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**FROM FOOD WASTE TO RESOURCES – THE IMPACT OF A SOCIO-  
ENVIRONMENTAL PROJECT ON THE COMMUNITY**

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## ABSTRACT

There has been a growing concern in food waste and food loss reduction while the number of food insecure families in the European Union has increased resulting in an increasing number of households depending on food assistance programs. The practice of up-cycling food to improve the diet of low-income households not only tackles food wastage and food insecurity, but also has the potential to contribute to the fulfilment of other Sustainable Development Goals (SDG) (SDG 2 and SDG 12, as well as the potential to contribute to the fulfilment of other SDG, such as SDG 1, SDG 3, SDG 10, and SDG 13).

After having conducted a scientific literature compilation in the food waste reuse field adopting a methodology based on the use selected key words, extracted results were divided in two categories: raw material and food security. Actual and predictable trends on food waste management were identified for both categories: food waste is regarded as a source of raw materials to produce biofuels and high value biomaterials, or as a solution to food insecurity through food aid organizations. However, there has been an increasing concern with the adequacy of food provided by these organizations, whether up cycled or not, due a lack a fresh food. Therefore, we endeavoured in a pilot study concerning the contribution of up-cycled fresh food to vulnerable households.

This study analyses the contribution to a balanced diet of an upcycling food organization which rescues and redistributes fresh or freshly cooked food to low-income households, to determine the nutritional balance of food hampers provided by our case study organization, according to the Portuguese food guidelines. We also evaluate the ways in which the process of upcycling fresh food can contribute to achieve SDG.

We determine the nutritional content of food hampers provided by our case study organization, weighing all items of food hampers in three weighing rounds over a period of four months. To evaluate how these nutrients contribute to alleviate food insecurity of the beneficiary households, the Food Insecurity Experience Scale (FIES) was applied to measure households' food insecurity. In the conclusion we propose a strategy to make the food

rescue and redistribution process a perennial activity, naturally integrated into citizens' lives.

## **Keywords**

food insecurity; nutritional adequacy; food aid organization; up-cycled food; low-income households.

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## RESUMO ALARGADO

A insegurança alimentar e o desperdício de alimentos são abordados pelos Objetivos de Desenvolvimento Sustentável (ODS) da atual Agenda 2030, desenvolvidos pelos países membros das Nações Unidas (ONU). Cada um dos estados-membros da ONU promoveu planos, programas, estratégias e / ou legislações aprovadas, destinados a lidar com o desperdício e a perda de alimentos (DPA) ao mesmo tempo em que alcançam os objetivos de todos os ODS. Essas participações efetivas são descritas por cada país num Relatório Nacional voluntário divulgado pela ONU na sua Plataforma de Conhecimento de Objetivos de Desenvolvimento Sustentável.

Para ajudar a União Europeia (UE) a alcançar os ODS, a UE desenvolveu uma estratégia para reduzir o desperdício e a perda de alimentos, uma vez que a redução de DPA pode também: 1) lutar contra as alterações climáticas, através da redução das emissões de gases com efeito de estufa (GEE); 2) ajudar na erradicação da fome e da desnutrição, por meio da redistribuição dos alimentos resgatados; 3) gerar poupança económica para produtores e distribuidores; 4) ter impactos sociais positivos na vida das populações empobrecidas; 5) fortalecer os sistemas alimentares. Esta estratégia, denominada Estratégia Farm to Fork, apresenta uma série de ações que visam uma transição mais rápida para um sistema alimentar sustentável a qual deve ter um impacto ambiental neutro ou positivo, reverter a perda de biodiversidade, ajudar a mitigar as mudanças climáticas, garantir a segurança alimentar, nutrição e saúde pública, e preservar a acessibilidade dos alimentos. As políticas da UE com relação ao DPA são postas em prática pelos membros da UE aprovando leis ou implementando outras iniciativas para prevenir, reciclar ou reutilizar o DPA.

Em Portugal, para promover a redução do desperdício alimentar através de uma abordagem integrada e multidisciplinar, a Presidência do Conselho de Ministros instituiu a Comissão Nacional de Combate ao Desperdício Alimentar (CNCDA). Um dos objetivos da Comissão Nacional de Combate ao Desperdício Alimentar (CNCDA) é identificar, avaliar e monitorizar as necessidades de adaptação da Estratégia Nacional de Combate ao

Desperdício Alimentar (ENCUDA) e do Plano de Ação de Combate ao Desperdício Alimentar (PACDA), apresentando relatórios periódicos ao Ministro da Agricultura. Depois de promover um inquérito às partes interessadas ao longo da cadeia alimentar, durante o 3º trimestre de 2020, o CNCDA concluiu que, exceto no canal HORECA: 1) houve um aumento nas doações / excedentes de alimentos resgatados, embora o canal HORECA não tenha seguido esta tendência global; 2) em todos os setores de atividade, a percepção geral era de que a pandemia COVID-19 tinha contribuído para a redução do desperdício de alimentos.

Em simultâneo com as políticas internacionais e nacionais, os movimentos civis surgiram com o foco no combate ao desperdício, em todas as suas dimensões, da produção ao consumo. Esses movimentos têm como objetivo unir várias partes interessadas em uma luta ativa contra o desperdício de alimentos usando abordagens e possibilidades inovadoras. Uma das abordagens para combater a insegurança alimentar das famílias de baixos rendimentos, consiste em organizações de ajuda alimentar que resgatem e redistribuem os excedentes alimentares, do canal HORECA e do setor de distribuição.

Como resultado, a adequação dos alimentos ou refeições distribuídas por cantinas sociais, mercearias solidárias ou bancos de alimentos têm sido objeto de investigação científica em diversos países. No entanto, os alimentos fornecidos nas organizações estudadas são, principalmente, ou adquiridos pela organização ou adquiridos por doadores que posteriormente doam esses alimentos à organização, ou ainda, em quantidades menores, resultantes de sobras de alimentos. Nessas organizações, devido ao seu custo e às necessidades de logística de transporte e refrigeração, os alimentos frescos costumavam ser fornecidos em quantidades baixas ou muito baixas. Como resultado, o teor de nutrientes das refeições e cestas de alimentos geralmente carece de vitaminas e minerais.

Além disso, os resíduos alimentares sendo um reservatório de hidratos de carbono, proteínas, lípidos e outros macro e micronutrientes orgânicos e inorgânicos, podem ser considerados como uma fonte material na indústria de alimentos, indústria de ração animal ou indústria farmacêutica como aromatizantes e fragrâncias, antioxidantes, aditivos e suplementos alimentares. No entanto, como os processos de extração industrial exigem know-how e consomem mais tempo, materiais, energia e recursos

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humanos, a maneira mais favorável do ponto de vista ambiental de aumentar o ciclo de alimentos é usá-los como estão, para alimentar a população em insegurança alimentar.

Tanto quanto sabemos, nenhuma outra investigação mediu e avaliou a contribuição de alimentos frescos ou preparados na hora, para uma dieta equilibrada de famílias de baixos rendimentos. Assim, nesta tese de doutoramento, pretendeu-se explorar as formas como o desperdício de alimentos é reciclado, focando principalmente no processo que leva ao consumo humano, medindo seus resultados no que diz respeito à quantidade de micro e micronutrientes reaproveitados, para a contribuição para uma alimentação equilibrada, para o alívio da insegurança alimentar e, finalmente, para a contribuição para o alcance dos ODS.

Com base na lacuna de investigação identificada acima, esta tese é regida por quatro questões investigativas principais:

- a) Com é que o desperdício de alimentar está a ser reutilizado?
- b) Como é que os alimentos reciclados podem contribuir para a dieta equilibrada de famílias de baixos rendimentos?
- c) Qual é o conteúdo nutricional dos alimentos resgatados e redistribuídos veiculados por uma organização de ajuda alimentar, em relação aos valores de doses diárias recomendadas?
- d) Como é que o processo de reciclagem e redistribuição de alimentos pode contribuir para o cumprimento dos ODS?

Derivando destas questões, foram estabelecidos seis objetivos principais de pesquisa:

- i) Fornecer uma atualização sobre o que foi encontrado para aumentar a reutilização do desperdício alimentar como um material ou fonte de energia, mas também para encontrar soluções de uso de desperdícios alimentares para consumo humano.
- ii) Avaliar o contributo dos alimentos frescos ou acabados de confeccionar, resgatados e redistribuídos como complemento da alimentação das famílias de baixos rendimentos, de acordo como guia alimentar português (Roda dos Alimentos), utilizando a organização ReFood-Leiria como estudo de caso. Esta avaliação é feita, em primeiro lugar, apenas considerando os dados categorizados como alimentos redistribuídos pertencentes à Roda

dos Alimentos Portuguesa. Em segundo lugar, são considerados os dados totais, pertencentes ou não à Roda dos Alimentos Portuguesa, o que permite também a terceira avaliação, que consiste em comparar os alimentos reciclados, na organização do estudo de caso, com o padrão alimentar da população portuguesa em geral.

iii) Quantificar os nutrientes dos alimentos resgatados e redistribuídos na organização do estudo de caso.

iv) Avaliar como esses nutrientes contribuem para aliviar a insegurança alimentar das famílias beneficiárias.

v) Avaliar as formas pelas quais o processo de reaproveitamento de alimentos frescos pode contribuir para o alcance dos ODS.

vi) Propor uma estratégia para tornar o processo de resgate e redistribuição de alimentos uma atividade perene, naturalmente integrada na vida dos cidadãos.

O projeto de investigação escolhido leva naturalmente a um desenvolvimento de pesquisa sequencial. A questão-chave inicial no início desta pesquisa foi “O que está a ser feito para melhorar a reutilização dos alimentos, principalmente para consumo humano?”. Após pesquisa exploratória da literatura, realizou-se a reflexão crítica, identificou-se uma possível organização do estudo de caso, foram estabelecidas questões de pesquisa mais específicas e consequentes objetivos iniciais.

Além disso, um projeto à escala de uma tese de doutoramento requer constante aperfeiçoamento e adaptação. Assim, num processo iterativo, os objetivos iniciais i), ii) e iii) foram expandidos para iv), v) e vi).

Em termos de materiais, novamente num processo iterativo, paralelamente à constante pesquisa bibliográfica, foram solicitadas autorizações, na organização do estudo de caso, para recolha de dados relativos aos alimentos redistribuídos e dados sociodemográficos. Foram pesquisadas e selecionadas ferramentas adequadas para avaliar o conteúdo nutricional dos alimentos redistribuídos e sua adequação, bem como valores de referência nutricional e guias alimentares. Para medir a insegurança alimentar, foi selecionada a Escala de Experiência em Insegurança Alimentar (FIES).

Os programas utilizados na análise e tratamento dos dados foram o Food Processor Plus®

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(ESHA Research, Salem, Oregon), Microsoft Excel Office® 365 e IBM® SPSS® Statistics versão 27 para Windows®.

Esta tese tem um formato cumulativo e baseia-se em três publicações científicas com revisão por pares, resultantes das diferentes fases da investigação. As publicações foram organizadas em três partes principais.

A Parte I é baseada no capítulo do livro *“Rerouting Food Waste for Climate Change adaptation: the paths of research”*, apresentado no 4th World Symposium on Climate Change Adaptation WSCCA- 2021), que decorreu em paralelo com a COP26 em Glasgow, Scotland, a 3 de novembro de 2021, e aceite como capítulo do livro 4th World Symposium on Climate Change Adaptation Book - *“Climate Change Strategies: handling the challenges of adapting to a changing climate”*, a publicar na editora Springer. Fornece uma compilação de como a investigação para a reutilização de DPA tem evoluído desde a crise económica de 2008, para encontrar soluções inovadoras de uso de DPA tanto como fonte de biomateriais e bioenergia, como para consumo humano para combater a insegurança alimentar. Os resultados são discutidos sob as seguintes perspetivas: distribuição geográfica da instituição do autor, categorias temáticas e palavras-chave dos autores. Foram identificadas as tendências atuais e previsíveis na gestão de resíduos alimentares como matéria-prima e para a segurança alimentar. Verifica-se que os campos de interesse da pesquisa de DPA têm sido, por um lado, o desperdício alimentar como fonte de matéria-prima para a produção dos biocombustíveis e dos biomateriais e, por outro lado, a reciclagem dos resíduos alimentares para consumo humano, como solução para a insegurança alimentar.

A Parte II é baseada no artigo *“The Contribution of Up-Cycled Food Waste to a Balanced Diet of Low-Income Households”* publicado na revista Sustainability (2021), 13 (9): 4779. <https://doi.org/10.3390/su13094779> e compreende a avaliação da contribuição de alimentos frescos ou recém confecionados, resgatados e redistribuídos para complementar a dieta familiar de baixo rendimento, de acordo com o guia alimentar português (Roda dos Alimentos), tendo como estudo de caso a organização ReFood-Leiria. Em primeiro lugar, apenas são considerados os dados categorizados como alimentos redistribuídos pertencentes à Roda Alimentar Portuguesa. Em segundo lugar, são tidos em consideração os dados totais, pertencentes ou não à Roda dos Alimentos Portuguesa,

o que permitirá também a terceira avaliação que consiste na comparação dos dados recolhidos, relativos a alimentos resgatados e redistribuídos, com o padrão alimentar da população portuguesa em geral. Os resultados sugerem que os alimentos reciclados podem contribuir para uma alimentação mais equilibrada em termos de “Batata, Cereais e Produtos de Cereais”, “Legumes”, “Carne, Peixe, Marisco e Ovos” e “Frutas”, ambos de acordo com a Roda Alimentar Portuguesa e em comparação com a população portuguesa em geral.

A Parte III é baseada no artigo “*The Nutritional Content of Rescued Food Conveyed by a Food Aid Organization*”, publicado na revista *International Journal of Environmental Research and Public Health* (2021), 18(22):12212. <https://doi.org/10.3390/ijerph182212212>.

Concentra-se na determinação do conteúdo nutricional de cestas de alimentos fornecidos pela nossa organização de estudo de caso. Todos os itens de cestas de alimentos são pesados, em três rodadas de pesagem durante um período de quatro meses. A Escala de Experiência de Insegurança Alimentar (FIES) foi aplicada para medir a insegurança alimentar das famílias. Os resultados mostraram que, no nosso estudo de caso de organização de ajuda alimentar, as doações de alimentos contribuem substancialmente para a ingestão da Dose Diária Recomendada (DDR) de energia, macro e micronutrientes. Ao avaliar como esses nutrientes contribuem para aliviar a insegurança alimentar das famílias beneficiárias, concluímos que a perceção de insegurança alimentar é independente da quantidade de nutrientes servidos. Tanto quanto sabemos, este é o primeiro estudo que mede o conteúdo nutricional de alimentos resgatados frescos ou recém confecionados, redistribuídos por uma organização de ajuda alimentar.

Essas três partes são acompanhadas de um capítulo anterior, uma introdução geral à tese, e um último capítulo sobre as reflexões e conclusões finais em que as questões de pesquisa são respondidas. Limitações do estudo, bem como uma perspetiva sobre futuras investigações estão incluídas no último capítulo desta tese, seguidas pela bibliografia compilando todas as fontes citadas de todos os capítulos. Ao final da tese, são fornecidos dois apêndices, nos quais estão organizados todos os materiais de pesquisa relevantes, como os diagramas metodológicos da Parte II e da Parte III, Escala de Insegurança Alimentar em Língua Inglesa e Língua Portuguesa. O Apêndice B contém o diagrama da

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metodologia usado na parte II, e o Apêndice C contém todos os materiais usados na parte III.

