An explorative assessment of environmental and nutritional benefits of introducing low-carbon meals to Barcelona schools

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Highlights:

- Barcelona signed the "Good Food Cities Declaration" to promote dietary shifts
- Barcelona proposes low-carbon meals in public schools in the Academic year 20-21
- Low-carbon meals can potentially reduce 46-60% the environmental impacts
- Interventions on energy saving and food waste are also key for a better performance
- Research on the acceptance and satisfaction of the new menus is needed

Abstract

Shifting to plant-based and low-carbon diets is a key measure for climate change mitigation. In this regard, national and local governments are setting goals and actions to tackle this issue. The municipality of Barcelona has set an intervention for the academic year 2020-21: introducing low-carbon meals in public schools. This study assesses the environmental and nutritional benefits of this intervention by applying the Life Cycle Assessment (LCA) methodology, with an energy and nutritional functional unit; and combined it with the Water-Energy-Food (WEF) nexus approach, by considering three WEF resources-based impacts (Blue Water Footprint (BWF), Primary Energy Demand (PED) and Land Use (LU)) and the Global Warming Potential (GWP). The transition to a low-carbon meal would reduce between 46 and 60% the environmental impacts. These benefits could even be higher when extra interventions within the school boundaries are applied. More research in behavioural change is needed in order to evaluate both: the acceptance of the new menus by scholars and the adaptation of the school kitchen staff to the new menu. Finally, it is suggested to monitor the environmental and nutritional changes of the introduction of low-carbon meals within the school menus in an integrated way.

Words: Life Cycle Assessment, public meals, school canteens, sustainability, WEF nexus

1. Introduction

Global food systems are resource intensive (Springmann et al., 2018). They are responsible of about 30% of global greenhouse gases (GHG) emissions (Vermeulen et al., 2012), and larger values are expected if mitigation measures are not being put in place (Tilman and Clark, 2014). In this regard, Springmann et al. (2018) found that dietary shift is key to reduce GHG emissions; and technological changes (i.e., yields' improvement, fertilizer application) and food losses and waste (FLW) are also essential measures to reduce the blue water and land used for food production.

Facing the potential environmental benefits of dietary changes, global and local diet-related initiatives have emerged. Cities worldwide have recently signed the "Good Food Cities Declaration" (C40 Cities, 2019) to commit to actions to reduce food waste and ensure sustainable eating patterns for all citizens by 2030. As a signing city, Barcelona has established several actions, two of them related to the public-sector meals: (1) increase organic and locally sourced food products, and (2) reduce meat. Moreover, Barcelona has set a more ambitious plan to reduce food-related GHG emissions by declaring the climate emergency in January 2020 (Municipality of Barcelona, 2020). Concerning public meals, the key action is to: "*Implement and promote healthier diets that are low in carbon in 2021, in schools and all municipal dining rooms: seasonal, ecological, locally produced, reducing the consumption of animal protein (especially red meat) and highly processed foods.*" In this regard, this study aims to evaluate the nutritional and environmental benefits of this transition to low-carbon lunches in public schools of Barcelona, expected to start for the academic year 2020-21. To do so, the Life Cycle Assessment (LCA) is used, and a functional unit (FU) that considers the caloric energy and nutritional quality of the meals (Batlle-Bayer et al., 2020c) is applied.

This study contributes to the current literature by providing more insights regarding the environmental and nutritional effects of diet transitions; specifically, at the school meal level within the Spanish context. Most published LCA studies of Spanish schools focus on energy-related issues without considering food (Gamarra, 2018; Gamarra et al., 2019; Sanjuan-Delmás et al., 2016), except of Ribal et al. (2015) and González-García et al. (2020) that have addressed the food-related GHG emissions.

Besides, this article combines the LCA approach with the Water-Energy-Food (WEF) nexus framework. The WEF-nexus is a concept that analyses the interactions between the three resources - water, primary energy and food - systems, and it identifies the synergies and trade-offs between them for an optimal integrated management (FAO, 2014). This holistic perspective is essential since the pressures on these resources will increase due to future population growth and socioeconomic development.

Most WEF nexus studies focus on specific issues at the production level, such as irrigation (Serrano-tovar et al., 2019), water reservoirs (Si et al., 2019) or technological changes (Namany et al., 2019) for food production. In this regard, Al-Ansari et al. (2015) developed an LCA tool to assess the food production in Qatar with a WEF perspective. However, little has been done from the consumption-side. Moreover, there is no specific methodology for WEF studies (Albrecht et al., 2018), but the LCA has been considered as a prominent approach to quantify the environmental burdens of systems considered within the WEF nexus (Batlle-Bayer et al., 2020a; Mannan et al., 2018). On this subject, Bozeman et al. (2019) were the first ones to explicitly apply the WEF nexus at the diet level, and combined it with the LCA methodology. They used GHG emissions, water footprint and land use as the LCA impacts (with a cradle-to-fam gate scope) to be linked to the WEF nexus. Other diet-related studies have also used LCA to refer to other type of nexus, such as environment-food-health nexus (He et al., 2019; Song et al., 2019a) and water-food-health nexus (Song et al., 2019b); but no specific work has previously applied the LCA-WEF nexus perspective at the meal level. Hence, the current study is the first one applying this approach to assess the environmental benefits of introducing low-carbon meals in schools. To do so, this study has focused on three environmental impacts linked to WEF resources - Blue Water Footprint (BWF), Primary Energy Demand (PED) and Land Use (LU) - together with the Global Warming Potential (GWP). Moreover, this work follows the ISO 14044 standard (ISO, 2006) by, first, defining the goal and scope of the study (subsection 2.1 in the Methodology); second, developing the inventory analysis (section 2.4); and, third, performing the impact assessment and interpreting the results (section 3). Last, this study also assesses the potential benefits of other interventions. Introducing low-carbon meals aims at minimizing meal's GHG emissions, by selecting food products with low emissions in their production; but further reduction would require changes in the agricultural/production management, and schools do not have a direct influence on this matter, except by growing the demand. Instead, schools can implement other interventions within their physical boundaries – their influential zone - to further reduce GHG emissions, such as changing the energy source and reducing food waste in schools. In this regard, this study also estimates the environmental benefits of these interventions.

