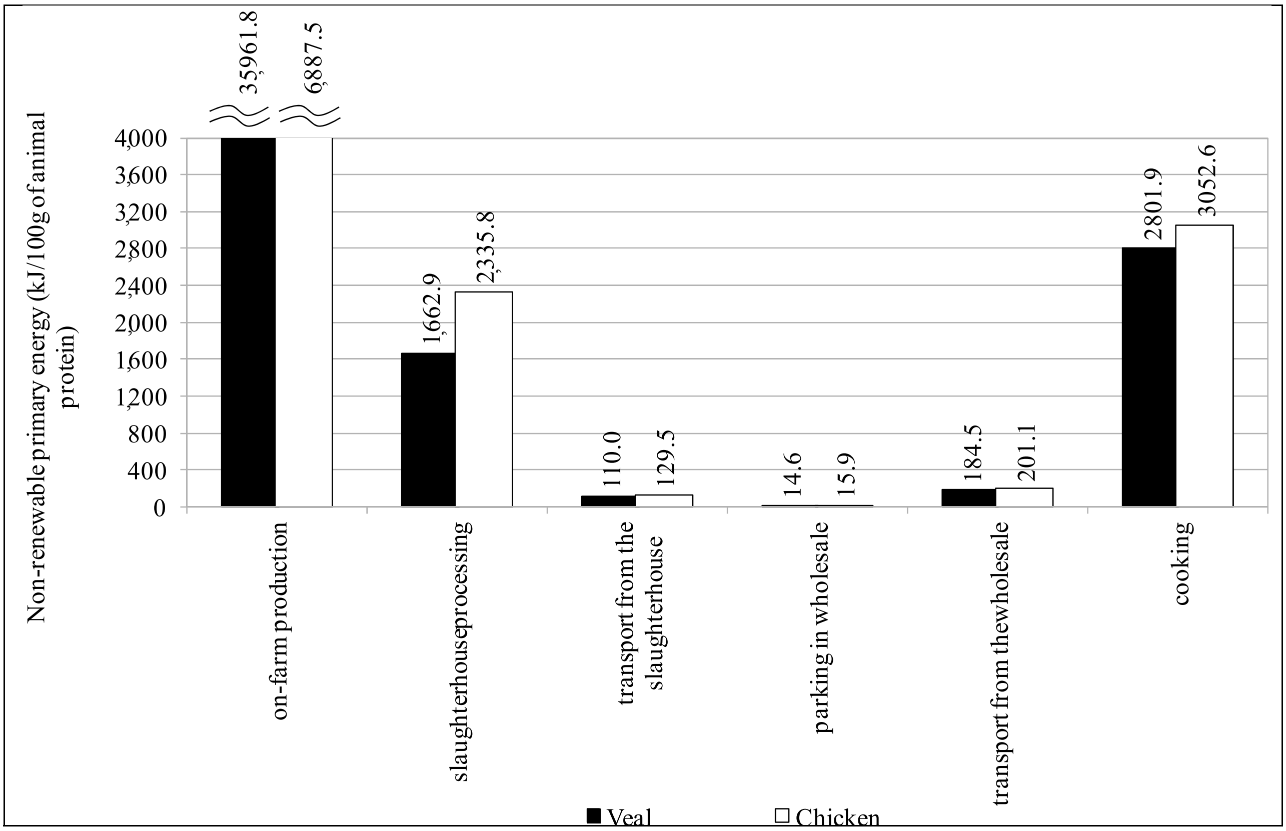
Figure 5. Non-renewable primary energy used to produce 1 kg of tomatoes in greenhouses in the Netherlands and GWP_{100}.



Regarding the second point, some kinds of organic cultivation imply a lower embodied energy compared to conventional crops, such as in the case of wheat and bread. According to the procedures of conventional cultivation, the production of a kg of wheat requires an amount of energy equal to 2.46 MJ, while in the case of biological crops would require 1.74 MJ [27], recording a 30% decrease.

Considering point 3, "choosing different foods with the same nutritional contents", Figure 6 shows what would happen by substituting poultry meat to the beef used in the menu (the amount of poultry meat ensures the same amount of protein relative to the beef replaced). The quantities shown in the graph refer to 100 g of protein. The comparison between different meats, considering the same protein content and the same distance between the chain nodes, shows that the greater contribution due to the transport phase and cooking (due to the greater amount of mass for protein content in the chicken chain) is contrasted by a considerable reduction of energy consumption in the production phase, at around 70%. The adoption of the amount of protein as a reference functional unit is a choice aimed at making the most effective and simple menu selection on the basis of the daily requirement [24]. This option is made possible as the FCM model has information relating to nutritional values of the products and to the environmental impacts of each steps of the supply chain.

Figure 6. Non-renewable primary energy for the same amount of protein in the food chain of veal and chicken [23].