Palavras-chave

insegurança alimentar; adequação nutricional; organização de ajuda alimentar; alimentos reciclados; famílias de baixo rendimento.



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## LIST OF ABBREVIATIONS AND ACRONYMS

BMI	Body Mass Index
CNCDA	National Commission to Combat Food Waste
DRV	Dietary Reference Value
EFSA	European Food Safety Authority
ENCDA	National Strategy to Combat Food Waste
EPA	Environmental Protection Agency
ESHA	Elizabeth Stuart Hands and Associates
EU	European Union
FAO	Food and Agriculture Organization
FIES	Food Insecurity Experience Scale
FL	Food Loss
FLW	Food Loss and Waste
FSC	Food Supply Chain
FW	Food Waste
GFN	Global FoodBanking Network
GHG	Greenhouse Gas
GHGE	Greenhouse Gas Emissions
HACCP	Hazard Analysis and Critical Control Point
HORECA	Hotels, Restaurants and Catering
IOM	Institute of Medicine
NFPAS	National Food and Physical Activity Survey
PACD	Action Plan to Combat Food Waste
RM	Raw Material
SDG	Sustainable Development Goal
SNAP	Supplemental Nutrition Assistance Program
SPSS	Statistical Package for the Social Sciences
UK	United Kingdom
UN	United Nations
USA	United States of America
WHO	World Health Organization



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## **GENERAL INTRODUCTION**

# I. OVERVIEW

This general introduction aims to introduce the overall research topic and the organization of this doctoral thesis. The introduction is divided into four subsections. First, the research problem is identified, justifying the relevance of the research as well. Next, the research questions and objectives are pointed out, followed by the explanation of the methodological approach and the research design chosen. In the fourth subsection, the structure of the thesis is presented and finalized with some general remarks.

## i.1 Identification of the problem and relevance of the research

Food insecurity and food waste are addressed by the 17 Sustainable Development Goals (SDG) of the current 2030 Agenda developed by the United Nations (UN) member countries. Each of the UN state members have engaged in plans, programs, strategies and/or approved legislations designed to address food waste and food loss (FLW) while achieving the aims of all of SDG's. These effective participations are described by each country in a voluntary National Report released by the UN on its Sustainable Development Goal Knowledge Platform (FAO, n.d.).

To help the European Union (EU) achieve the SGD, the EU has developed a strategy to reduce food waste and food loss as reducing FLW can also: 1) fight against climate change, through the reduction of greenhouse gas (GHG) emissions; 2) help the eradication of hunger and malnutrition, through the redistribution of rescued food; 3) produce economic savings for producers and distributors; 4) have positive social impacts on the lives of impoverished populations; 5) strengthens food systems (European Commission, n.d.-b). This strategy, called *Farm to Fork Strategy*, puts forward a series of actions aiming a faster transition to a sustainable food system that should have a neutral or positive environmental impact, reverse loss of biodiversity, help to mitigate climate change, ensure food security, nutrition, and public health, and preserve affordability of food (European Commission, n.d.-a). EU policies with respect to FLW, are put in practice by the EU members by passing laws or implementing other initiatives to prevent, recycle or reuse FLW.

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In Portugal, to promote the reduction of food waste through an integrated and multidisciplinary approach, the Portuguese Presidency of the Council of Ministers established the National Commission to Combat Food Waste (CNCDA) (Presidência do Conselho de Ministros, 2016).

One of the National Commission to Combat Food Waste (CNCDA) objectives is to monitor, evaluate and identify adaptation needs of the National Strategy to Combat Food Waste (ENCDA) and the Action Plan to Combat Food Waste (PACDA), presenting periodic reports to the Minister of Agriculture. After promoting an inquiry to stakeholders all along the food supply chain, during the 3<sup>rd</sup> trimester of 2020, the CNCDA concluded that, except on the HORECA channel: 1) there was an increase in donations / rescued food surpluses, even though the HORECA channel did not follow this global trend; 2) in all sectors of activity the general perception was that the pandemic had contributed to reducing food waste (Comissão Nacional de Combate ao Desperdício Alimentar, 2020).

Simultaneously to international and national policies, civil movements emerged with the focus of combating waste, in all its dimensions, from production to consumption. These movements aim to unite several stakeholders in an active fight against food waste using innovative approaches and possibilities (Unidos Contra o Desperdício, n.d.; Zero Desperdício, n.d.). One of the approaches consists of food aid organizations that rescue and redistribute food surpluses, from the HORECA channel and the distribution sector, to tackle low-income households' food insecurity.

As a result, the adequacy of food or meals distributed by soup kitchens, food pantries or food banks has been the object of research in different countries. In the American continent studies addressed the nutritional content of food provided to beneficiaries of emergency nutritional programs by food banks (Hoisington, Manore, & Raab, 2011), food pantries (Leung et al., 2012; Leung, Musicus, Willett, & Rimm, 2017; Mousa & Freeland-Graves, 2017; Simmet, Depa, Tinnemann, & Stroebele-Benschop, 2017) and soup kitchens (Buttorff, Trujillo, Diez-Canseco, Bernabe-Ortiz, & Miranda, 2015; Lyles, Drago-Ferguson, Lopez, & Seligman, 2013).

In the USA, Hoisington *et al.* (2011) analyzed the nutritional quality of emergency food of the Food Banks of Delaware and Oregon, USA, based on an emergency food warehouse inventory data, to establish a baseline data of how emergency foods met the needs of food insecure individuals. The collected data was compared with the MyPyramid Day measurement unit, a tool developed by the United States Department of Agriculture (USDA) Centre for Nutrition Policy and Promotion (USDA Center for Nutrition Policy and Promotion, 2005), nowadays often replaced by the Dietary Reference Values (DRV)(EFSA European Food Safety Authority, 2019). Results showed that the consumption of fresh fruit and vegetables, milk and milk foods was much lower than recommended, up to only one serving a day. Hoisington *et al.* (2011) advise food networks to request donations of nutritious food, usually donated in lower quantities (Hoisington et al., 2011).

The Supplemental Nutrition Assistance Program (SNAP) being the largest nutrition assistance program in the USA, it has been not surprisingly the object of research (USDA, n.d.-b, 2021). Leung *et al.* (2012, 2017) explored over the years the impact of SNAP on dietary patterns. Their results point out the fact that no adults met all the food and nutrient guidelines. Low-income SNAP participants may be inclined to consume low-cost, nutrient-poor foods high in added fats and sugars, to maximize their food budget, for nutrient rich foods tend to be more expensive (Leung et al., 2012).

Simmet *et al.* (2017), in a cross-national review-based research (Australia, USA, Canada), point out that food pantries are unable to provide the amount and types of food to support healthy diets. Simmet *et al.* (2017) also suggests that, to address malnutrition in vulnerable population groups, food banks and food pantries, apart from increasing distribution of perishable foods such as fresh fruit and vegetables, whole grains, and milk products, should also promote educational interventions to provide clients with the ability to meet their basic needs (Simmet et al., 2017).

Like researchers on the American continent, Europeans have also shown concern about the nutritional adequacy charitable meal services (Fallaise, Newlove, White, & Lovegrove, 2020; Maioli, Colosio, Muzio, & Cioni, 2016; Pelham-Burn, Frost, Russell, & Barker, 2014; Sprake, Russell, & Barker, 2014).

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In the UK, Sprake *et al.* (2014) used mixed methods to update the reasons of the nature of the homeless food choices while visiting charitable meal services, finding that low income and lack of cooking and storage facilities were the major reasons described by beneficiaries (Sprake *et al.*, 2014). Food bank distributed parcels examined in Oxfordshire, UK, exceeded energy requirements and provided disproportionately high sugar and carbohydrate and inadequate vitamin A and vitamin D compared to the UK guidelines, suggesting that improved links with distributors and access to cold food storage facilities would help to address these issues, via increased fresh food provision (Fallaize *et al.*, 2020).

Still in the UK, Pelham-Burn *et al.* (2014) quantified the nutritional content of breakfast and lunch provided by a charitable organization. For at least 20% of breakfast and lunch meals, energy, potassium, calcium, vitamin C, vitamin A, zinc and magnesium content of meals were below Dietary Reference Value (DRV) targets. Moreover, and mirroring previously mentioned studies, researchers identified a pattern of low fruit, vegetables and wholegrain intake and high intake of foods rich in fat and sugar and salt (Pelham-Burn *et al.*, 2014).

Maioli *et al.* (2016), an Italian group of researchers who examined the nutritional content of a soup kitchen in Milan, found that most macronutrients and micronutrients were well represented. However, they reported high amounts of salt and a scarcity of dairy products resulting in a lack of calcium, vitamin D and zinc (Maioli *et al.*, 2016).

In all previously mentioned research, focusing on the dietary adequacy of food served by food aid organizations, provided foods were, mainly, either purchased by the organization and by donors who donate these foods to the organization (The Global Food Banking, n.d.) or, in smaller amounts, resulting from food surpluses. In these organizations, due their cost, and to transportation and refrigeration logistics needs, fresh foods were often found to be provided in low or very low amounts. As a result, meals' and hampers' nutrients content often lacked vitamins and minerals.

Moreover, food waste being a reservoir of carbohydrates, proteins, lipids and other organic and inorganic macro and micronutrients, can be regarded as a material source in the food industry, animal feed industry or pharmaceutical industry as flavorings and

fragrances, antioxidants, food additives and nutraceuticals (Barik & Paul, 2017). However, industrial extraction processes require the know-how and are more time, material, energy, and human resources consuming (Ravindran & Jaiswal, 2016). Hence, the most environmentally favorable way of up-cycling food is to use it as is, to feed the food insecure.

To the best of our knowledge, no other research has measured and evaluated the contribution to a balanced diet of low-income households of fresh or freshly cooked food. Therefore, in this doctoral thesis, it was intended to explore the ways in which food waste is up cycled focusing mainly on the process that leads to human consumption, measuring its outcomes with respect to the amount of micro and micronutrients upcycled, to the contribution to a balanced diet, to food insecurity alleviation and finally to the contribution to SDGs achievement.

## **i.2 Research questions and objectives**

Based on the research lacuna identified above, this research is guided by four main research questions:

- a) How is food waste being up cycled?
- b) How can up-cycled food contribute to the balanced diet of low-income households?
- c) What is nutritional content of rescued and redistributed food conveyed by a food aid organization, with respect to the dietary recommend intake values?
- d) How can the process of up-cycling and redistributing food contribute to achieving the SDGs?

Deriving from these questions, six main research objectives were set up:

- i) To provide an update on what has been found to upcycle FLW as a material or energy source, but also to find about solutions of using FLW for human consumption.

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ii) To evaluate the contribution of fresh and freshly cooked rescued and redistributed food to supplement low-income household diet, according to the Portuguese guidelines, using the ReFood-Leiria organization as a case study.

Firstly, only the data categorized as redistributed foods belonging to the Portuguese Food Wheel is considered. Secondly, the total data, whether belonging or not to the Portuguese Food Wheel is considered, which also allows the third evaluation, consisting of comparing the up-cycled food, at the case study organization, to the dietary pattern of the general Portuguese population.

iii) To quantify the nutrients of rescued and redistributed foods at the case study organization.

iv) To evaluate how these nutrients contribute to alleviate food insecurity of the beneficiary households.

v) To evaluate the ways in which the process of upcycling fresh food can contribute to achieve SDGs.

vi) To propose a strategy to make the food rescue and redistribution process a perennial activity, naturally integrated into citizens' lives.

### **i.3 Research design and methods**

The chosen research design naturally leads to a sequential research development. The initial key question at the beginning of this research was “What is being done to up-cycle food, especially for human consumption?”. After an exploratory literature research, critical reflection took place and a possible case-study organization was found, more specific research questions were established, and consequent objectives initial objectives were set (section 1.2).

Moreover, a project on the scale of a doctoral thesis requires constant improvement and adaptation. Thus, in an iterative process, the initial objectives i), ii) and iii) were expanded to iv), v) and vi).

In terms of materials, again in an iterative process, parallel to constant bibliographical research, authorizations were requested, at the case study organization, for redistributed foods and sociodemographic data collection. Appropriate tools to evaluate the nutritional content of redistribute foods and its adequacy were searched and selected, as well as nutritional reference values and food guidelines. To measure food insecurity the Food Insecurity Experience Scale (FIES) was selected.

The programs used in the data analysis were the Food Processor Plus® (ESHA Research, Salem, Oregon), Microsoft Excel Office® 365 and IBM® SPSS® Statistics version 27 for Windows®.

Figure i.1 shows the questions and objectives of each research stage with the corresponding applied methods. The respective research phases are mirrored in the thesis' chapters, referred to as Part I-III, as well as their connection to the thesis objectives.

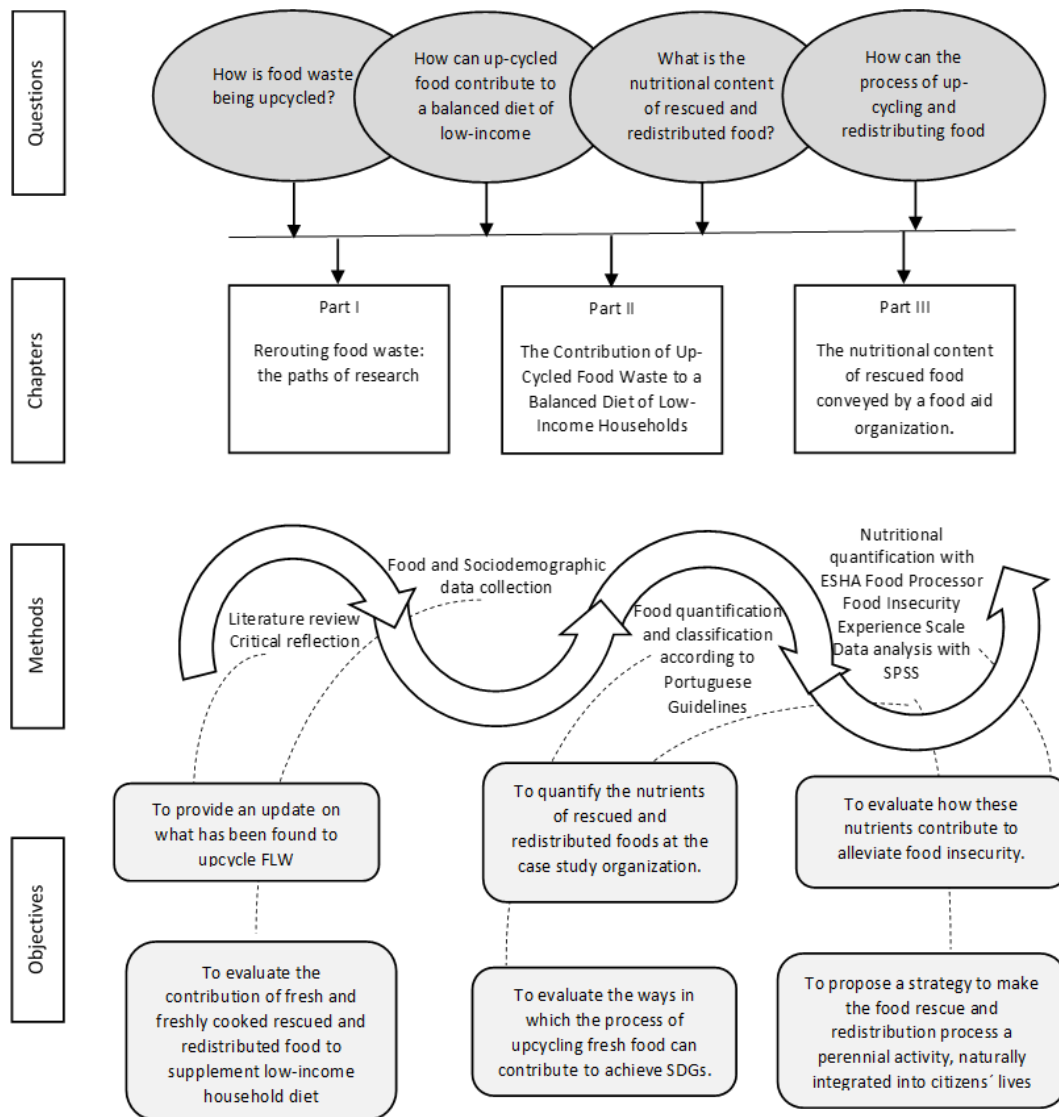


Figure i.1: Research development and respective thesis structure

#### i.4 Structure of the thesis

This thesis has a cumulative format and is based on three peer review scientific publications (one currently in press), resulting from the different research stages. The publications were organized in **three main parts**.