2. Methodology

2.1. Goal and Scope

The goal of this study is to assess the environmental and nutritional performances of public school lunches and analyse the benefits of introducing the recommended low-carbon meal. As a case study, meals served during a week in seven public high schools in Barcelona (Spain) have been considered.

The system boundary is from cradle to plate, considering all stages from primary production to the consumption stage (Fig.1). Other components of the nurturing system, such as the tableware, unlikely in other systems (Blanca-Alcubilla et al., 2020), are not considered here, as it is almost 100% made of reusable steal; neither the different impact on food logistics due to packaging materials or distribution distances.

Figure 1: System boundary of the study

2.1.2. Functional Unit

According to ISO 14044 (ISO, 2006), the Functional Unit (FU) defines the performance characteristics of the studied system, and it gives the reference to which the inputs and outputs are related to. Here, we defined the function of a school meal as the meal, comprised of two dishes, dessert and bread, that supplies the energy and nutrients required for a meal of a 12-16 years old student. Based on this definition, the FU must be selected. A mass-based FU cannot be considered, since it does not take into account the nutritional level of the meal; an essential aspect for diet LCAs (Heller et al., 2013). The isocaloric FU, which adjusts all meals to the same energy level, does not allow the comparison among non-isocaloric meals, and it does not consider the supply of nutrients. Therefore, this study applied the energy- and nutrient- (E&N-) based FU, proposed by Batlle-Bayer et al. (2019b) at the diet level, and also applied for meals at restaurants (Batlle-Bayer et al., 2020c).

The basis of this E&N-based FU is to correct the environmental impacts of a meal by its energy and nutritional scores. In this study, three resources-based environmental impacts - Blue Water

Footprint (BWF) and Primary Energy Demand (PED) and Land Use (LU) – were selected, as being related to the WEF nexus approach, as well as GWP. Each environmental impact of a lunch (EI_{lunch}) was defined as the sum of the environmental impacts (EI) of all the parts of the lunch [Eq.1]: two dishes, dessert and bread. These impacts were corrected ("c-" in the equations) with the energy and nutritional quality of the meals - the energy and nutritional scores (ES, NS; [Eq.2]) - in order to comply with the FU.

The ES [Eq.3] is the ratio between the caloric energy content of a school lunch ($kcal_{lunch}$) and the one of the recommended one ($kcal_{rec}$). The caloric energy contents of all the food ingredients were retrieved from the Spanish food composition database (BEDCA, 2020). If data was not available, the French (CIQUAL, 2020) or the USDA (USDA, 2020) databases were used. The $kcal_{rec}$ was assumed to be 898 kcal, a third of the daily average energy intake for a child between 12 and 16 years old (EFSA, 2017). As proposed by Batlle-Bayer et al. (2019b), to penalize overconsumption, the ES was inversed [Eq.4] when the $kcal_{lunch}$ was higher than $kcal_{rec}$.

$$EI_{lunch} = EI_{dish1-2} + EI_{dessert} + EI_{bread} \quad [Eq.1]$$

$$\mathrm{c-EI}_{lunch} = \frac{\mathrm{EI}_{lunch}}{\alpha * \mathrm{NS}} \quad [Eq.2]$$

$$\alpha = \mathrm{ES} = \frac{kcal_{lunch}}{kcal_{rec}} \quad if\ kcal_{lunch} < kcal_{rec} \quad [Eq.3]$$

$$\alpha = \frac{1}{ES} \quad if\ kcal_{lunch} \geq kcal_{rec} \quad [Eq.4]$$

$$\mathrm{NS} = \frac{NRM9.3_{lunch}}{NRM9.3_{rec}} \quad [Eq.5]$$

The nutritional score (NS; Eq.5) is the ratio between the nutritional quality of a school lunch and the one of the recommended lunch. The nutritional quality of the meals was assessed with the Nutritional Rich Meal index (NRM9.3 [Eq.6]; Batlle-Bayer et al., 2020b). It is based on nine nutrients to encourage (protein, fibre, Vit A, C and Ca, Fe, Mg and K), and three nutrients to limit their intake (saturated fat, added sugar and salt). The Total Nutrient Rich 9 (TNR9) [Eq.7] is the sum of percent recommended meal values (RV_i) for nutrients to encourage, and Total Nutrient Limiting (TNL3) [Eq.8] is the sum of percentages of Maximum Values (MV_j) per meal for the three nutrients to limit. Table 1 shows the RV_i and MV_j. The nutrient contents of a meal were estimated as the sum of the nutrient content of all the cooked food ingredients used to prepare the meal. Data on the nutrient content were retrieved from the Spanish food composition database

(BEDCA, 2020), or the French (CIQUAL, 2020) or the USDA (USDA, 2020) databases when needed.

$$NRM9.3 = TNR9 - TNL3 \qquad [Eq. 6]$$

$$TNR9 = \sum_{i=1}^{i=9} \frac{nutrient[dish1-2; dessert; bread]_{i,capped}}{RV_i} * 100 \qquad [Eq. 7]$$

$$TNL3 = \sum_{j=1}^{j=3} \frac{nutrient[dish1-2; dessert; bread]_j}{MV_j} * 100 \qquad [Eq. 8]$$

Table 1:
Recommended (RV_i) and maximum values (MV_j) for a child (12-16 years old) of nutrients per lunch. Based on the daily values from EFSA (2017).

Nutrients	Units	RV_i
Protein	g lunch^{-1}	12.5
Fibre	g lunch^{-1}	6.7
K	mg lunch^{-1}	1033.3
Ca	mg lunch^{-1}	320.0
Fe	mg lunch^{-1}	2.5
Mg	mg lunch^{-1}	91.7
Vit A	µg lunch^{-1}	200.8
Vit C	mg lunch^{-1}	27.5
Vit E	mg lunch^{-1}	4.0
Nutrients	**Units**	**MV_j**
Saturated fat	g lunch^{-1}	10.0
Added sugar	g lunch^{-1}	22.4
Na	mg lunch^{-1}	800

2.2.2. School Lunches

The lunches, which are composed of two courses, dessert and bread, were retrieved from the websites of seven schools located in Barcelona city. A total of 33 lunches (Table 2) and 57 meal recipes (TS.1) were evaluated. The amount of ingredients needed for all recipes were based on the recommended portions per food category, given by the Catalan Agency of Health (Table 3).