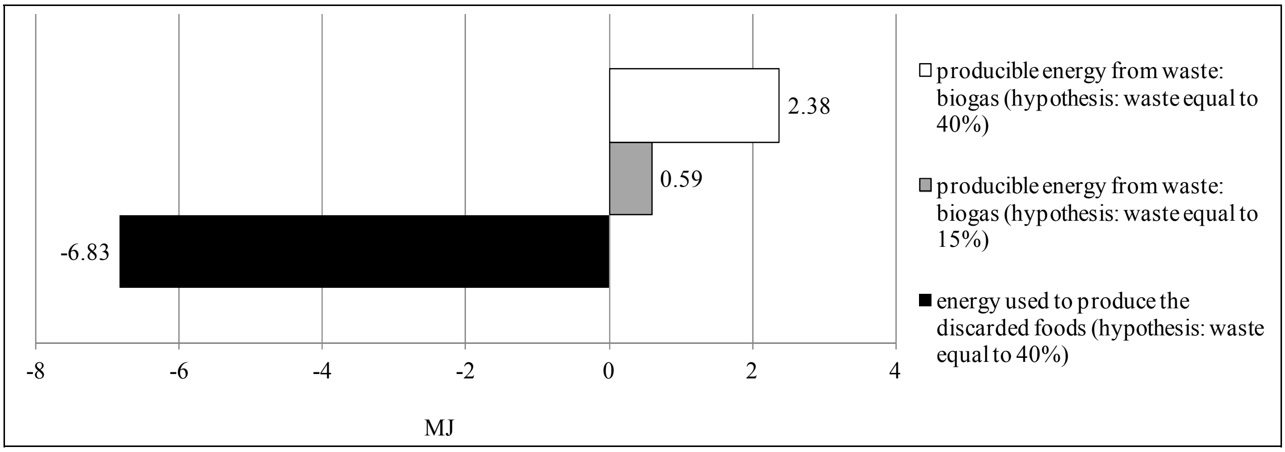
Regarding point 4 on the list, the distance between nodes was fixed hypothetically to 250 km. Changing the overall distance between the nodes of the supply chain of each product from 50 km to 1,000 km, the incidence on total energy consumption of the menu will change from 4.5% (50 km/node) to 43.7% (1,000 km/node). By focusing on the menu of the case studies, products with less values of energy, due to the production and processing phases, consume more energy in the transportation phase.

In the case of beef, for example, the incidence varies from a minimum of 0.4% (50 km/node) to a maximum of 8% (1,000 km/node). In the case of chicken it varies from 2.6% (50 km/node) to 43.7% and with courgettes from 20.2% (50 km/node) to 83.35% (1,000 km/node).

In regards to point 5, "choosing different systems of waste management", the data entered in the database, integrated with the quantitative values obtained from the "waste survey" described above, also allow having impact assessments about waste management. Of course, it would require a description of the actual waste management system: the data actually collected for the case study do not allow making a comparison, but only some considerations.

By taking, as an example, the possibility of discarding a percentage of the food in the dish equal to 40%, it is possible to quantify the primary energy used to produce that part of discarded food. The data can be compared with the potential energy recoverable from the use of waste, for example through the production of biogas. The data shown in Figure 7 allow comparing the primary energy used to produce, process, and cook the discarded food, with the energy obtainable from the same waste through conversion into biogas. The results show that it is possible to enhance a percentage share of the energy used to produce the foods on the menu equal to about 35%.

Figure 7. Comparison between the energy used to produce biogas from waste and the energy used to produce the discarded food (MJ per week per people).



These data take into account a coefficient of biogas production from the organic fraction waste collection equal to about 120 m^3 per ton of organic waste and a calorific value (LHV, or Low Heating Value) of 5.5 kWh/m^3 (data collected from the project feasibility of the production plant of Albairate [31]). Data on energy needed for the production of biogas is extracted from the database Ecoinvent [22] through the software SimaPro [21].

4. Further Developments of the Model towards an Integrated Assessment of the Service

Future developments of the research could be classified into two areas, the first one relating to the project “Bioregione” and the second one referring to the development of tools to assess the environmental sustainability of educational facilities.

In the first case, the database will be updated with missing data on some processes such as the food preparation and cooking, the energy consumption in catering areas and the methods of waste management. It will also be completed with a greater number of foods in order to make it applicable to the principal menus of the institutional catering in Lombardia.