- Part I is based on the book chapter “Rerouting food waste for climate change adaptation: the paths of research”, 2022, *Climate Change Strategies: handling the challenges of adapting to a changing climate*, Leal Filho, W. (ed.), New York: Springer International Publishing, and provides a compilation of how research to upcycle

FLW has been evolving since the economic crises of 2008, to find about innovative solutions of using FLW both as a source of biomaterials and bioenergy, and for human consumption to tackle food insecurity. The results are discussed under the following perspectives: geographic distribution of author's institution, subject categories, and author keywords. Actual and predictable trends on food waste management were identified for food waste as a raw material and for food security. It is found that FW fields of research interest has been, on one hand, food waste as a source of raw materials to produce biofuels and the biomaterials and, on the other hand, food waste upcycling for human consumption, as a solution to food insecurity.

- Part II is based on the paper *"The Contribution of Up-Cycled Food Waste to a Balanced Diet of Low-Income Households"* published in *Sustainability* (2021), 13(9):4779. <https://doi.org/10.3390/su13094779> and comprises the evaluation of the contribution of fresh and freshly cooked rescued and redistributed food to supplement low-income household diet, according to the Portuguese guidelines, using the ReFood-Leiria organization as a case study. Firstly, only the data categorized as redistributed foods belonging to the Portuguese Food Wheel is considered. Secondly, the total data, whether belonging or not to the Portuguese Food Wheel is taken into account, which will also allow the third evaluation that consists of comparing collected data, concerning rescued and redistributed food, with the dietary pattern of the general Portuguese population. Results suggest that upcycled foods can contribute to a more balanced diet in terms of "Potato, Cereal and Cereal Products", "Vegetables", "Meat, Fish, Seafood and Eggs" and "Fruits", both according to the Portuguese Food Wheel and compared to that of the general Portuguese population (data collection and treatment process described in Appendix B).

- Part III is based on the paper *"The Nutritional Content of Rescued Food Conveyed by a Food Aid Organization"* published in *International Journal of Environmental Research and Public Health* (2021), 18(22):12212. <https://doi.org/10.3390/ijerph182212212> and focuses on the determination of the nutritional content of food hampers provided by our case study organization. All items of food hampers are

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weighed, in three weighing rounds over a period of four months. The Food Insecurity Experience Scale (FIES) was applied to measure households' food insecurity. Results showed that, at our case study food aid organization, food donations substantially contribute for energy, macro, and micronutrient DRI (Dietary Recommendation Intake) intake. When evaluating how these nutrients contribute to alleviate food insecurity of the beneficiary households, we found that perception of food insecurity is independent of the amount of nutrients served. To our knowledge, this is the first study that measures the nutritional content of fresh or freshly cooked rescued food conveyed by a food aid organization.

These three parts are accompanied by this preceding chapter, a general introduction to the thesis, and a last chapter about final reflections and conclusions in which the research questions are answered. Limitations of the study as well as an outlook on future research are included in the last chapter of this thesis, followed by the bibliography compiling all cited sources of all chapters. At the end of the thesis, two appendices are provided, in which all relevant research materials, such as methodology diagrams for Part II and for Part III, Food Insecurity Scale in English Language and Portuguese Language, are organized. Appendix A contains world food redistribution organizations. Appendix B contains the methodology diagram used in part II, and Appendix C contains all materials used in part III.

#### Organizational note:

Because we opted for a cumulative thesis format, there are sections that may appear repetitive, as the research topic is introduced and contextualized in every publication.



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## **I – THE PATHS OF FOOD WASTE RESEARCH**

## Rerouting food waste: the paths of research

*Nogueira A, Alves F, Vaz-Fernandes P. (2021). Rerouting food waste for climate change adaptation: the paths of research. Climate Change Strategies: handling the challenges of adapting to a changing climate, Leal Filho, W. (ed.), New York: Springer International Publishing.*

**Abstract:** In a context of climate change where, on the one hand, large amounts of food are lost or wasted and on the other hand climate refugees are victims of food insecurity, there has been a growing interest in food waste and in research into reducing food loss. In order to identify research trends and gaps in this area, we have conducted a systematic review in this field adopting a methodology based on the use of selected key words and temporal boundaries from 2008 to 2021. The results extracted were divided in two categories: raw material and food security. The results are discussed under the following perspectives: geographic distribution of author's institution, subject categories, and author keywords. Based on research topics found and researchers' suggestions, actual and predictable trends on food waste management were identified for food waste as a raw material and for food security. It is found that Food Loss and Waste (FLW) fields of research interest have been: 1) food waste as a source of raw materials to produce biofuels and biomaterials; 2) food waste upcycling for human consumption as a solution to food.

### 1.1. Introduction

Widely known data from FAO point out to the global annual food loss and waste (FLW) of 1.3 billion tons, which is 1/3 of the total food produced for human consumption, while 11% of the population suffers from hunger or malnutrition (FAO, n.d.-b). Also, according to FAO, the costs of the world annual food loss and waste are roughly of US\$ 680 billion in industrialized countries and US\$ 310 billion in developing countries.

While researching Food Loss (FL) and Food Waste (FW) one can easily come across broadly accepted concepts (FAO 2011b) related to FL which refers to the decrease of the edible food mass throughout the part of the supply chain that leads specifically to food for human consumption. Food losses can occur during production, post-harvest and the

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processing stages of the food supply chain (FSC) (Parfitt, Barthel, & MacNaughton 2010). When these losses occur at the end of the food chain (distribution and final consumption) they are referred to as “food waste”, relating specifically to retailers and consumer behaviour (Hodges, Buzby, & Bennett 2011; Parfitt et al. 2010).

There is yet another side to the FL and FW concepts. The Food and Agriculture Organization (FAO) of the United Nations, only measures FL and FW as parts of the food chain *leading to human consumption*, excluding planned animal feed and inedible parts. Hence, all unplanned loss along the human food supply chain is accounted for as FL or FW, even when later redirected to animal feed or bioenergy production (Parfitt et al. 2010).

Food waste and food loss reduction have been one of the priorities of the international political, economic, environmental, and social agenda. Economically FLW represent an income reduction for farmers, industries, distributors, and an increase in expense for consumers. Annually, adding to capital loss, one must not forget major depletion of resources such as 250 km<sup>3</sup> of water, 1.4 billion hectares of land (28 percent of the world's agricultural area), energy, and labour. Moreover, associated to FLW, there is a needless production of 3.3 billion tonnes of CO<sub>2</sub> equivalent to Greenhouse Gas Emissions (GHGE), contributing to global warming and climate change (FAO, 2011b, 2013). The International Panel on Climate Change Report of 2021 outlines the larger direct influence of global warming in climate change causing, among other negative impacts, agricultural and ecological droughts which stresses the interconnection of all FLW impacts (IPCC, 2021).

As a result, the scientific interest in FLW has been increasing, as has its social, economic, and environmental sustainability. In this context, we have identified a lack of scientific literature reviews on food waste recovery for human consumption.

In response to this situation, FAO has developed the Global Initiative on Food Loss and Waste Reduction promoting a new strategic framework, adjusted to the specific needs of each region and country. Each role-player in the programme is urged to raise awareness, establish public-private partnerships, implement policies, strategies and programmes designed to bring stakeholders together to reduce food waste and loss (FAO 2015).

In September of 2015, the world leaders attended United Nations Sustainable Development Summit where the Sustainable Development Agenda until 2030 was

adopted. This agenda includes 17 Sustainable Development Goals (SDG), two of which directly address FLW impacts: SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (UN 2015).

The SDG Zero Hunger is directly related to the concept of food security which, according to FAO, exists “when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO 2009). Food insecurity has been on the rise. In the 2014–2019 period, 22.4% to 25.9% of the world population was affected by moderate or severe food insecurity, while millions of tonnes of food are wasted every year (UN 2020).

The European Union (EU), one of the Save Food Regions of the Global Initiative on Food Loss and Waste Reduction, estimates that the annual amount of FLW in the EU is of 88 million tonnes, with the economic value of 143 billion euros (Vittuari et al., 2016). To reduce FLW, reduce the consumption of natural resources and the associated economic costs, the EU aims to achieve the SDG proposed by the UN, amongst other actions, by implementing a European Action Plan for the Circular Economy adopted in 2015 (European Commission 2015 2016). One of the SDG targets related to FWL is target 12.3. It states: “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.” (FAO n.d.-a). Halving FLW benefits the environment, as it reduces GHG emissions and water consumption while also benefiting the economy avoiding the watering cost and contributing towards food security and even to eventual job creation companies that help redistribute food that would otherwise be wasted (Flanagan, Robertson, & Hanson 2019).

Upcycling food for human consumption contributes to the fulfilment of several SDG. In fact, while feeding the hungry with nutritious food, it contributes to sustainable production and consumption (preventing the need to produce more food), and avoids the environmental burdens and economic costs of food waste management (Nogueira, Alves, & Vaz-Fernandes, 2021a, 2021b).

Every year, the UN releases data on SDG progress for each country member. The 2020 SDG Report shows progress was uneven although not at the required speed and rate

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to meet the 2030 Agenda (UN 2020). Some of the SDG recorded gains were: 1) the fall in the number of children and youth dropping out of school; 2) the decline in the incidence of many communicable diseases; 3) improved access to safely manage drinking water; 4) the increase in women's representation in leadership roles. However, the world has faced dramatic economic recession with rising cases of food insecurity, and natural environment depletion (UN 2020).

Reduction of FLW has raised an increasing interest by governments, non-governmental organisations, multi-national food and distribution companies and social solidarity institutions and, not surprisingly, also that of the scientific community.

During current research on FLW we found out that there is a wide amount and range of FLW data available through national and intergovernmental agencies. However, when researching for scientific literature about what is being done to tackle FLW we did not find any review articles on food surplus reuse for human consumption despite the increasing number of publications on this subject during the past years. Given the global impact of FLW on global socioeconomic and environmental sustainability, it is crucial to keep conducting studies that will further consolidate the knowledge on how to rescue and reuse FLW prioritising reuse for human consumption according to the hierarchy for waste prevention and management proposed in the Food Recovery Hierarchy Priorities (European Commission 2008; European Parliament 2019).

In this paper we aim to provide a compilation of how research to upcycle FLW is evolving to find about innovative solutions of using FLW.

## **1.2. Methods**

To tackle this issue in this systematic review, we have adopted a methodology based on the use of carefully chosen key words and temporal boundaries narrowed down to the past 13 years, from 2008 to 2021. The 2008 economic crisis impacted on all phases of the food chain from farm to industry, the redistribution sector, and the livelihood of families, hence the emphasis of this research on the rerouting of food

waste, concentrating on solutions for food insecurity (Food and Agriculture Organization of the United Nations 2010). The body of the literature so constituted was divided into 2 categories and further analysed by types of publication, geographic distribution, and key word frequency to determine the research emphasis. We also discuss the trends on food waste management as a raw material even though industrial extraction is more material and energy demanding, and therefore contributes more to climate change.

In terms of research design, we followed guidelines that propose a review process in three stages (planning, execution and reporting) (Tranfield, Denyer, & Smart 2003) (Figure 1). In the planning phase, research keywords and terms were defined according to the aim and main topic of the study. “Food Waste” (FW) and “Food Loss” (FL) were naturally the first research keywords used.

Despite what has already been referred with regard to FL and FW, some studies opted either for their own FL and FW system boundary, methods, and definitions (Hodges et al. 2011; Parfitt et al. 2010). For this reason, other designations for FL and FW concepts such as “food surplus” and “food residue”, were added to our keyword list. Because we focus on upcycling FLW we decided to make use of other research keywords such as “food waste recovery”, “food recovery”, “food reuse”, “food rescue” and “rescued food” to ensure that food waste for human consumption research was prioritised.

To secure a broad coverage of literature about FLW reduction through upcycling, Web of Science, Scopus, Google Scholar, and b-on were used to search for papers. These platforms were selected because they provide access to a series of scientific articles and because of the search filters available. Furthermore, data extracted from at least two platforms is reported to yield a more robust and reliable bibliometric analysis (de Oliveira, da Silva, Juliani, Barbosa, & Nunhes 2019).