The low-carbon meal (Table 4) was an average meal based on the low-carbon school lunches proposed for a week by the Municipality of Barcelona (2020b). The main aspect of this new menu is the reduction of meat products in the second dish, and the introduction of legumes-based dishes as a protein source.

Table 2: Lunches of seven high schools in Barcelona for a week.

School	Monday (M1)	Tuesday (M2)	Wednesday (M3)	Thursday (M4)	Friday (M5)
S1	1) Pumpkin cream 2) Roasted chicken; lettuce and maize 3) Fruit	1) Spaghetti carbonara 2) Hake 3) Fruit	1) Fish soup with rice 2) Omelette with potatoes & courgette; lettuce 3)Fruit	1) Beans & potatoes 2) Sausages with Vegetables 3) Yogurt	1) Chickpeas 2) Cod croquettes; lettuce and carrot 3) Fruit
S2	1) Poultry stock with pasta 2) Spanish omelette; lettuce & carrot 3) Fruit	1) Lentils with rice 2) Hake 3) Yogurt	1) Italian pasta 2) Roasted chicken; vegetables 3) Fruit	1) Beans & potatoes 2) Pork sausages 3) Fruit	1) Stewed chickpeas 2) Hake; vegetables 3) Fruit
S3	1)Rice Salad 2)Omelette with ham 3) Fruit	1) Pasta with tomato sauce 2) Andalusian squid 3) Yogurt	1) Peas and potatoes 2) Grilled chicken 3) Fruit	1) Beans & potatoes 2) Pork sausage 3) Fruit	-
S4	1) Pasta with vegetables 2) Omelette with Courgette; lettuce & cucumber 3) Fruit	1) Pumpkin cream 2) Roasted chicken; hot potatoes 3) Fruit	1) Rice with vegetables 2) Hake; lettuce & olives 3) Fruit	1) Beans & potatoes 2) Beef burger & carrot 3) Fruit	-
S5	1) Lentils with vegetables 2) Spanish omelette; lettuce & cucumber 3) Fruit	1) Poultry stock with pasta 2) Beef 3) Fruit	1) Hummus 2) Rice with vegetables 3) Fruit	1) Chard & potato 2) Breaded chicken; tomato and carrot 3) Yogurt	1) Spaghetti with cheese 2) Cod; vegetables 3) Fruit
S6	1) Poultry stock with pasta 2) Spanish omelette; lettuce 3) Yoghurt	1) Bolognese pasta 2) Ham croquettes; tomato & corn 3) Fruit	1) Rice with tomato 2) Hake; lettuce & Olives 3) Fruit	1) Stewed dried beans 2) Roasted chicken; lettuce & carrot 3) Fruit	1) Pumpkin cream 2) Hake; hot potatoes 3) Fruit
S7	1) Beans & potatoes 2) Chicken croquettes; lettuce & cucumber 3) Fruit	1) Pasta with tomato 2)Hake; lettuce & corn 3) Yogurt	1) Chickpeas with spinach 2) Omelette; tomato & lettuce 3) Fruit	1) Rice with vegetables 2) Turkey; carrot 3) Fruit	1) Pumpkin cream 2) Baked loin; mushrooms 3) Fruit

Table 3: Recommended amount (g) of different type of foods, when they are present in a recipe. These values are based on dishes of school meals served to children between 13 and 16 years old. Source: (ASPCAT, 2020)

Food category	**Type of dish**	**Weight (g raw)**
Vegetables	Main dish	200
	Side dish	120
Fruit		175
Legumes	Main dish	80
	Side dish	40
Potatoes	Main dish	275
	Side dish	150
Rice, pasta	Main dish	90
	Side dish	35
	Soup	35
Bread		50
Meat	Piece	112.5
	Rips	132.5
	Mince (meatballs)	112.5
	Mince (for pasta, rice)	45
	Chicken (roasted)	225
Fish		137.5
Eggs		100
Dairy products	Milk	225
	Yoghurt	125
	Cheese	50

Table 4: Food composition of the average low-carbon meal, based on the low-carbon meals served in a week, proposed by the Municipality of Barcelona.

Parts of the Meal	**Food category**	**Amount** (g raw product)
1st Dish	Rice	8
	Pasta	23
	Legumes	9
	Vegetables	120
2nd Dish	Fish	36
	Chicken	15
	Red meat	16
	Eggs	16
	Legumes	63
	Vegetables	144
Dessert	Fruit	206
	Yoghurt	16

2.4. Life Cycle Inventory

Data on the resources used to produce the meals' ingredients and the related GHG emissions were retrieved from Batlle-Bayer et al. (2019a). For LU, data on the average country-specific crop yields from the FAOSTAT were used to estimate the land required to produce all plant-based food products considered in this study. Animal feed consumption was based on the studies considered in Batlle-Bayer et al. (2019a). About BWF, country-specific data from Mekonnen and Hoekstra (2010b, 2010a) were used.

Due to the lack of primary data on preparing and serving meals in schools, data from García-Herrero et al. (2019) on the amount of energy and water use per meal in commercial kitchens and schools were considered as a proxy:

- 0.763 kWh of electricity and 1.5 kWh of natural gas for meal preparation
- 0.074 kWh of electricity for the food service.

Food losses from primary production to wholesale were based on Garcia-Herrero et al. (2018). Data on food waste in the kitchen and catering service were retrieved from García-Herrero et al. (2019): 25%, in average, of the food prepared.

All inputs and outputs were introduced and modelled in GaBi software, and GaBi database SP39 was used for the background data.

2.5. Energy and food waste scenarios

To simulate the environmental benefits of other potential interventions within the school boundaries, three types of scenarios were modelled. First scenario (SOL) was based on assuming that all energy within the kitchen and dining area is supplied by energy from photovoltaic. Second, a variety of scenarios were based on reducing the energy use (10%, 30% and 50%) during cooking and serving the food: E10, E30 and E50. The third type of scenarios was based on reducing food waste (10%, 30%, 50%) within the consumption phase: FW10, FW30 and FW50.

3. Results and Discussion

3.1. Nutritional and environmental impacts of school meals

Table 5 shows the energy content and the nutritional status (NRM9.3) of all schools meals. The energy contents range between 664 and 955 kcal per meal, and the NRM9.3 values vary between 410 and 741; compared with the 898 kcal and a NRM9.3 of 775 for the low-carbon meal (LC). While in most cases the school meals provide a correct amount of proteins, fibre, iron and Vitamin A; they undersupply Calcium and Vitamin E (Supplementary material, TS.2).