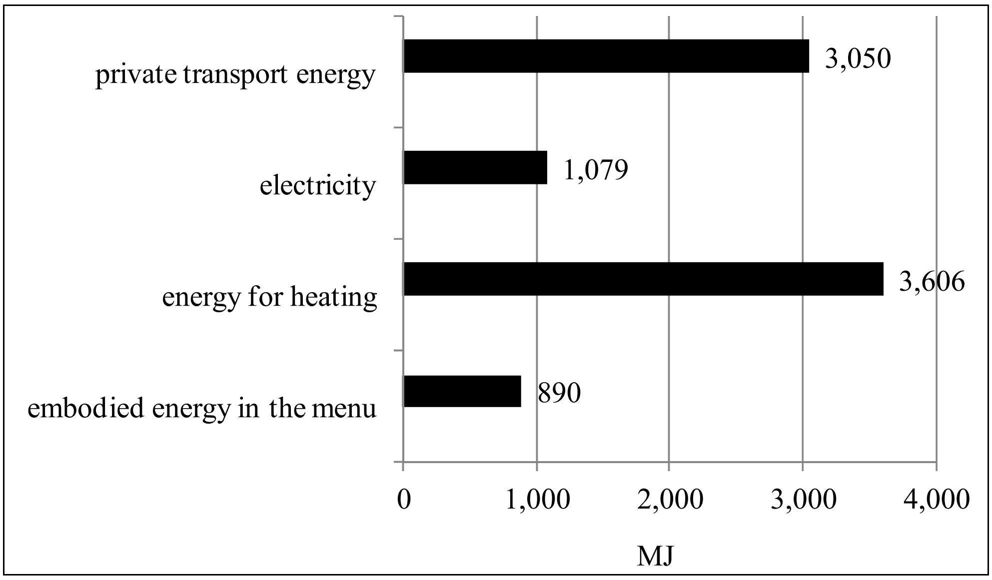
Regarding the second area, the FCM model could be improved and enlarged taking into account other aspects towards an integrated assessment of educational facilities. This approach could start by noting that the main activities that involve the use of energy in relation to this sector can be summarized as follows:

- Electric energy consumptions of the school;
- Energy to heat the school;
- Energy for the transportation of the student.

As example, Figure 8 compares the energy flows related to the main activities of the school sector on the basis of the following hypothetical conditions:

- Transport by private gasoline car for 10 km every day (round trip, 2 passengers), assuming the operation of the service 5 days a week (as for the power supply, it has been assumed continuous operation throughout the year without considering the holiday breaks);
- The energy consumption for heating and electricity refers to the average per student of the overall energy consumption of all the Italian public schools (representing approximately the 85% of the total energy consumption in the schools sector) and private schools. It was estimated at 990,000 TEP/year, of which 762,000 of fuel for heating and 228,000 of electricity. The total number of Italian schools is 62,217 buildings and they comprise up to 8,845,213 students [32].
- Food consumption refers to the menu of the case studies.

Figure 8. Comparison between the average electrical consumptions of a school building, the energy to heat a school building, the energy for the private transport, and the embodied energy of the menu.



5. Conclusions

The issue of institutional food system has become very important in the highly urbanized and developed societies, such as the Lombardy Region. Considering the wide demand for daily meals, the institutional food system significantly affects the flow of energy and matter within a territory. It represents a growing sector, relevant to both the food production/processing and to the waste production/management. In an optimization mechanism, the institutional food system needs to be taken into account, especially in view of the difficult times that we are living, in which the best practices would help us to avoid wasting energy and money.

The main aim of this research is to promote the sustainable local development through the organization of the food demand and supply in the institutional food system. To achieve this goal, the research proposes methods and tools to rationalize the food supply chains and to outline optimal scenarios of production, processing, and consumption at the local scale. For the moment this is carried out by the adoption of indicators to quantify the energy flows in the different steps of the food supply chain. The importance of analyzing all the food chain (following the LCA approach) makes a comparison between the processing steps and, consequently, an optimization of the phases with the highest level of energy impacts possible. This could lead to a reorientation of both the production systems and consumption, especially considering institutional food system, in which there are reliable and programmable food consumptions.

Thus, the main strategies that could lead to the general aim of the research can be summarized as follows:

- A greater use of seasonal products (and field growing);
- A greater use of less energy-intensive products, considering equal nutritional content;
- The promotion of local products to boost the local economy in a sustainable way.

As shown in the experimental part of the research, in the institutional food system the wide public demand for meals is followed by a very large amount of food waste. One of the aims of the research should be just to give some guidelines to reduce or manage the waste. For example the waste could be subjected to an energy conversion. The decree of 6 July, 2012 [33], recognizes a prominent role to the by-products from agriculture or forestry. Food waste, which often is thrown out as waste, in fact, represent a potential energy source for the production of biogas and biomethane. Currently, in Italy, there are still many barriers that must be overcome from the technological and organizational point of views, such as to produce biogas the wet waste must be brought away from the waste production areas.

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Author Contributions

The authors equally contributed to the development of the research and of the paper. In particular, Paola Caputo coordinated the researches activities, Matteo Clementi and Chiara Ducoli developed the FCM model and Chiara Ducoli led the survey about waste of food among the schools.

Conflicts of Interest

The authors declare no conflict of interest.

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