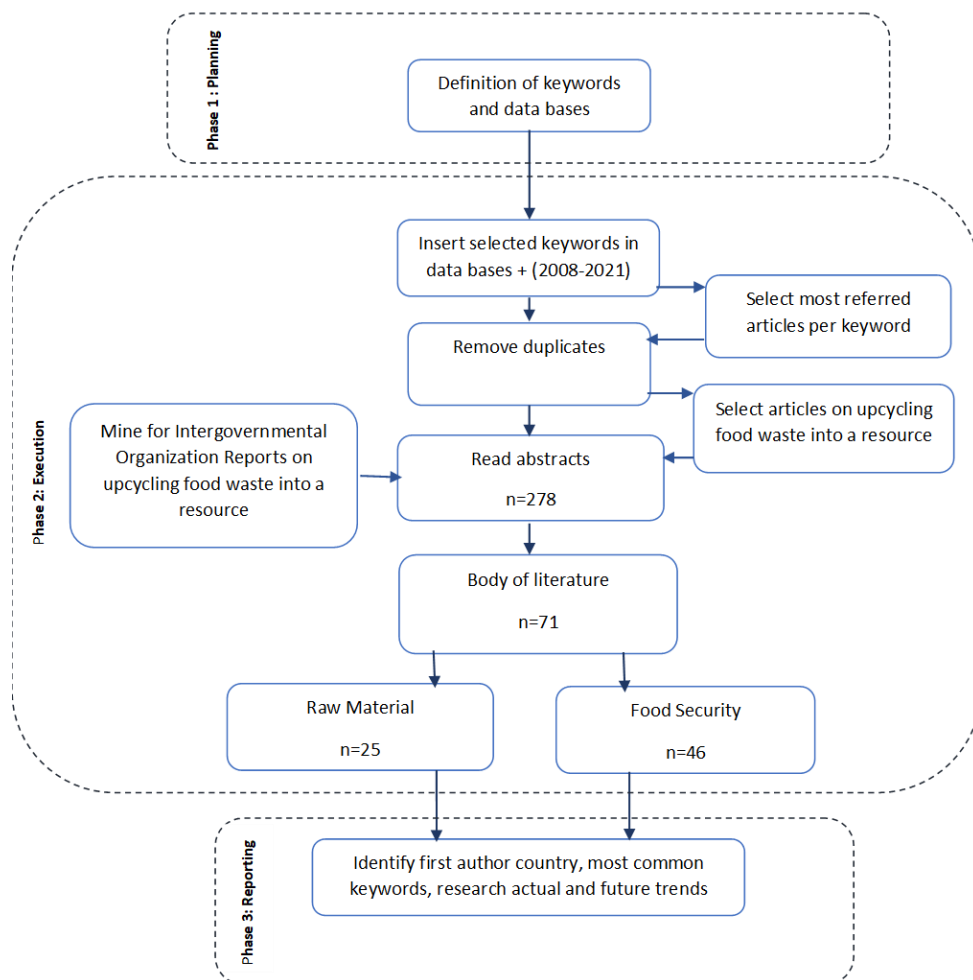
No geographical boundaries were set. All global, national, or local studies were included. We considered the country of the first author’s affiliation institute to be the country to publish the study.

We also searched for reports prepared by academic institutions and by governmental and nongovernmental organizations in the so-called grey literature. All previously mentioned keywords were used<sub>6</sub> in the search for titles of publications. In

addition, no specific language filter was used, and results were ordered by relevance.

All duplicates and all articles that did not focus on proposing novel systems of transforming FLW into a resource as a raw material or to tackle food insecurity, were discarded.

After reading through abstracts of roughly 280 published documents, extracted from B-On, Scopus, Web of Science and Google Academic, a body of literature of 71 publications provided an update on how to upcycle FLW. Even though our focus of interest is the reuse of food surplus and food waste for human consumption, the 71 compiled publications were divided into two main categories called Raw Material, and Food Security (Figure I.1).



**Figure I.1-** Methodology design

The raw material (RM) category includes articles that focus on using FLW as a source of bioenergy or as a material source for extraction of high-value compounds or molecules to be applied in various types of industry. This is the category where, by far, most found papers fall into, confirming there is a growing interest in the use of FLW as a source a clean energy and material resource. In 2017 an extensive biometric study on food waste research (as a raw material) from 1997 to 2014 was published concluding that research on clean energy sources, treatment, valorisation, and innovative management of food waste have attracted extensive attention and will continue to be the focus point of the decision-making and policy of FW management for governments in the future (Chen, Jiang, Yang, Yang, & Man 2017). Thus, we believe it is important to highlight the most recent works on FLW as an energy or material resource.

The Food Security category includes articles that focus on a wide variety of issues related to the use of FLW for human consumption such as vectors and how the following are expected to evolve: recoverable food waste; practices leading to the reduction of FLW; comparative studies on the best option to reuse FLW; values and behaviours in relation to foods that contribute to the propensity to waste food in residential, institutional and commercial sectors; projects or strategies to deal with food surplus; food waste in developing countries; the environmental impact of food surplus; the economic benefits of food surplus recovery; food waste management policies.

### **1.3. Results and discussion**

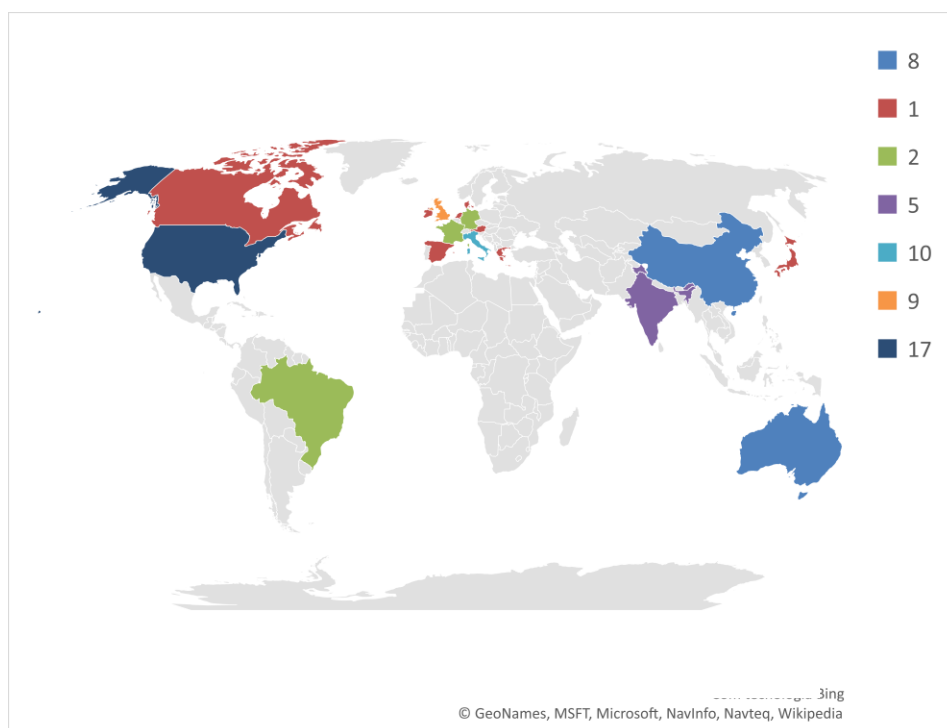
After analysing the content of each paper, it was clear that there is an unbalanced focus on the different stages of the food supply chain. Almost all studies focus on food waste at retailing and consumer levels, while only very few address immediate postharvest losses. Considering that FAO estimates that postharvest losses can reach up to 20.7% percent in Central and South Asia, 15.7% in Northern America and Europe, 14% in Sub-Saharan Africa, 11.6% in Latin America and Caribbean, 10.8% in Northern Africa and Western Asia, with a mean value of 13.8% worldwide, this result suggests that, to tackle hunger and malnourishment, further research is needed in addressing post-harvest losses, hopefully resulting in innovative ways of tackling the problem.(FAO 2016).

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Once we had gathered the literature available, we found it could be divided into four different types of documents: articles in peer review journals, books, reports, and conference proceedings. Journal articles were the most common type with 90% accounting for literature, followed by 6% for books, 3% for reports, and 1% for conference proceedings.

Journals dedicated to different, often overlapping, fields focused mainly on waste management, biotechnology, chemical engineering, environmental sciences, food sustainability research, and socio-economic sciences fields.

The few countries in which literature is published is indicative of its narrow spatial coverage. Figure I.2 illustrates the total distribution of where the main author's institution is geographically located. It also shows that the top seven most productive countries on FLW research are the USA, Australia, Italy, the UK, and China, followed by India.



**Figure I. 2** – Total geographical distribution of where the main author's institution is located

Although most existing studies on FLW are conducted in industrialized countries, (79 % of main authors), there is also a clear interest in the subject in some emerging countries, (21% of main authors) indicating a worldwide interest in FLW management. The global socioeconomic crisis that began in 2008 and international policies (FAO 2015; UN,

n.d. 2015; United Nations 2018) could be at the origin of the national interests of these countries. Furthermore, this distribution reflects the large values of the per capita food losses and waste, at consumption and pre-consumptions stages, in Europe, North America, Oceania, and Industrialized Asia as well as emerging countries (24). Food losses in industrialized countries are as high as in developing countries. However, in developing countries more than 40% of the food losses occur at post-harvest and processing levels, while in industrialized countries, more than 40% of the food losses occur at retail and consumer level (FAO 2011a). Moreover, national and global socioeconomic adversities were aggravated by the COVID-19 pandemic, to such an extent that it is considered the worst economic recession since the Great Depression with an increasing number of people suffering from food insecurity (UN 2020).

Since 2008, we have been witnessing an outburst of FLW research publications related to aspects of food waste management and bioenergy production through anaerobic digestion of FLW, as a way of both producing biofuels and manage food waste (Chen et al. 2017). From our body of literature of 71 publications, 25 fell into the Raw Material category, and 46 into the Food Security category.

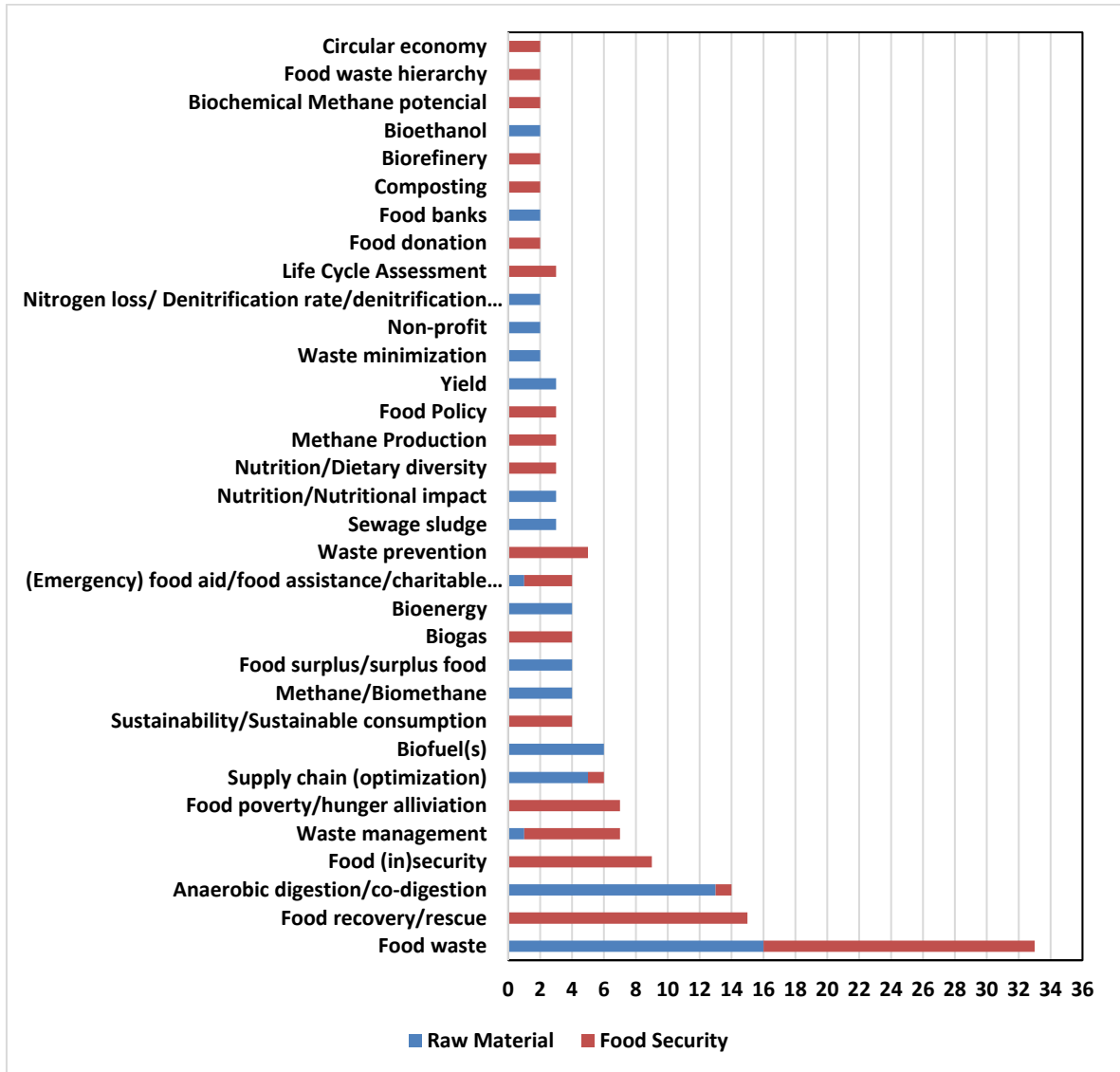
The USA is one of the most productive countries, followed by Australia, Italy, and the UK. Households' food waste estimates provided by the United Nations 2021 Food Waste Index Report (United Nations Environment Programme 2021) indicate values of 59 kg/capita/ year in the USA, 102 kg/capita/ year in Australia, 67 kg/capita/ year in Italy, and 77 kg/capita/year in the UK. FAO estimates that consumers waste 95-115 kg of food/year per capita in Europe and North America, with similar values at production to retailing level (~180 kg/capita/year) for Europe, North America and Oceania (FAO 2011a). All four countries have published in the food security category showing a large interest in upcycling food as a resource to feed food insecure populations.

The number of publications in the Raw Material category in some emerging countries such as China and India, addressing the issue of FLW on the different stages of the food supply chain as a clean source of energy and raw materials, suggests a national interest in waste management and biofuel production. Food waste estimates in India,

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at household level, are 20kg/capita per year (UN n.d.). China is noteworthy as it is a very large country with a substantial internal variation in terms of population, and thus showing a wide range of food waste estimates from 64 kg/capita/year at national level but 150 kg/capita/year in urban areas (United Nations Environment Programme, 2021). Due to a rapid growth, it is predictable that research in the food waste field will continue to develop in both countries.

In order to examine the emphasis of the research carried out, a total of 241 author keywords were quantified and classified by total frequency and frequency in each category. In this classification process, groups of words in different order, such as “food surplus” and “surplus food”, or groups of words conveying the same concept, *e.g.* “nitrification loss” and “denitrification rate”, were classified as one and the same keyword. Figure I.3 shows all the 33 keywords that were used more than once ranked by total frequency.



**Figure I.3-** Absolute frequency of author keywords mentioned more than once, with frequency per category (total frequency, n=169).

Considering only 13.7% (33/241) author keywords were mentioned more than once indicates that mainstream research on FLW focused on a small area. To draw on the research trends from 2008 to 2021, we analysed the top 33 most frequent author keywords. Keeping in mind the previously established categories (Raw Material and Food Security) helped to relate broad meaning keywords like “food waste” or “sustainability” to the research field they were applied to.

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Results show the top 33 keywords were related to: 1) food waste treatment and disposal (food waste (RM); anaerobic (co-) digestion, sewage-sludge, composting); 2) bioenergy production (biofuel, bioenergy, biogas, methane production, methane/biomethane, bioethanol, biorefinery, biochemical methane potential, nitrogen loss, yield); 3) food waste management (waste prevention, sustainability, waste management, waste minimization, food waste hierarchy, circular economy); 4) food security (food waste (FS), food (in)security, food poverty, emergency food aid/food assistance, nutrition/dietary diversity, food banks, food donation, non-profit, food recovery, food surplus, supply chain optimization).