Table 5. Energy content and NRM9.3 of all school meals and the low-carbon (LC) meal

Meal		kcal	NRM9.3
Plant-based	LC	898	775
	S5M3	971	624
Egg-based	S5M1	955	728
	S7M3	770	737
	S4M1	725	707
	S3M1	842	630
	S1M3	718	647
	S2M1	672	554
	S6M1	676	410
Poultry-based	S6M4	850	751
	S4M2	823	683
	S7M4	900	691
	S7M1	730	652
	S3M3	655	699
	S2M3	789	689
	S1M1	664	692
	S5M4	653	615
Fish-based	S1M5	863	632
	S2M5	761	741
	S6M5	756	707
	S6M3	834	715
	S3M2	836	424
	S4M3	838	593
	S5M5	773	664
	S1M2	772	580
	S7M2	874	559
	S2M2	841	513
Pork-based	S2M4	861	565
	S3M4	861	565
	S6M2	839	543
	S7M5	631	523
	S1M4	899	425
Beef-based	S4M4	757	703
	S5M2	671	477

Regarding the environmental impacts, in average, the low-carbon meal has 60%, 46%, 48% and 53% less c-BWF, c-PED, c-LU and c-GWP than the current meals; and only in a few cases, school lunches perform better than (the c-LU of three fish-based meals: S4M3, S6M5 and S6M3) or close to (the c-GWP of three egg-based meal: S5M1, S5M3, S7M3) the low-carbon meal. Figure 2 shows that plant-based products (i.e. vegetables, fruits, legumes and cereals) play an important role for the BWF and LU; animal husbandry-based products are crucial for LU and GWP; fish products are highly energy demand, as well as cooking and the service stages.

The beef-based menus have high values for the 4 environmental impacts (Fig. 3), especially for c-GWP (Fig.3d); being the S7M5 meal the highest emitter, due to the beef's large emissions and the low caloric energy content and nutrients intakes (α=0.75; NS=0.61; TS.3). Eggs-based meals show low emissions, close the ones of plant-based and LC meals - due to its more plant-based composition and the overall good quality of the meal (α=0.94 and NS=0.94)-, but they have relatively high WEF resources-based impacts. The median values of the environmental impacts of poultry-based meals are similar to the ones of the pork-based, but the emissions are even higher for the poultry-based meals, even the lowest emissions per grams of products. This is because of the assumption of larger proportion of poultry meat in a meal (Table 3).

The environmental benefits of the low-carbon meal are in line with current research: more plant-based meals reduce environmental impacts (Saarinen et al., 2012; Virtanen et al., 2011). However, while other articles report meals' composition as the most contributor factor influencing these impacts (De Laurentiis et al., 2019); here, the nutritional aspect of the meals also plays a crucial role, since the environmental impacts are corrected by their energy supply and nutritional quality (TS.4). In addition, it is essential to add more than one environmental impact, since meals' performance varies depending on the impact, as shown here and elsewhere (Batlle-Bayer et al., 2020c; Benvenuti et al., 2016; De Laurentiis et al., 2019).

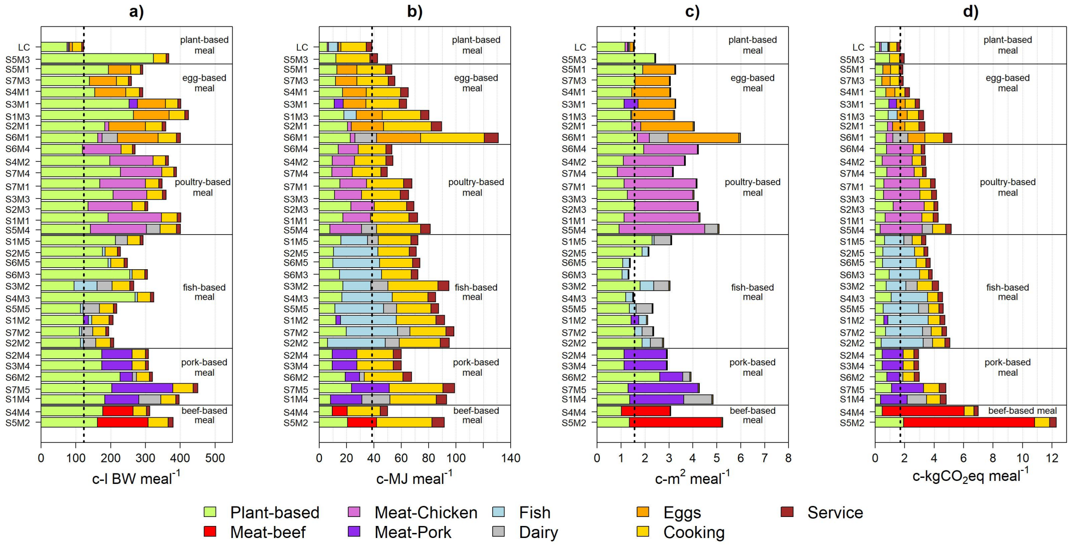

Figure 2: The three corrected WEF resources-based impacts ((a) Blue Water Footprint, (b) Primary Energy Demand and (c) Land Use) and (d) Global Warming Potential of all school meals and the Low-Carbon (LC) meal.