### **I.3.1. Food Waste as Raw Material**

During the period of study for the category of Raw Material, operational conditions of bioenergy production through anaerobic digestion and co-digestion were the centre of several research papers (Chen et al., 2017; Cheng et al., 2021; Karmee, 2016; Sen, Aravind, Kanmani, & Lay, 2016; Talan et al., 2021).

The interest in the effect of the composition of mixtures that are fed to anaerobic digesters on the yield of biomethane production for different mixtures of food waste or mixtures of food waste and sewage sludge indicates that efficient ways of solving disposal problems while replacing the use of fossil fuels are being sought (Ebner, Labatut, Lodge, Williamson, & Trabold 2016; Fisgativa, Tremier, & Dabert 2016; Fitamo, Boldrin, Boe, Angelidaki, & Scheutz 2016; Koch, Plabst, Schmidt, Helmreich, & Drewes 2016; Yong, Dong, Zhang, & Tan 2015; Zhang et al. 2016). The search for high efficiency processes of producing biomethane has led to the proposal of corrective chemical or micro-wave pre-treatments of the digesters feeding mixtures (Fisgativa et al. 2016; Karthikeyan et al. 2018; Zhang et al. 2016). Alternative solutions to optimize biofuel production involve controlling process variables like pH, electrical conductivity, nitrogen loss or recirculation (Chan, Selvam, & Wong 2016; Zamanzadeh, Hagen, Svensson, Linjordet, & Horn 2016) or using an innovative high-solid anaerobic membrane bioreactor (Cheng et al., 2021).

Besides that, monitoring and controlling the evolution of microbial community structure, can also enhance productivity and contribute to harness bioenergy production at lower costs (Sen et al., 2016; Talan et al., 2021; Zamanzadeh et al., 2016; Junya Zhang et al., 2016; Zhen, G., Lu, X., Kobayashi, T., Kumar, G., Xu, 2016). Other biofuels can similarly be produced from the controlled fermentation of FW, such as bioethanol (and possibly longer chain alcohols) and biohydrogen, a most promising option of sustainable energy source due to its energy yield (Han, Fang, Liu, & Tang, 2016; Hegde, Lodge, & Trabold, 2018; Karmee, 2016; Talan et al., 2021). Moreover, hydrogen can be directly used to produce electricity through fuel cells with the advantage of being environmentally friendly with limited impact on global climate change, when compared to fossil fuels and even when compared to other biofuels. To a lower extent, due to high energy costs and low efficiency, pyrolysis of FW can produce biooil, biochar, and biofertilizers (Karmee 2016).

In recent years, FW was found to be an adequate raw material for more than the production of biofuels. Ravindran (2016), Barik (2017) and Xu (2018) advocate that the extraction of value-added materials from FW should precede the production of biofuels, reducing the size of the landfill discarded fraction, increasing revenues and reducing co-digestion costs (Barik & Paul 2017; Ravindran & Jaiswal 2016; Xu, Yang, Ge, & Li 2018). The concept of extracting biomaterial from FW adds another dimension to the keyword *biorefinery*. FW is a reservoir of carbohydrates, proteins, lipids, and other organic and inorganic substances, hence the application of the term “biorefinery” to the process of recovering material from FW using industrial processing technologies. Recycling inside the food supply chain can be an economical and environmentally sustainable way of producing renewable feedstock for industrial uses (Galanakis 2015; Girotto, Alibardi, & Cossu 2015). Ongoing research already addresses several industry sectors. Recovered nutrients, molecules and metals, can either be used in the food industry, animal feed industry or pharmaceutical industry as flavourings and fragrances, antioxidants, food additives and nutraceuticals (Barik & Paul 2017; Kim, zu Ermgassen, Salemdeeb, Al-Tabbaa, & Balmford 2016; Ravindran & Jaiswal 2016).

Other industrial sectors could benefit from the production of metabolites, enzymes, bioactive compounds, biodegradable plastics, nanoparticles or as catalysers of nitrogen removal in waste water treatment (Li, Tang, Zhang, Cheng, & Wang 2015; Ravindran & Jaiswal 2016).

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All previously mentioned extractions can occur in integrated biorefineries that produce extracted chemicals with one fraction of the feedstock, and bioenergy with the remaining fraction. Even though integrated biorefineries still present many challenges they are a promising way to circular economy (Xu et al. 2018). Furthermore, integrated biorefineries have a closed loop approach to waste valorisation, contributing to promote the switch from fossil fuels to green fuels while reducing the production of greenhouse gases with corresponding positive impact on climate change.

### **I.3.2. Food Security**

By analysing the top 33 keywords in the current study we found that 59.5% (frequency percentage) of them concerned food security – this shows that food security is yet another research trend.

Food insecurity is felt in developing and developed countries, and even in food surplus areas. It was found that increasing the production does not ensure food and nutritional security, which makes food insecurity a question of access to food, rather than a supply problem (Papargyropoulou, Lozano, Steinberg, Wright, & bin Ujang 2014).

Tackling both food insecurity and food waste have been the centre of several international guidelines based on the European Community Strategy on Waste Management first proposed by the European Parliament Council in 1984 (COMMISSION OF THE EUROPEAN COMMUNITIES 1989). This strategy (meanwhile adopted worldwide as the main waste management framework) is depicted as an inverted waste hierarchy pyramid (UNEP 2013). It prioritises prevention as the most favourable option and considers landfill disposal as the least favourable. In the model presented, the second-best option – reuse - is the distribution of food surplus to low-income groups followed by recycling, the use

of FW in animal feed and composting, with the last but one option being energy recovery of unavoidable food waste (UNEP 2013).

Even though *Prevention* through minimization of food surplus and avoidable food waste is the most preferred option of food waste hierarchy, waste prevention is the centre of very few studies. In this chapter, it is important to mention that not all FW is avoidable. Some parts of food must go to waste, such as certain peels and fruit stones (*e.g.* pineapple peel or mango stones). Considering that the percentage of avoidable food waste in some developed countries ranges from 34% (in Sweden) to 60% (in the UK), food waste prevention policies could reduce the amount of FW treated in all other hierarchy stages until disposal, with huge environmental and economic benefits (Thyberg & Tonjes 2016). Unfortunately, waste goals are usually defined in terms of recycling or diversion, rather than prevention indicators, namely SDG targets for FW reduction, defined as: “By 2030, halve global food waste per capita at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” (FAO 2011b). Not only SDG provides no target specifically concerning prevention, but the only measurable target is situated at retail and consumer levels. Therefore, it is a priority to adjust policies towards food to prevent the generation of FW along the whole food supply chain (Redlingshöfer, Coudurier, & Georget 2017; Thyberg & Tonjes 2016).

In order to ensure universal access to nutritious food in adequate quantities, the change in waste prevention policies must reflect a change from a weak prevention model to a strong prevention model (Mourad 2016). Weak prevention solutions usually focus on technical or logistic innovation to improve the efficiency of consumption but are not a sustainable option from a long-term perspective (Longo-Silva, Toloni, Rodrigues, Rocha, & Taddei 2013). Moving from weak to strong prevention requires a change in governance along the food supply chain, involving all the actors – producers, retailers and consumers – in a sustainable system imbued activity (Mourad 2016). This change of production and consumption paradigm presents implementation limitations due to constraints in individual behaviour and policy changes which are the object of several studies.

In a household environment, the required changes may be as simple as planning serving portions and changing the content of served meals or even consuming leftovers. The consumption of leftovers is regarded as a sacrifice that sustains and perpetuates

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family roles, reinforcing family bonds or engaging in redistribution practices (Cappellini 2009). Readjustment of serving sizes and content may also be a strategy to tackle the problem of food surplus and leftovers in school and company canteens (Evans 2012). Moreover, unavoidable surplus may be diverted from landfills in school canteens through programmes that promote the volunteer participation of students in the process of sorting uneaten food. This process facilitates food recovery while equipping the next generation with environmental stewardship habits (Prescott, Grove, Bunning, & Cunningham-Sabo 2020). In developing countries food waste at household level is considerably lower than at production to retail level, 40% of food loss occurring at post-harvest and processing stages (FAO 2011a). Numerous developing countries have been living in a protracted crisis with populations in need of enhanced effectiveness in terms of assistance programmes. Technology transfer and access to microcredit are needed to support and protect livelihoods, as are education programmes for farmers, better infrastructures to connect small farmers to markets, and the adoption of collective marketing. (Cicatiello, Franco, Pancino, & Blasi 2016; Hodges et al. 2011; Katz & Rivero 2015; Parfitt et al. 2010; Walia & Sanders 2019).

Another line of research that attracts researchers from countries as different as the USA (Mittal, Oran Gibson, Krejci, & Marusak 2021; Shi & Lizarondo 2021), Italy (Cicatiello et al., 2016; Ciccullo, Cagliano, Bartezzaghi, & Perego, 2021; Muriana, 2015), the Netherlands (Ciulli, Kolk, & Boe-Lillegraven 2020), and Australia (Nair, Grzybowska, Fu, & Dixit 2018; Rey, Almi'ani, & Nair 2018) is the development of mathematical models to solve FW management problems at the *Reuse* stage of the FW hierarchy inverted pyramid.

Food waste or food surplus is often redistributed to the food insecure populations through food banks and other non-profit organizations. One of the first identified problems of these type of organizations is the cost of food transportation from the food source (*e.g.* farmers, retail distribution centres) to the food redistribution centres. A 2013 report by the World Resources Institute suggests that the transportation obstacle can be overcome by establishing additional food redistribution centres and optimizing FW picking up and delivery routes (Lipinski et al. 2013). Humanitarian logistics optimization has evolved through the use of different mathematical algorithms (very often based on

linear regression), presenting novel approaches for the food rescue and delivery problems. It is important to highlight that the optimization of pickup and delivery routes, while lowering operating costs, also reduces the environmental impact of the pickup process and alleviates climate burdens due to food surplus (Hiç, Pradhan, Rybski, & Kropp 2016).

Rey *et al.* (2018) found that using fewer vehicles is likely to help improve the fairness of FW allocation, thus proposing a solution of using a single large capacity vehicle with longer routes to ensure enough food supply (Rey et al. 2018). Recruiting additional donors and volunteers was also found to be an efficient strategy to decrease economical costs of food relief logistics (Mousa & Freeland-Graves 2017; Phillips, Hoenigman, Higbee, & Reed 2013; Shi & Lizarondo 2021).

Food rescue and redistribution, of perishable foods may be more economically and environmentally costly and complex than landfill and composting or even than acquiring, storing and redistributing dried staple foods (Krishnan, Agarwal, Bajada, & Arshinder 2020; Philip, Hod-Ovadia, & Troen 2017; Reynolds, Piantadosi, & Boland 2015). It also requires infrastructures to safeguard food hygiene and safety standards and particularly when redistributing frozen and chilled food (Alexander & Smaje 2008; Garrone, Melacini, & Perego 2014). Nevertheless, procuring food for the food insecure is a lower cost method than purchasing meals directly, with improved nutritious quality when compared with the dried and staple foods usually distributed in foodbanks (Philip et al. 2017). A review article published in 2019 documented the need for additional evaluation of food rescue interventions, with consistent metrics, but still suggesting promising effects, including large quantities of food rescued and served clients, positive return on investment, and decreased environmental burden (Hecht & Neff 2019). Life Cycle Analysis results suggest that, apart from reducing environmental pressure and capital loss, food waste rescue may also generate work opportunities, while conditioning stakeholders' behaviour (Santagata, Ripa, Genovese, & Ulgiati, 2021).

To ensure high stakeholder satisfaction and the sustainability of charitable networks it is vital to understand the relationship between supply and demand (Hecht & Neff 2019; Krishnan et al. 2020; Nair et al. 2018). In FW management and redistribution this means being able to forecast food donations while correctly estimating food demand,

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minimizing the fraction of recovered food that is not used for human consumption (Ciulli et al. 2020; Garrone et al. 2014). A software based on structural equation modelling and neural networks was found to provide improved demand estimation when compared with multiple linear regression (Nair, Rashidi, & Dixit 2017).

Researchers also focus on modelling the suppliers' side of FW redistribution to determine the optimal shelf life and quantity of products to be removed from distribution shelves and shipped to non-profit organizations (or livestock feed). Sustainability of the donation process means that the optimal point found must correspond to maximum profit for the retailer (Giuseppe, Mario, & Cinzia 2014; Muriana 2015). Implementation of circular economy at retail level can also be achieved through the adoption of repositioning, reallocating, reacting, re-engineering, and relating practices, with economic, social and environmental benefits (Huang et al., 2021).

Digital platforms have recently emerged as a response to the need for circularity brokers. These innovative tools facilitate the brokerage of food surplus supply and demand all along the food supply chain, as well as transportation and human resources logistics (Ciccullo et al., 2021; Mittal et al., 2021; Nair et al., 2018, 2017; Shi & Lizarondo, 2021).

Although it may seem that recovery and redistribution of food waste and food surplus is a contemporary form of socioenvironmental activism supported by the whole scientific community, this issue is not that linear (Edwards & Mercer 2012). If some researchers consider that alternative food networks are a way to ensure food justice and environmental sustainability, through social innovation, in need of a special set of tools, resources and laws, others have another set of concerns (Baglioni, De Pieri, & Tallarico 2017; Lindberg, Lawrence, Gold, & Friel 2014; Planchenstainer 2013). A first concern regards the pertinence of the charitable food sector, in those policies targeting which determinants of food insecurity should be implemented to reduce demand for emergency food, together with governmental regulations on FW minimization, rather than relying on the power and initiative of civil society organizations. Empowering community governance only, depoliticizes food insecurity issues and transfers the responsibility of rescuing and redistributing food waste and food surplus to local community members (Lindberg et al. 2014; Warshawsky 2015; Wingrove, Barbour, & Palermo 2017).

A second concern is related to the rescue and redistribution system where each party at each transfer point passes on property waste disposal obligations (Alexander & Smaje 2008). This may lead to situations where parties might be more interested in avoiding disposal costs than providing the food insecure with nutritious food, transferring food in poor hygiene and safety conditions.

### **1.3.3. Food Waste future research trends**

Due to the ever-increasing population, resource, and commodity limitations, to climate change, and unpredictable scenarios such as the COVID-19 pandemic, we will see an economic, social, and environmental increase in the price of food, leading to the need for more efficient food production and consumption systems (Aldaco et al. 2020; Pollard et al. 2018). Thus, in addition to the ongoing research paths, as another result of this literature review, we have identified possible future FLW research trends.

Affluent countries are likely to develop responses to FSC waste trends such as: 1) circular economy implemented in the legislation of all countries; 2) new strategies to reuse FW as a bioenergy and biomaterial source; 3) clear labelling and consumer education campaigns; 4) better policies on FCS waste and FW taxation; 5) public and private partnerships; 6) better demand forecast; 7) optimized (shared) logistics; 8) domestic kitchen technologies; 9) better packaging; 10) technology transfer to BRIC countries (Brazil, Russia, India and China) (Cicatiello et al. 2016; Facchini, Iacovidou, Gronow, & Voulvoulis 2018; Hodges et al. 2011; Katz & Rivero 2015; Parfitt et al. 2010; Walia & Sanders 2019). In order to reduce the impacts of FW significantly and generate social and environmental benefits, less developed countries will have to implement: 1) widespread education programmes directed at farmers; 2) better infrastructures to connect small farmers to markets; 3) adoption of collective marketing; 4) improve access to technologies through microcredit; 5) financial incentive opportunities that improve efficiency along the FSC (Hodges et al. 2011).