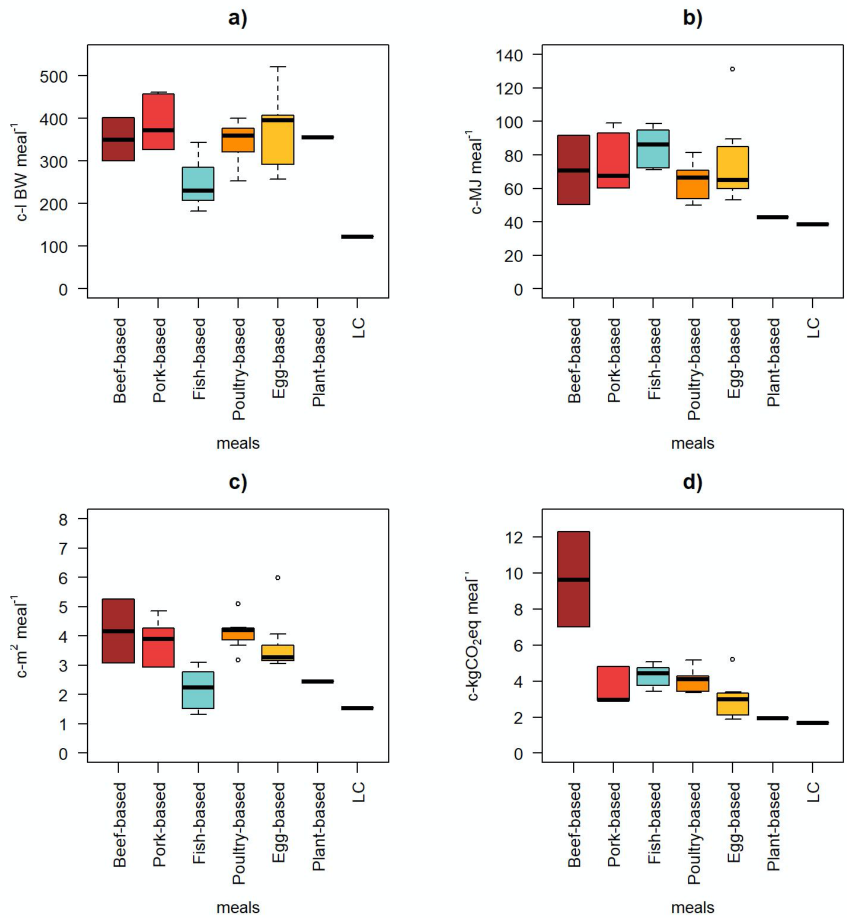

Figure 3: Boxplot of the three corrected WEF resources-based impacts - (a) Blue Water Footprint, (b) Primary Energy Demand and (c) Land Use - and (d) Global Warming Potential of all meals

3.2. Climate benefits of other WEF resources-based intervention strategies

The preparation and consumption stages (kitchen and service) are energy-resource intensive, as shown in Fig. 2b. Therefore, interventions towards increasing energy efficiency/savings or changing energy source can potentially decrease even more the emissions of the low-carbon lunches. For example, increasing to 100% the solar energy share of the electricity supply could reduce the emissions by 16%; and halving the energy use to prepare and serve a meal (i.e., cooling or cooking) could reduce, in average, 13% of meals' emissions (E50 in Fig.4). To achieve this, technological interventions, such as efficient appliances, may be essential. Nevertheless, Mudie et al. (2016) found that actions related to the behaviour of the kitchen staff and the maintenance of the equipment are key measures to reduce the energy consumption, potentially, by 70% and 45%, respectively.

Intervention strategies to prevent food waste (FW) are also crucial to optimize the use of WEF resources, and the related GHG emissions since food waste contributes to 21% of meals' emissions (FW100; Fig. 4). However, few initiatives have been taking place in school canteens in Barcelona (Derqui et al., 2020). In this regard, the current initiative of low-carbon meals should ensure the well acceptance of students to avoid food waste. To do so, several factors should be considered when designing these interventions: the quality of the meal – that is related to the taste and palatability of the food – , satiation, meal size, food choices, the location of the kitchen and social interactions (Boschini et al., 2020; Byker et al., 2014; Cohen et al., 2013; Mirosa et al., 2016; Zhao et al., 2019). Moreover, Derqui et al. (2018) suggested raising awareness and education as one of the potential interventions to tackle consumption behaviour, and Strotmann and Ritter (2017) observed that food waste reduction interventions in food services of the hospitality sector had higher success when involving staff.

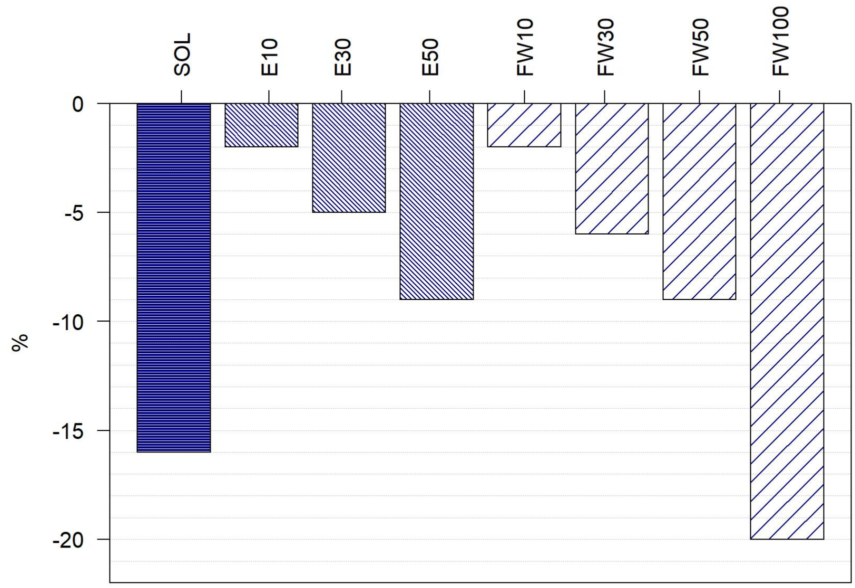

Figure 4:
Average reduction (%) of c-GWP of school meals for the alternative scenarios of energy source (SOL), energy saving (E10, E30, E50) and food waste (FW10, FW30, FW50 and FW100).

3.3. Limitations & recommendations for further research

The main limitation of this study is the lack of primary data on the actual food portions served per dish (which can largely vary in school canteens; Marcano-Olivier et al., 2019), and the data on the energy consumption and food waste in school/catering kitchens. In this respect, the proxy values used for energy use and food waste, based on García-Herrero et al. (2019), were found within the published ranges: 1.5 - 3.3 kWh per meal in commercial kitchens (Mudie et al., 2016), and 17% - 45% of food wasted per meal (Byker et al., 2014; Cohen et al., 2013; Liz et al., 2014; Silvennoinen et al., 2019). Moreover, this study did not consider organic food ingredients for school meals. Although changes in the type of agricultural systems have less environmental benefits than dietary shifts (Clark and Tilman, 2017), further research comparing organic to conventional is needed. Additionally, more research on the environmental, as well as socio-economic, impacts of local and non-local food products being sourced at schools is required.

To achieve good outcomes from school food interventions to mitigate climate change, more investigation in behavioural change will be needed. For instance, questions of interest will be, first, how the kitchen staff will adapt to design new menus and to other energy-related interventions, such as changing to less-energy intensive cooking methods and appliances.