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#### **I.4. Conclusions**

This compilation provides an overview on the evolution of FLW throughout the investigation period of 2008/2021. Based on the selected publications, the following conclusions were drawn from the current study: 1) FLW as raw material research, mainly concentrated in China, India and the USA, focuses on the fields of chemical engineering, energy fuels, environmental engineering, biotechnology, and microbiology applied to engineering; 2) A second FLW research field, taking place mainly in Australia, European countries and the USA, focuses on food security, FW upcycling for human consumption improvements in terms of humanitarian logistics, concerning supply, transportation, conservation and volunteerism; 3) For lower and medium income countries FLW resides mainly at production to retail level where farmer support programmes could promote environmental and social improvements; 4) There is a lack of research focusing on measuring the potential of rescued and redistributed perishable FW as a way of tackling food insecurity.

Valorisation of food waste turning it into a material or bioenergy source requires know-how and more time, energy and other material consumption than the process of upcycling food as is. To reduce climate change resulting from the environmental burdens of food waste, we advocate that FW upcycling through technological innovation should be sponsored towards developing solutions for inevitable and non-edible parts of FW.

To address food insecurity, the future decision-making and policy of FW management should prioritise targeting determinants of food insecurity which in turn would reduce the food aid demand. Furthermore, climate change causing food insecurity and malnourishment should also be addressed with policies aiming at changing the food production and consumption paradigm throughout the food chain.

The main limitation of this review is that it cannot comprise an in-depth study of all subjects. Issues such as policies, laws, and technical particularities of all the processes to transform food waste into a material or energy source were approached in a descriptive way since the aim was to identify the different paths of food waste research.



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## **II. UP-CYCLED FOOD IN A BALANCED DIET**

# The contribution of up-cycled food waste to a balanced diet of low-income households

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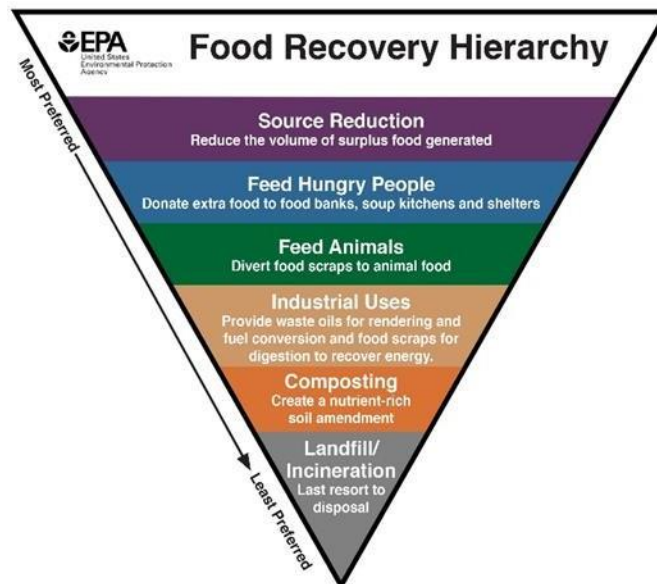
**Abstract:** This paper focuses on the contribution to a balanced diet of an upcycling food organization which rescues and redistributes fresh or freshly cooked food to low-income households. To determine the nutritional balance of food hampers provided by our case study organization, according to the Portuguese food guidelines, we have weighed all items of food hampers in three weighing rounds, over a period of 4 months. Results suggest that upcycled foods can contribute to a more balanced diet in terms of “Potato, Cereal and Cereal Products”, “Vegetables”, “Meat, Fish, Seafood and Eggs” and “Fruits”, both according to the Portuguese Food Wheel and comparing to that of the general Portuguese population. The novelty of this study is the evaluation of the contribution to the balanced diet of population in a vulnerable situation, of perishable foods such as freshly cooked, in traditional restaurants, cafes, bakeries, and hotels, or is naturally fresh (fruit and vegetables food aid services) up cycled by a food aid organization.

## II.1. Introduction

At a time when the world continues to use natural resources unsustainably, food recovery and redistribution activities offer the opportunity to build a more sustainable future. Food redistribution initiatives to address both food insecurity and food waste.

The United States Environmental Protection Agency (EPA) released, on its official website, a food recovery hierarchy (Figure II.1), prioritizing actions to prevent and divert food waste. This scheme is designed in an inverted triangular shape divided in levels, where the top option corresponds to food waste prevention and the second-best option, called “Feed Hungry People”, amounts to donating food surpluses to food banks, kitchens, and shelters.

Food waste is a reservoir of carbohydrates, proteins, lipids and other organic and inorganic macro and micronutrients, which can be regarded as a material source in food industry, animal feed industry or pharmaceutical industry (Barik & Paul, 2017) as flavorings and fragrances, antioxidants, food additives and nutraceuticals. However, industrial extraction processes require know-how and is more time, material, energy, and human resources consuming (Ravindran & Jaiswal, 2016). Hence, being less environmentally favorable way of up-cycling food, whether for low-income populations or not (Alfio, Manzo, & Micillo, 2021; Ali, Singh, & Sharma, 2017; Vaish, Srivastava, Singh, Singh, & Singh, 2020), it is referred in the fourth level of food hierarchy as “Industrial Uses”.



**Figure II.1:** Food Recovery Hierarchy (EPA Environmental Protection Agency, n.d.)

Food rescue integrates several of the 17 Sustainable Development Goals (SDG) of the current 2030 Agenda (UN, 2015; United Nations, 2017), developed by the UN member countries to mobilize stakeholders’ networks, coming together for a common purpose. Rescuing and redistributing food helps feeding low-income populations (SDG 2), as well as reduces greenhouse gas (GHG) emissions (SDG 13), land use, energy, and water consumption all along of the food production chain (Vittuari et al., 2017). The food upcycling process prevents the need of producing more food to feed the population it is distributed to, while avoiding the environmental and economic costs of managing the

recovered food as waste. SDG 12, sustainable consumption, and production is about the use of resources without jeopardizing the needs of future generations and thus food recovery and redistribution perfectly fits this goal.

Along environmental and economic savings, social benefits can be produced when food redistribution initiatives are put in place, leading to more sustainable cities and communities (Cicatiello et al., 2016). In fact, most food redistribution activities are community-driven innovative solutions created by non-governmental organizations to alleviate malnourishment, using food surplus as an upcycled resource (SDG 9). When basic needs like housing and decent balanced nourishment are covered, one can argue that conditions are set to the sustained and inclusive economic growth of the impoverished populations, which would include food redistribution activities as changes in local practices that contribute to the concretion of SDG 8.

Several studies have been conducted to examine the nutritional adequacy of meals, from food bags, soup kitchens, and pantries, provided to low-income populations in the USA (Hecht & Neff, 2019; Hoisington et al., 2011; Mousa & Freeland-Graves, 2019), Canada (Jessri, Abedi, Wong, & Eslamian, 2014; Tse & Tarasuk, 2008), Australia (Lindberg et al., 2014), Germany (Depa, Hilzendegen, Tinnemann, & Stroebele-Benschop, 2015), UK (Pelham-Burn et al., 2014; Preston & Burley, 2015a; Sprake et al., 2014), the Netherlands (Neter et al., 2018), Italy (Maioli et al., 2016; Vittuari et al., 2017), and in a cross-national study in Australia, UK, and USA, finding the common conclusion that food donations, albeit nutritionally insufficient, can improve the nutritional status of recipients (Simmet et al., 2017).

Yet, none of the mentioned research was focused on the contribution exclusively of recovered, and mainly fresh or freshly cooked, food to a balanced diet of low-income population. Even so, similar research will be used for results comparing purposes, regardless of whether the studies were about soup kitchens (Maioli et al., 2016; Pelham-Burn et al., 2014; Sprake et al., 2014; Tse & Tarasuk, 2008), food pantries (Mousa & Freeland-Graves, 2019; Simmet et al., 2017) or food hampers (Hoisington et al., 2011; Jessri et al., 2014; Preston & Burley, 2015b).

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The main aim of this study is to evaluate the contribution of fresh and freshly cooked rescued and redistributed food to supplement low-income households' diet, according to the Portuguese guidelines, using as a case study the ReFood-Leiria organization. Firstly, we will consider only the data categorized as redistributed foods belonging to the Portuguese Food Wheel. Secondly, we will consider the total data whether belonging or not to the Portuguese Food Wheel, which will also allow the third evaluation comparing with the dietary pattern of the general Portuguese population.

## **II.2. SDG Global Situation, Global and Local Initiatives**

Every year the UN collects and summarizes information released by all country members. The 2020 Sustainable Development Goals Report brought together data showing that, before the COVID-19 pandemic, progress remained uneven, and that the world was not on track to meet the Goals by 2030. Table II.1 summarizes the 2020 situation with respect to the SDG 2, 8, 9, 12 and 13, directly involved in this paper, highlighting pre and amid COVID-19 conditions, plus main related concerns (UN, 2020).

Globally, in 2020 there were SDG gains recorded, such as the share of children and youth out of school that had fallen, the decline in the incidence of many communicable diseases, the improvement of access to safely managed drinking water, and the increase women's representation in leadership roles. At the same time, the world faced the worst economic recession since the Great Depression with a rising number of people suffering from food insecurity, and the natural environment continued to deteriorate at a dramatic rate. All in all, halfway through 2020, the UN considered that change was not happening at the required speed or scale (UN, 2020).

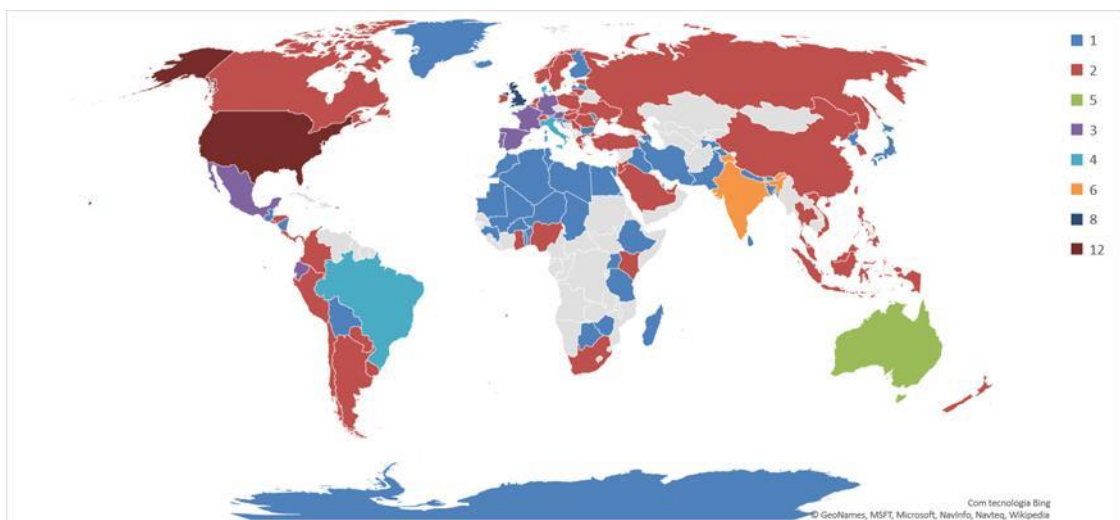
**Table II.1:** Global situation of SDG 2, 8, 9, 12 and 13 pre and amid COVID-19, reported by the UN in 2020 (UN, 2020)

SDG	Before COVID-19	COVID-19 Implications	Other Concerns
<b>SDG 2 Zero Hunger</b>	Food insecurity was already on the rise; 2014-2019 Population affected by moderate or severe food insecurity: 22,4% to 25,9%	The pandemic is an additional threat to food systems (lockdown prevents small-scale food producers from getting their products to consumers), together with conflicts, climate shocks, locust crises.	Stunting and wasting among children are likely to worsen; 21.3% (144 million) of children under 5 are stunted; 6.9% (47 million) of children under 5 are affected by wasting (2019)
<b>SDG 8 Decent work and Economic Growth</b>	Global economic growth was slowing down; 2010–2018 2.0% GDP per capita growth 2019- 1.5% GDP per capita growth	The world faces the worst economic recession since the Great Depression  2020 - GDP per capita expected to decline by 4.2%	During the pandemic 1.6 billion workers in the informal economy risk losing their livelihoods  Tourism is facing unprecedented challenges
<b>SDG 9 Industry Innovation and Infrastructure</b>	Manufacturing growth was declining due to tariffs and trade tensions	The aviation industry has suffered the steepest decline in history; January - May 2020 Air passenger numbers fell by 51%	Financing for small-scale industries is needed for their survival through the crisis;  Investment in R&D is growing but needs to accelerate
<b>SDG 12 Responsible Production and Consumption</b>	The world continues to use natural resources unsustainably; 2010 – 2017 Global material footprint rose from 73.2 billion to 85.5 billion Metric tons 2017- 2019 -79 countries and the European Union reported at least one policy to promote Sustainable Consumption and Production	The pandemic offers an opportunity to develop recovery plans that build a more sustainable future.	2010–2019 Electronic waste grew by 38% But less than 20% is recycled.  2015-2018 Rising fossil fuel subsidies are contributing to the climate crisis from \$318 billion to \$427 billion
<b>SDG 13 Climate Action</b>	Global community shies away from commitments to reverse the climate crisis 2019 was the second warmest year on record 2100 - Global temperatures are projected to rise by up to 3.2°C	COVID-19 may result in a 6% drop in greenhouse gas emissions for 2020  Still short of 7.6% annual reduction required to limit global warming to 1.5°C	Climate change continues to exacerbate the frequency and severity of natural disasters  2018- affecting more than 39 million people

An online overview collection was conducted to identify food waste recovery and redistribution organizations around the world, and their most common types of self-reported aims, activity, management, and redistribution. In some cases, redistribution initiatives were identified searching for official online sites (e.g. Global Food Banking Network), and in other cases, when there are no organization sites due to the nature of the initiatives, some grey literature was used (e.g. Solidarity Fridge).

Food waste recovery and redistribution initiatives are sustainable, usually local bottom-up (Grabs, Langen, Maschkowski, & Schöpke, 2016), practices in supply food chain that provide consumers with otherwise wasted food (Vittuari et al., 2017). We found that these local practices, which very often combine the aims of providing food for people in need with reducing the environmental impact of binning perfectly edible food (Nikravech, Kwan, Dobernig, Wilhelm-Rechmann, & Langen, 2019; Vlaholias, Thompson, Every, & Dawson, 2015), can be found worldwide in a large range of sizes, types of management and redistribution (Appendix A available with identification of all organizations found online).

In terms of geographical coverage, we have identified food waste recovery and redistribution initiatives in 126 regions/countries of all 5 continents, unevenly distributed. In fact, these organizations can be found in larger numbers in America, Europe, and Australia than in Asia and Africa (Figure II.2).



**Figure II.2:** Number of food recovery organizations identified per country (Appendix A - Identification Food Recovery Organizations)

Even though the Global FoodBanking Network (GFN) doesn't rely exclusively on food surpluses it still is, by far, the largest worldwide network of redistribution of donated food, whether surpluses or not, with members and partners of all continents. This organization of 947 foodbanks, each one acting at a local level, alleviates hunger in more than 40 countries where food banks partner (The Global Food Banking, n.d.). The distribution takes place with the partnership of around 56,000 community-based agencies, which in turn redistribute the food to the population (Alimento para Todos, n.d.; Feeding America, n.d.; Mesa Brazil, n.d.; Siticibo, n.d.).

Initiatives like the Solidarity Fridge, operate on their own through the actions of a group of citizens who replicate a model that works in other countries (The salt, n.d.), while others redistribute food surpluses using a digital App such as Feeding Forward in the USA (Feeding Forward, n.d.) or OLIO (OLIO, n.d.-a) in over 118 countries (OLIO, n.d.-b).

In terms of organizations with local or micro local activities of collecting food, along the food supply chain, and redistributing it to low-income households, the most common means of (European Commission, 2017) distribution are: 1) transforming uncooked food in meals distributed in soup kitchens (DC Central Kitchen, n.d.; Fareshare, n.d.; FoodCycle, n.d.; LA Kitchen, n.d.); 2) solidarity grocery programs (no-cost, symbolic cost or in exchange of social food vouchers) (Boulder Food Rescue, n.d.; City Harvest, n.d.; Daily Table, n.d.; OzHarvest, n.d.); 3) periodically distribution of food baskets to needy families (Annakshetra, n.d.; Food Recovery Network, n.d.; Foodforward, n.d.; Grow Sheffield's abundance, n.d.; Hands for hunger, n.d.; ReFood, n.d.; Second Bite, n.d.; Society of St Andrew, n.d.; Stop spild af Mad, n.d.).

Collecting food surplus and redistributing to low-income families is precisely what is done by our Portuguese case study, the ReFood project, a bottom-up organization, developed initially in Lisbon, currently with national coverage even though each operation center has micro-local recovery and redistribution activity. In other terms, the ReFood project can also be categorized as a grassroots initiative considering it is a collaborative social initiative organized at local community level, with a high degree of participatory decision-making process (Grabs et al., 2016).

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The Refood project started its activity in Lisbon in 2011 (Refood, n.d.). This organization is a 100% voluntary micro-local project that rescues food, from the large or small distribution (groceries, supermarkets, fruit, and vegetable minimarkets), as well as from the HORECA channel (hotels, restaurants, and cafes), barbecue takeaway, and canteens (food sources of the project) and redistributes food surpluses to needy families and social support institutions at a micro local level.

By 2020, Refood grew to involve, at national level, around 10,000 volunteers at national level and serve more than 2,000,000 meals a year, at a cost of 10-15 cents each, to around 6,500 beneficiaries. In Portugal it has more than 60 operations centers across the country with plans to open other centers in Portugal, Spain, and Italy (Refood, n.d.). Each operation center benefits and replicates the organization's know-how, operating at micro-local level. The choice of Refood-Leiria as a case study was due to previous experience and contact, resulting from the functions performed in project management since 2013 and the scientific interest in the socio-environmental implications of food rescue, which gives us access to greater knowledge of the processes and resources involved as well as ease of access to data and facilities.

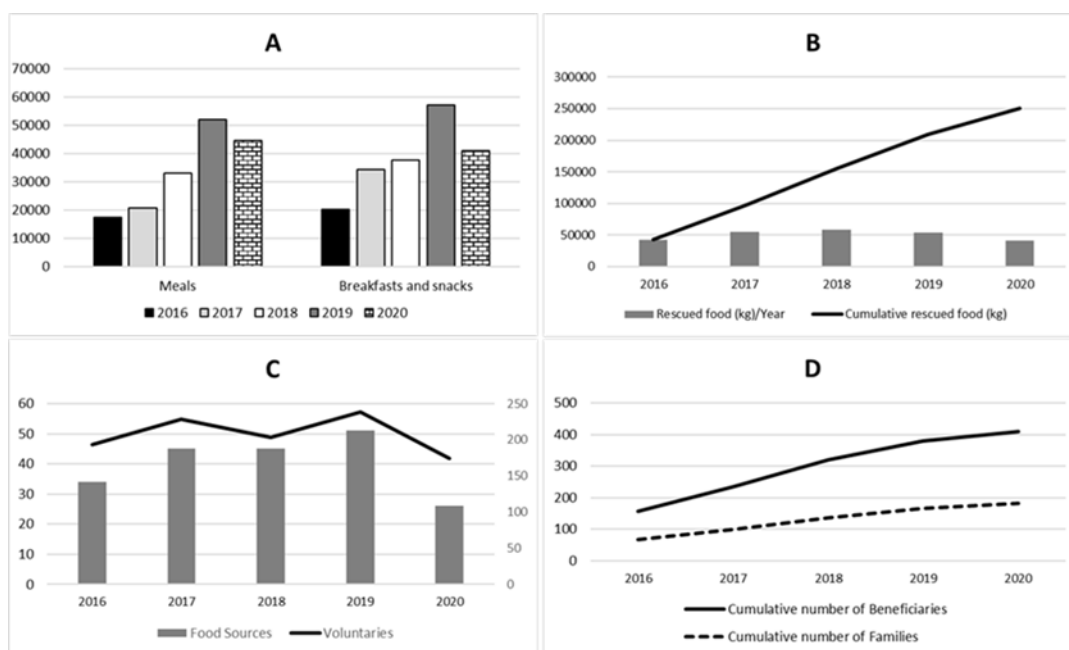
The particularity of the Refood-Leiria project is a collection system that takes place in four shifts from 10 a.m. to 10 p.m. allowing the rescue of eve's dinner cooked and unserved foods, during morning shifts, lunch surplus foods during the afternoon and supermarket fresh fruit, vegetables, dairy, and cold cuts at closing time, around 9.30 p.m. This collection system requires about 220 volunteers, a considerable number for a small town. It allows a constant incoming flow of about five tons a month of quality fresh and freshly cooked goods that is redistributed within the following 24 hours. This flow of rescued food not only helps feeding around 180 to 200 direct beneficiaries, but also supplies food to five other charitable institutions which in turn feed hundreds of people.

The rescued food redistribution takes place once a day in the form of hampers containing at least the amount of food required for each family to be provided with one full meal. Traditionally, in Portugal, one full meal involves vegetable soup, a main course with fish or meat plus a starch source like potatoes, pasta or rice, a vegetable side dish like

a salad and finally one sweet or fruit dessert. Moreover, all hampers also contain breakfast and mid-afternoon snacks like bread, cakes, dairy products, and fruit.

Because the Refood project food sources' surpluses are unpredictable, every day there is a surplus of rescued food that does not represent a balanced meal. To avoid food waste, by the end of the day all foods that haven't been served to direct beneficiary families are forwarded to the other five charitable institutions. This is often the case of rescued fresh bread, cakes, fruits and vegetables or large amounts of cooked meals collected from inconstant social events like marriages or corporate dinners. It should be noted that if bottles of wine, whether already open or not, are collected from social events, they are forwarded to charitable institutions to be used as seasoning.

Although no formal scientific research was conducted on the subject, numbers of rescued food kilos, meals, breakfasts and snacks, beneficiaries, families, voluntaries, food sources, from 2016 to 2020, were kindly provided by Refood-Leiria's the management group and cross-checked with the information available on social media (Figure II.3).



**Figure II.3:** Number full meals and breakfasts and snacks provided by Refood-Leiria for 2016-2020; B – Total rescued food (Kg)/Year; Cumulative rescued food (Kg) for 2016-2020; C- Number of Food Sources and Number of Voluntaries for 2016-2020; D- Cumulative number

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EPA’s Food Recovery Hierarchy (Figure II.1) establishes that the second-best option for food waste, after prevention at source, is to reuse the food surplus for human consumption, also called “Feed the Hungry”. The impact that a food rescue and redistribution organization have on achieving the SDGs can be assessed considering the three pillars of sustainability.

When assessing the environmental cost-benefit ratio of food recovery, the balance is heavily skewed towards the benefits side. On the costs side, material and energetic resources consumed to rescue food, and GHG produced in the rescue process, must be taken into consideration. These costs are minimized by the fact that the ReFood organization model was projected to operate at a micro local level, to minimize environmental impacts of the food rescue and redistribution process, on air quality and global warming. On the benefits side, from 2016 to 2020, more than 250 Tons of fresh or freshly cooked food was diverted from landfills (Figure II.3B), avoiding environmental burdens such as land use, material and energy resources that would be needed to produce food equivalent to the one rescued, resulting, as well, in the production of more pollutants. Furthermore, pollutants, either solids, liquids, gases, or GHG are not produced as an effluent of food as waste treatment.

The economic impact of food recovery and redistribution activity concerns the organization involved in the process, general society, food sources, and beneficiaries. A food aid organization has operation center expenses (electricity, water, internet, cleaning product) and fuel cost to provide for. At national level, the organization calculated economic cost of each meal is 10-15 cents. On the benefits side there are avoided costs of the production, distribution, and transportation of more food that would have replaced the non-rescued one. By donating food surpluses, most of the 51 ReFood-Leiria food sources (Figure II.3C) have tax benefits, and avoid waste management costs, which represents a considerable benefit when large amounts are donated. Sert *et al.* estimated that the net benefit for a food source, from the surplus food redistribution by retailers, was about three times of the value of the recovered food (Sert, S., Garrone, P., Melacini, M., Perego, 2016). For a cumulative total of 410 beneficiaries from 181 families, (Figure II.3D) provided with

meals, breakfasts, and snacks (Figure II.3A) save money, allowing them to access to other goods or services.

In terms of social outcomes, beneficiary families, voluntaries, food sources, and other supported institutions must be considered. Beneficiary families (Figure II.3D) with less or no feeding concerns may benefit in terms of health, opportunities to find or keep a job, school results, and change in nutritional pattern. Since 2015, Refood-Leiria organization has involved more than 500 voluntaries who have benefited of socialization while supporting community members (Figure II.3C) and contributing to food up-cycling. For the 51 food sources (Figure II.3C), forwarding food surpluses to support low-income households is a sign of corporate social and environmental responsibility, often mentioned in their sustainability report (Aldi, n.d.). As a result, the whole community witnesses to the possibility of a circular and solidary economy driving change in their own local neighborhood.

When evaluating the relative percentage of each food group served by the Refood-Leiria project one must bear in mind that the content of each hamper does not represent only one meal, but the content of what has been collected during the previous 24 hours divided by all the families that are served each day. To avoid wastage or very unbalanced meals on the beneficiary side of the food chain, when large amounts of surpluses of a single species are rescued (very often bakery products), they are sent to other institutions that support populations in need.

Foods redistributed by Refood are entirely the result of up-cycling of food waste, diverted from its original end, the landfill. Thus, their quantity and nature are not completely controlled by the project, although their quality is controlled through the application of HACCP (Hazard Analysis and Critical Control Point). All rescued foods are fresh (fruit, vegetables, dairy, bread, cakes), unserved freshly cooked in restaurants and canteens, or close to the “best by date”, and, for these reasons, served within a maximum of 24 hours. However, Refood-Leiria reserves the right to refuse the redemption of food, whenever by nature and / or quantity there is no logistic capacity for storage or redistribution.

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In Portugal, in 2017, the percentage of total population at risk of poverty was of 18,3% (European Commission, 2017), but still one million ton of food is wasted per year (Baptista, Campos, Pires, & Vaz, 2012). During the past decades, the poverty situation of the Portuguese population has been partially tackled by the public welfare system, and more recently also by non-governmental organizations such as the Food Bank, and the Refood project.

The Portuguese dietary guidelines, that reflect Portuguese society, have been developed since 1980s by a group of researchers of the Faculty of Food Science and Nutrition of Porto University. These guidelines are usually conveyed in form of an instrument called the Food Wheel (circular shape) which has been revised and updated over the years to reflect evolutions both in scientific knowledge and society (Rodrigues, Franchini, Graça, & de Almeida, 2006).

The Food Wheel has been designed transforming nutritional scientific knowledge in a pictorial representation of basic concepts to reach as many people as possible. To insure a captivating and easy to understand food guide, a circle shape divided into 7 slices was chosen. It also includes an image of drinking water in its center to highlight the importance of hydration.

The whole wheel was developed, considering common usage in Portuguese food habits and the recommendations for the Portuguese Adult Population of National Council for Food and Nutrition (Conselho Nacional de Alimentação e Nutrição, 1997). To guarantee that all recommendations in terms of macronutrients were met, 7 food groups were created, hence the seven Food Wheel slices, and several subgroups and specific items included (Table II.2).

**Table II.2:** Food Groups and Subgroups of the New Portuguese Food Guide, Number of Food Items Included (Raw or Cooked) adapted from Rodrigues et al. (Rodrigues et al., 2006)

<b>Food Groups</b>	<b>Food Wheel relative weight percentage</b>	<b>Number of Items and Subgroups Included</b>
<b>Milk and Dairy Products</b>	18%	30 items (all raw); 5 subgroups: milk, yogurts, hard cheese, fresh cheese, curd cheese
<b>Meat, Fish, Seafood and Eggs</b>	5%	72 items (all cooked); 2 subgroups: meat (pork, beef, lamb, veal, rabbit, chicken, duck turkey, game)/fish/seafood (molluscs and crustacean), and eggs
<b>Pulses</b>	4%	12 items (all cooked); 2 subgroups: fresh and dried pulses
<b>Potato, Cereal and Cereal Products</b>	28%	64 items (cooked values for potato, rice, and pasta; raw values for all others); 6 subgroups; bread, maize bread, potato, ready-to-eat breakfast cereal, semi-sweet biscuits, and rice/pasta
<b>Vegetables</b>	25%	34 items (raw values for lettuce, garlic, carrots, cucumbers, onions, and tomato; cooked values for all others); no subgroups
<b>Fruits</b>	20%	20 items (all raw); no subgroups
<b>Fats and Oils</b>	2%	13 items (all raw); 4 subgroups: olive oil/other vegetable oils; Lard, butter/margarine, cream

The size of each slice of the Food Wheel represents the desirable percentage in portions of the contribution of each food group to a healthy diet.

### II.3. Materials and Methods

Due to the lack of human and logistic resources it was impossible to analyze the total of 4.5 to 5 tons of food per month that are rescued by Refood-Leiria. Therefore, we decided to restrict the analysis to foods that, after being collected, are redistributed directly to beneficiary families in the project's operations center and thus the portion of rescued food daily distributed to institutions was not analyzed.

Each beneficiary family receives a basket of food 1, 2 or 3 times a week depending on the socioeconomic characteristics of the household. The total number of families

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supported varies over time as the households can leave the project when their socioeconomic situation improves or can be excluded from the project due to non-compliance with established basic rules (e.g., not showing to collect the food basket on agreed days, without prior notice). As some households abandon the project, others join it on their own initiative or by reference of social support institutions. In consequence, the ReFood-Leiria project has supported a constant number of families around 45, whose anonymity was guaranteed throughout this investigation.