Second, how students will respond to the new healthy and sustainable menus, and how this will contribute to changing food choices/behaviours outside the school. Schools represent an appropriate environment for children and youth to learn issues on food (Oostindjer et al., 2017), but usually further implication outside the school is lacking. Moreover, monitoring will be required to assess the actual environmental benefits of implementing a low-carbon meal. In this regard, we recommend performing an environmental and nutritional integrated assessment. Furthermore, performing optimizations can be as well an excellent tool to design optimal meals. Especially, when it is investigated together with the school meal planners, and the satisfaction of students is analysed; as done by Colombo et al. (2020) in Swedish schools. Finally, since results may slightly differ per region (Batlle-Bayer et al., 2020b) and by age group (Steen et al., 2018), it is suggested to enlarge this study within schools, as well as to other type of public meals, such as the ones served in hospitals.

4. Conclusion

This study evaluates the potential environmental and nutritional benefits of implementing the intervention of introducing low-carbon meals in schools located in the municipality of Barcelona. To do so, this study applied the Life Cycle Assessment (LCA), and combined it with the Water-Energy-Food (WEF) nexus framework by selecting three WEF resources-based environmental impacts - Blue Water Footprint (BWF), Primary Energy Demand (PED) and Land Use (LU) - and the Global Warming Potential (GWP). For this study, the functional unit - the basis of comparison for LCA studies – was not mass-based (the grams being consumed per meal) but energy- and nutrient-based. Results show that the transition toward a low-carbon meal can potentially have large nutritional and environmental benefits, by about halving all four environmental impacts. In addition, other interventions (i.e, ensuring renewable energy, saving energy and reducing food waste) have great potential to further reduce the already lower emissions of the low carbon meal.

This article is an exploratory study and, thus, to improve the current assessment we suggest to involve all key stakeholders within the school food system to obtain primary data on food ingredients and resources (i.e., energy and water) used to prepare and serve the food, as well as the food wasted in the plates in Barcelona schools. We also suggest more research on behavioural change in order to understand the students' satisfaction of the low-carbon meals, how their eating behaviours are modified outside the school, and how this can influence to their closed social groups, such as family and friends. Ultimately, this will allow to assess the potential nutritional and environmental impacts of the low carbon food intervention outside the school boundaries.

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SUPPLEMENTARY INFORMATION

TS.1. Nutritional information of all the main and side dishes of the school lunches

Dish	Energy (kcal)	Proteins (g)	Fiber (g)	K (mg)	Ca (mg)	Fe (mg)	Mg (mg)	Vit A (µg)	Vit.C (mg)	Vit.E (mg)	STA (g)	Added sugar (g)	Na (mg)
Baked loin	211	24	0	258	11	1	18	0	0	0	5	0	53
Beans and potatoes	250	6	6	965	101	3	58	86	56	1	2	0	12
Beef burger	202	27	0	344	11	1	21	0	0	0	4	0	77
Beef meat with mushrooms	347.7	44.3	1.2	762.6	22.9	2.1	40.5	10.5	3.8	0.4	6.6	0.0	192.6
Bread	120	4	2	60	28	1	13	0	0	0	0	0	325
Breaded chicken	205.2	15.8	0.2	18.0	21.1	1.3	17.4	15.6	0.0	0.8	2.6	0.0	21.3
Carrot	34	0.8	2.6	286	42	0.3	10	1346	7	0.5	0.05	0	70
Chard and potatoes	144.5	6.4	3.7	1013.8	158.6	5.8	125.9	426.8	40.0	0.1	0.2	0.0	213.2
Chicken croquettes	184.8	6.9	2.9	208.1	26.9	1.4	31.6	6.7	0.0	0.1	0.9	0.0	863.0
Chickpeas with spinach	313.1	9.8	13.0	791.2	181.3	4.6	95.3	882.1	26.9	2.6	0.2	0.0	69.8
Chips	107.6	1.3	0.8	238.0	7.4	0.4	10.0	0.0	2.0	0.8	1.5		140.0
Cod	82.5	18.7	0.0	325.6	16.7	0.3	24.0	6.4	1.5	0.4	0.1	0.0	48.7
Cod croquettes	269.9	18.3	0.0	112.4	0.0	1.3	24.3	0.0	0.0	1.0	11.0	0.0	203.7
Cucumber	12	0.7	0.8	150	19	0.3	12	2	5	0.09	0	0	3
Fish soup with pasta	198.9	5.7	3.6	325.2	68.7	1.5	35.1	61.1	27.8	0.8	1.3	0.0	3.8
Fish soup with rice	153.7	4.9	0.5	190.9	6.6	0.3	16.8	2.0	0.2	0.2	0.2	0.0	157.5
Fruit	92	5	3	297	54	1	26	230	12	1	1	0	137
Roasted chicken	231	43	0	392	16	2	31	9	0	0	2	0	104
Hake	164	12	0	257	34	1	24	15	1	1	2	0	98
Ham croquettes	161.7	6.1	2.6	182.1	23.5	1.2	27.6	5.8	0	0.1	0.8	0	755.2
Hot potatoes	197.8	4.1	7.6	550.1	32.6	6.8	0.6	0.9	12.9	0.04	0.02	0	20.16
Hummus	249.0	4.9	4.0	173.0	49.0	1.6	29.0	0.0	7.9	0.0	1.1	0.0	242.0

Italian pasta	264.1	23.1	2.4	470.6	58.1	2.3	35.3	126.8	30.2	4.8	4.7	0.0	90.4
Lentils with rice	405.9	8.8	3.1	201.0	51.7	0.3	15.5	347.7	15.5	2.3	0.2	0.0	166.1
Lentils with vegetables	320.7	20.5	11.5	945.0	84.2	7.4	78.6	345.8	28.4	1.9	0.3	0.0	86.6
Lettuce	19	1	1	84	23	0	7	159	7	1	0	0	76
Maize	97	3.34	2.7	252	2	0.55	31	0	6.2	0.09	0.197	0	253
Mushrooms	26	2	2	320	9	1	14	0	4	0	0	0	5
Olives	20	0	1	1	10	0	4	8	0	0	0	0	9
Omelette	155	13	0	133	57	2	12	211	0	1	3	0	223
Omelette with Courgette	172.0	15.0	1.5	471.5	81.8	2.6	32.5	215.6	13.6	1.0	3.5	0.0	223.9
Omelette with Courgette and potatoes	281.7	25.5	0.4	396.1	49.3	2.3	45.5	109.0	6.5	0.1	5.0	0.0	106.8
Omelette with ham	206.0	22.7	0.0	254.4	61.7	2.8	19.7	210.8	8.6	0.9	3.9	0.0	659.5
Pasta Bolognese	343.7	14.1	2.9	260.2	38.2	1.7	32.9	161.9	6.2	0.4	3.2	0.0	281.5
Pasta with tomato	322.7	18.7	1.9	43.5	30.3	1.3	34.3	33.2	0.0	2.7	1.3	0.0	3.8
Pasta with vegetables	268.2	9.8	3.8	185.4	33.7	1.0	31.4	26.3	22.5	0.5	0.7	0.0	40.5
Peas and potatoes	259.7	15.8	17.1	1084.8	78.4	4.3	70.1	125.6	51.3	0.4	0.5	0.0	17.9
Grilled chicken	131.4	20.0	0.0	190.1	12.0	0.9	14.2	0.0	3.3	0.2	1.7	0.0	47.5
Pork sausages	347	17	0	193	19	2	10	0	1	0	8	0	771.0
Poultry broth with pasta	241.7	25.1	0.0	309.6	19.2	1.1	32.2	139.2	0.1	1.7	2.6	0.0	425.5
Poultry stock with pasta	59.1	3.245	0.35	53.05	13.5	0.315	6.7	1.4	0	0.02	0.2	0	928.2
Pumpkin cream	131	3	3	499	17	1	20	28	18	0	0	0	11
Rice salad	372.3	17.5	1.9	436.2	24.3	1.2	44.2	52.7	12.5	0.9	0.1	0.0	37.4
Rice with pork and vegetables	458.2	12.6	3.3	272.8	24.8	1.5	35.2	16.6	4.6	0.2	1.8	0.0	176.6
Rice with tomato	368	7	2	163	11	1	27	9	3	0	0	0	56
Rice with vegetables	371.6	15.5	1.6	594.4	46.1	3.0	36.8	5.0	14.1	0.2	7.5	0.0	541.0
Spaghetti carbonara	344.5	10.2	1.9	55.5	19.9	0.9	23.5	7.6	0.0	0.1	5.3	0.0	93.4
Spaghetti with cheese	396.1	19.7	1.9	77.9	371.3	0.9	35.9	103.6	0.0	0.4	7.4	0.0	239.0
Spanish omelette	323	17	6	601	85	8	12	212	11	1	3	0	240
Stewed chickpeas	303	8	12	381	54	2	48	26	40	1	0	0	7

Stewed dried beans	329.0	23.5	17.0	1053.7	104.5	5.2	137.8	1.0	2.7	1.6	0.5	0.0	42.5
Tomatoes	19	0.9	1.1	236	10	0.5	10	82	19	0.89	0	0	18
Turkey	92.4	5.0	2.8	297.3	53.8	1.0	25.6	230.0	11.5	0.7	0.5	0.0	137.2
Vegetables	30.1	0.9	1.9	142.0	14.8	0.3	8.8	18.7	22.5	0.4	0.1	0.0	36.7
Yogurt	151.3	3.3	0.5	146.6	133.8	0.06	11.6	34	6.4	0.1	2	26.7	48.5

TS.2. The NRM9.3 for all meals

Meals	Energy (kcal)	Proteins	Fiber	k	Ca	Fe	Mg	Vit A	Vit C	Vit E	Saturated fat	Added sugar	Na	TNR9	TNL3	NRM9.3
LC	**898**	100	100	100	78	100	100,0	100	100	99	43	21	37	878	103	**775**
S1M1	**664**	100	100	100	53	100	100	100	100	67	30	0	98	820	128	**692**
S1M2	**772**	100	100	81	52	100	100	100	67	51	79	0	91	751	171	**580**
S1M3	**718**	100	100	100	60	100	100	100	100	61	63	0	110	820	173	**647**
S1M4	**899**	100	100	100	93	100	100	69	100	49	117	119	149	811	386	**425**
S1M5	**863**	100	100	100	62	100	100	100	100	100	124	0	105	862	229	**632**
S2M1	**672**	100	100	100	74	100	85	100	100	62	46	0	220	820	266	**554**
S2M2	**841**	100	83	64	77	94	70	100	81	84	41	119	80	753	240	**513**
S2M3	**789**	100	100	100	63	100	100	100	100	100	77	0	96	863	173	**689**
S2M4	**861**	100	100	100	72	100	100	100	100	62	104	0	165	835	269	**565**
S2M5	**761**	100	100	100	67	100	100	100	100	89	31	0	85	856	116	**741**
S3M1	**842**	100	100	100	62	100	100	100	100	72	49	0	154	833	204	**630**
S3M2	**836**	100	62	54	66	100	99	100	24	100	61	119	100	705	280	**424**
S3M3	**655**	100	100	100	63	100	100	100	100	43	32	0	75	806	107	**699**
S3M4	**861**	100	100	100	72	100	100	100	100	62	104	0	165	835	269	**565**
S4M1	**725**	100	100	100	79	100	100	100	100	90	52	0	110	869	162	**707**
S4M2	**823**	100	100	100	55	100	100	100	100	41	29	0	84	797	113	**683**
S4M3	**838**	100	100	100	70	100	100	100	100	87	107	0	158	857	265	**593**
S4M4	**757**	100	100	100	86	100	100	100	100	74	67	0	89	860	156	**703**
S5M1	**955**	100	100	100	100	100	100	100	100	100	50	0	123	900	172	**728**
S5M2	**671**	100	100	100	46	100	100	100	79	37	78	0	207	762	285	**477**
S5M3	**971**	100	100	94	58	100	100	100	100	31	39	0	120	783	159	**624**
S5M4	**653**	100	100	100	63	100	100	100	100	53	101	119	83	816	201	**615**
S5M5	**773**	100	100	100	100	100	100	100	100	58	86	0	108	858	194	**664**
S6M1	**676**	100	100	93	90	100	56	100	94	59	59	119	204	792	382	**410**
S6M2	**839**	100	100	100	56	100	100	100	100	54	51	0	217	810	268	**543**

S6M3	**834**	100	100	99	60	100	100	100	100	86	33	0	97	845	130	**715**
S6M4	**850**	100	100	100	82	100	100	100	100	100	34	0	97	882	131	**751**
S6M5	**756**	100	100	100	61	100	100	100	100	57	27	0	84	818	111	**707**
S7M1	**730**	100	100	100	88	100	100	100	100	87	36	0	187	875	223	**652**
S7M2	**874**	100	100	82	78	100	100	100	73	100	55	119	101	833	274	**559**
S7M3	**770**	100	100	100	100	100	100	100	100	100	47	0	116	900	163	**737**
S7M4	**900**	100	100	100	82	100	100	100	100	70	36	0	125	852	161	**691**
S7M5	**631**	100	100	100	46	100	90	100	100	40	88	0	165	776	253	**523**

TS.3. Energy (kcal), Nutritional quality (NRM9.3), α and the nutritional score of all meals analysed in this study

Meal	kcal	NRM9.3	α	NS
LC	898	775	1	1
S1M1	664	692	0.74	0.89
S1M2	772	580	0.86	0.75
S1M3	718	647	0.80	0.83
S1M4	899	425	1.00	0.55
S1M5	863	632	0.96	0.82
S2M1	672	554	0.75	0.71
S2M2	841	513	0.94	0.66
S2M3	789	689	0.88	0.89
S2M4	861	565	0.96	0.73
S2M5	761	741	0.85	0.96
S3M1	842	630	0.94	0.81
S3M2	836	424	0.93	0.55
S3M3	655	699	0.73	0.90
S3M4	861	565	0.96	0.73
S4M1	725	707	0.81	0.91
S4M2	823	683	0.92	0.88
S4M3	838	593	0.93	0.76
S4M4	757	703	0.84	0.91
S5M1	955	728	0.94	0.94
S5M2	671	477	0.75	0.61
S5M3	971	624	0.92	0.81
S5M4	653	615	0.73	0.79
S5M5	773	664	0.86	0.86
S6M1	676	410	0.75	0.53
S6M2	839	543	0.93	0.70
S6M3	834	715	0.93	0.92
S6M4	850	751	0.95	0.97
S6M5	756	707	0.84	0.91
S7M1	730	652	0.81	0.84
S7M2	874	559	0.97	0.72
S7M3	770	737	0.86	0.95
S7M4	900	691	1.00	0.89
S7M5	631	523	0.70	0.67

TS.4. Corrected and non-corrected GWP of all school meals

Meal	**GWP** (kg CO_2eq meal^{-1})	**c-GWP** (c-kg CO_2eq meal^{-1})
LC	1.70	1.70
S1M1	2.82	4.28
S1M2	3.05	4.74
S1M3	2.19	3.28
S1M4	2.64	4.82
S1M5	2.69	3.43
S2M1	1.81	3.38
S2M2	3.15	5.08
S2M3	3.33	4.26
S2M4	2.06	2.95
S2M5	2.90	3.58
S3M1	2.28	2.99
S3M2	2.19	4.30
S3M3	2.73	4.15
S3M4	2.06	2.95
S4M1	1.71	2.32
S4M2	2.76	3.42
S4M3	3.26	4.57
S4M4	5.35	7.00
S5M1	1.65	1.87
S5M2	5.64	12.29
S5M3	1.46	1.96
S5M4	2.98	5.17
S5M5	3.40	4.62
S6M1	2.07	5.20
S6M2	1.95	2.98
S6M3	3.30	3.86
S6M4	3.09	3.37
S6M5	2.87	3.74
S7M1	2.78	4.07
S7M2	3.39	4.83
S7M3	1.55	1.90
S7M4	3.08	3.46
S7M4	2.28	4.81

TS.5. Contribution analysis (%) of all life cycle states to the GWP

Meal	Cropping	Farming/ Fishery	Manufacturing	Packaging	Transports	Retail	Cooking	Service
LC	17%	30%	1%	3%	3%	2%	31%	13%
S1M1	61%	4%	3%	3%	2%	1%	18%	8%
S1M2	8%	60%	2%	2%	2%	2%	17%	7%
S1M3	30%	25%	3%	3%	4%	2%	23%	10%
S1M4	18%	38%	9%	3%	2%	2%	19%	8%
S1M5	15%	47%	3%	3%	3%	1%	19%	8%
S2M1	37%	8%	3%	3%	5%	2%	28%	12%
S2M2	10%	61%	3%	1%	1%	1%	16%	7%
S2M3	53%	9%	5%	8%	2%	1%	15%	7%
S2M4	18%	32%	6%	3%	3%	3%	25%	11%
S2M5	9%	59%	2%	2%	2%	1%	18%	8%
S3M1	36%	18%	4%	3%	5%	2%	22%	10%
S3M2	12%	36%	6%	8%	2%	3%	23%	10%
S3M3	59%	4%	3%	3%	1%	2%	20%	8%
S3M4	18%	32%	6%	3%	3%	3%	25%	11%
S4M1	32%	8%	4%	4%	6%	3%	30%	13%
S4M2	60%	4%	3%	3%	2%	1%	18%	8%
S4M3	18%	53%	2%	2%	2%	1%	16%	7%
S4M4	4%	79%	1%	1%	1%	1%	10%	4%
S5M1	30%	8%	3%	5%	6%	2%	31%	13%
S5M2	8%	75%	1%	1%	1%	1%	9%	4%
S5M3	36%	0%	4%	3%	3%	3%	35%	15%
S5M4	56%	11%	5%	3%	1%	1%	17%	7%
S5M5	10%	60%	3%	2%	2%	1%	15%	6%
S6M1	34%	17%	6%	3%	4%	1%	25%	11%
S6M2	22%	23%	6%	5%	4%	3%	26%	11%
S6M3	18%	52%	2%	3%	2%	1%	15%	7%
S6M4	55%	12%	3%	3%	2%	2%	17%	7%
S6M5	8%	60%	2%	2%	2%	1%	18%	8%
S7M1	61%	4%	3%	3%	2%	1%	18%	8%
S7M2	11%	57%	4%	5%	1%	1%	15%	6%
S7M3	30%	9%	3%	3%	6%	2%	33%	14%
S7M4	64%	4%	3%	3%	2%	1%	17%	7%
S7M4	25%	29%	6%	3%	3%	2%	22%	10%