To measure the contribution of upcycled food to a balanced diet, data was collected during three periods of five consecutive working days with intervals of two months, avoiding data collection during the holiday season, a naturally superabundant period compared to the rest of the year. The established dates were November 14-20, 2018, January 14-18, 2019, and March 11-15, 2019. To carry out this quantification, the food supplied to each beneficiary family was weighed daily using a calibrated Tissot® scale, with a maximum range of 15kg ± 0.005. The weighing was always carried out by the same person, differentiating, and identifying the nature of the food: soups, bread, main course, vegetables, fruit, dessert, and others (see Appendix B- Part II Methodology flow-chart).

The original sample was constituted of around 3500 items weighing 1.722 Ton, from 40 families. Because some of the families had left the organization during the data collection process, only the 27 families (59 individuals: 47 adults and 12 children) covered by all three weighing rounds were selected reducing the sample to 2597 items weighing 1.277 Ton. All hampers contain bread vegetable soup, main dish, vegetable side dish, fruit, and suitable breakfast snacks.

Tares were deducted, and edible percentages of foods calculated whenever relevant (e.g., fruit, vegetables, certain meats, and fish) (Instituto Nacional de Saúde Dr. Ricardo Jorge, n.d.).

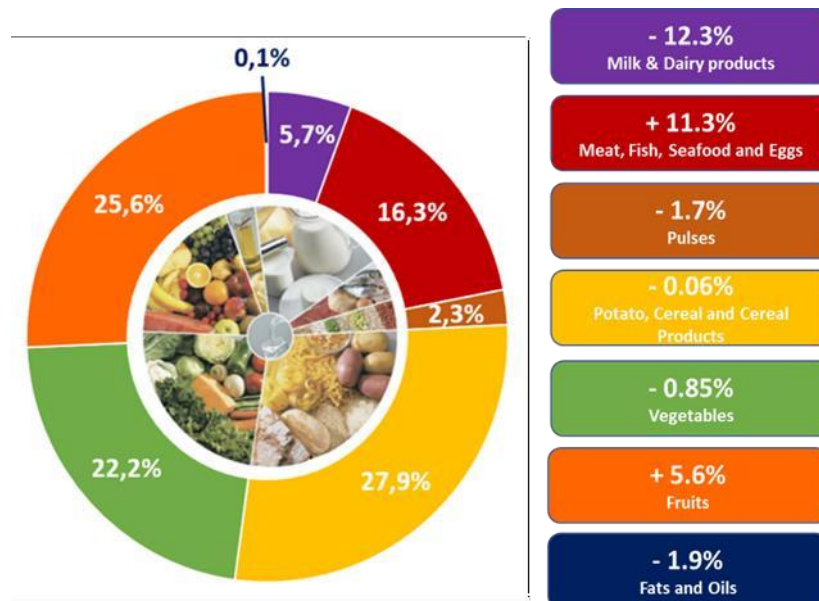
The selected data was then organized to fit into the 7 food groups (Table 2) of the Portuguese Food Wheel (Figure 3), plus 3 extra categories, representing usually consumed foods that are not recommended by the guidelines: 1) jams, cakes, and savory; 2) deli meats; 3) fruit nectars (non-alcoholic drink).

Whenever composed dishes were served (e.g. soups or casseroles) all recipes were broken down into constituent foods from each sector of the Food Wheel.

The evaluation of the totality of the redistributed foods was made in two different ways: firstly, considering only the foods that are part of the Portuguese Food Wheel as an official food guide for the Portuguese population (Rodrigues et al., 2006), and secondly considering the totality of the foods provided by the ReFood-Leiria project to the beneficiary families to be able to compare our results with the ones of the National Food and Physical Activity Survey (NFPAS), published in 2017 (Lopes et al., 2017). The constitution of each food hamper depends on the number of family members but doesn't vary in the global nature of foods which are soup, bread, main dish, side dish and fruit, plus other extra foods intended for breakfasts and snacks. After previous evaluation of family hampers distribution, through the calculation of the weight percentages of distributed food per family and per sector, no visible differences were found between hampers. Thus, the option of a global evaluation, of the totality of the served food in all 3 rounds of weighing, was chosen.

## **II.4. Results**

A first evaluation was made only with respect to the items belonging to the food groups included in the Portuguese Food Wheel, served to all 27 families, during the three weighing rounds. Global mean values of weight percentage per sector were calculated to be compared with the weight percentage per sector recommended by the guidelines (Figure II.4).



**Figure II.4:** Mean weight percentage of redistributed food (case-study results) per sector of Food Wheel and mean difference from required value per sector

When analyzing Figure II.5, the sectors of “Potato, Cereal and Cereal Products” and of “Vegetables” are the ones in which values are the closest to those recommended by the Portuguese food guide (Rodrigues et al., 2006), with a difference of respectively of - 0,06% and -0,85%. In all other food groups percentages were inadequate when compared to the recommended.

Two food groups are redistributed in higher amounts than recommended. The mean percentage of contribution of “Meat, Fish, Seafood and Eggs” donations exceed the dietary reference value for this sector in 11,3% and the contribution of the “Fruit” sector is 5,6% larger.

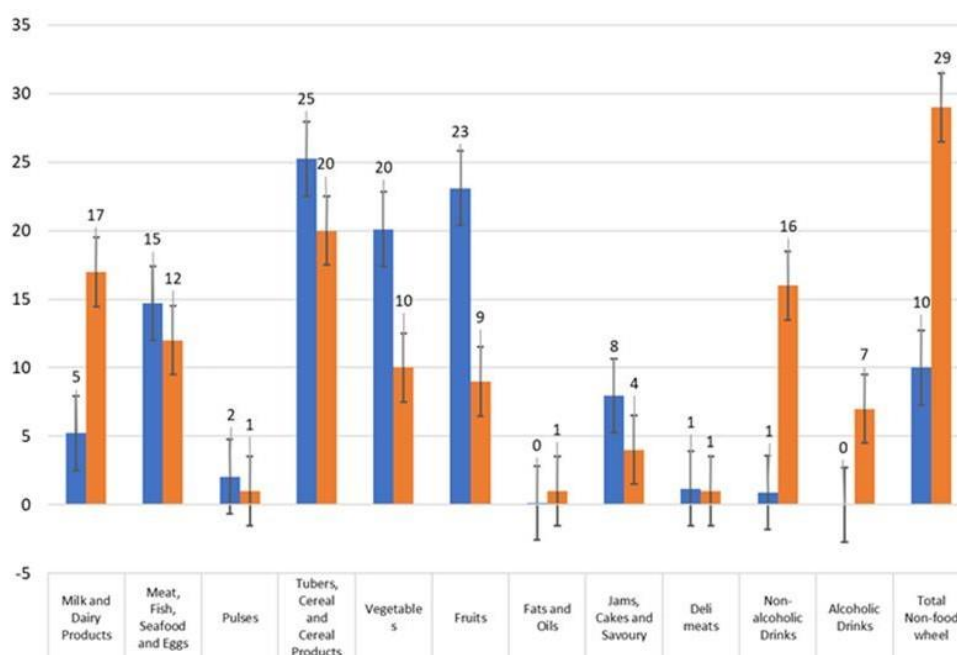
On the other hand, comparing with the guidelines recommended values, redistributed hampers contain -12,3% of “Milk and Dairy Products”, -1,9% of “Fats and Oils” and -1,7% of “Pulses”.

Secondly, we considered the total amount of food and beverages redistributed whether belonging to the Portuguese Food Wheel or not. In this case, the weight percentage (Figure II.5) and standard deviation of redistributed food in hampers by food

groups are 25%±3.8 of “Potato, Cereal and Cereal Products”, 23%±4.4 of “Fruits”, 20%±4.9 of “Vegetables”, 15%±3.2 of “Meat, Fish, Seafood and Eggs, 5%±2.9 of “Milk and Dairy Products”, 2%±1.7 of “Pulses” and 0.1%±0.2 of “Oils and fats”. The set of foods not included in the Food Wheel accounts for a percentage contribution of 10%±2.9, to which the “non-alcoholic drinks” group contributes 1%±0.9, “Deli meats” with 1.2%±1.07, and “Jams, Cakes and Savory” with 8%±2.5.

Thirdly we compared the Portuguese population food consumption with the Refood beneficiaries’. This comparison uses has a refence for food consumption habits of the Portuguese Population, the results of the National Food and Physical Activity Survey (NFPAS), published in 2017 (Lopes et al., 2017).

The most significant differences are related to the consumption of Non-Food wheel products (Figure II.5). In fact, the general Portuguese population consumes a total weight percentage of 29% of foods not recommended by the guidelines including 16% of non-alcoholic drinks and 7% of alcoholic beverages, while food hampers provided by Refood-Leiria only have 10% of Non-Food wheel products, 1% of non-alcoholic drinks, and never include alcoholic beverages, as an organization policy.



**Figure II.5:** Comparison of the results of the National Food and Physical Activity Survey (NFPAS), published in 2017 (Lopes et al., 2017), and the food redistributed by Refood-Leiria

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Furthermore, the ReFood-Leiria hampers provide a larger weight percentage of various groups of foods than the general Population usually consumes (Lopes et al., 2017), respectively, “Meat, Fish, Seafood and Eggs” (15% vs 12%), “Pulses” (2% vs 1%), “Potato, Cereal and Cereal Products” (25% vs 20%), “Vegetables” (20% vs 10%) , “Fruits”( 23% vs 9%), “Deli Meats” (1.2% vs 1%), and “Jams, Cakes and Savoury” (8% vs 4%). However lower percentages of “Milk and Dairy Products” (5% vs 17%), and “Fats and Oils” (0.1% vs 1%) were served.

## **II.5. Discussion**

Results showed that, taking into account only foods included in the Food Wheel, food donations contributed to supplement the recipient’s total diet, even if foods included in some of the sectors do not meet the guidelines recommendations (Figure 5).

Firstly, the mean percentage of “Meat, Fish, Seafood and Eggs” in the average hamper (16.3%) is more than three times larger than recommended (5%), while the amount of “Fruits” (25.6%) is 28% higher than recommended (20%) (Figure 5).

The content of the ReFood-Leiria hampers is meant to be a food supplement providing, 1 to 3 times a week, at least one full meal, plus breakfast and mid-afternoon snacks, according to the nature of the daily rescued food. This means that of the excess of “Meat, Fish, Seafood and Eggs” and “Fruit” can be consumed during other weekdays, reducing, or even cancelling the negative impact of this excess consumption. It is also the reason why more “Meat, Fish, Seafood and Eggs” and “Fruit” is provided to beneficiary families instead of being forwarded to other organizations. Furthermore, on days beneficiaries do not collect food from ReFood-Leiria, they still manage to prepare nutritious meals with ingredients that low-income families can’t usually afford.

Secondly, foods included in the sectors of “Milk and Dairy Products”, “Pulses” and “Fats and Oils” were redistributed in smaller weight percentages than recommended. Because ReFood-Leiria rescues and redistributes mainly perishable goods (fruits, vegetables, freshly cooked meals, bread, and cakes), “Milk and Dairy Products” and “Fats and Oils” are foods that are seldom collected by the organization, except when, eventually,

a “nearly past best-by-date” product is donated by a supermarket. Even though beneficiaries’ purchases need to compensate for the unoffered foods, hampers still supplemented the total diet with 32% of the necessary “Milk and Dairy Products” (5.7%/18%), 58% of “Pulses” (2,3%/4%) and 5% of “Fats and Oils” (0,1%/2%).

Remarkably, the percentages of foods served in the categories of “Potato, Cereal and Cereal Products”, and “Vegetables” matched the required percentages with a difference lower than 1% (Figure 4).

Considering the totality of redistributed foods, results showed that the addition of food donations to the diets of this low-income sample improved the balance of their diets, when compared to the general Portuguese population’s (Figure 5). The non-compliance to the guidelines of the case study sample vs general Portuguese population is especially relevant in terms of non-recommended by the Food Wheel food consumption, mainly due to the disparity of drink consumption.

“Deli Meats”, and “Jams, Cakes and Savory” are discretionary foods, and, as such, they may be high in saturated fats, sugars, salt, and energy dense. Therefore, they should be consumed in small amounts. Because these non-recommended by the Food Wheel foods are also traditional constituents of a breakfast or snack, they are collected and redistributed in appropriate portions with the purpose of supplementing families’ daily food requirements (*e.g.* children morning/afternoon snack at school). The reason why the general Portuguese population’s intake percentage of these foods is lower than the supplied by ReFood-Leiria may be related to the fact that these are costly products.

The estimates of “Milk and Dairy Products” provided by the food surplus donation in the present research are lower than recommended by the Portuguese national guidelines. Similar results of insufficient provision of “Milk and Dairy Products” were reported by other researchers with respect to each country’s guidelines namely in the USA (Hoisington et al., 2011), Canada (Jessri et al., 2014; Tse & Tarasuk, 2008), the UK (Pelham-Burn et al., 2014), Italy (Maioli et al., 2016) and in a multiple country study involving United States, Canada, Australia, and several European countries (Simmet et al., 2017). Likewise,

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insufficient provision of pulses was also reported in two organizations (Hoisington et al., 2011; Jessri et al., 2014).

Higher values than the recommended for saturated fat, salt and nonmilk extrinsic sugars, provided in the present research by discretionary foods such as “Deli Meats”, and “Jams, Cakes and Savoury”, were found also in kitchens and pantries led by other food collection organisations (Hoisington et al., 2011; Maioli et al., 2016; Preston & Burley, 2015b; Sprake et al., 2014). In Oregon, Hoisington (2011) found that up to a third of foods distributed by the foodbank were condiments, noncaloric beverages, convenience meals like soup and boxed casserole mixes, and discretionary foods such as chips and donuts while key foods were lacking (Hoisington et al., 2011). Even when bags provide sufficient energy and macronutrients to meet the needs of an average adult, as it is the case at the Bradford Metropolitan Food Bank (UK), they are often a source of high levels of salt and non-milk extrinsic sugars (Preston & Burley, 2015a).

The lack of key foods adequate for a balanced diet such as meat (Hoisington et al., 2011; Jessri et al., 2014), and meat and alternatives (Hoisington et al., 2011), whole grains (Hoisington et al., 2011; Pelham-Burn et al., 2014; Simmet et al., 2017), fresh fruits (Hoisington et al., 2011; Jessri et al., 2014; Pelham-Burn et al., 2014; Simmet et al., 2017; Tse & Tarasuk, 2008) and vegetables (Hoisington et al., 2011; Jessri et al., 2014; Pelham-Burn et al., 2014; Simmet et al., 2017; Tse & Tarasuk, 2008) was a constant in the results of the previously cited studies. Comparing with the outcomes of this study, our sample consumed balanced amounts of “Potato, Cereal and Cereal Products”, and “Vegetables”, and higher amounts of “Meat, Fish, Seafood and Eggs” and “Fruit”. These differences may be since most food redistribution organizations rely mainly on dry staple foods while our case-study organization recovers and redistributes almost exclusively fresh or freshly cooked foods.

While Sprake, in 2014, found that the dietary fibre intake of the individuals accessing two charitable meal services in Sheffield, UK, was significantly lower, than population average intake, the present research found balanced amounts of vegetables, according to the Portuguese guidelines (Sprake et al., 2014). This fact may be due to the

Portuguese culture of vegetable soup consumption which provides hydration, vegetable fiber vitamins and minerals intake.

## II.6 Conclusions

In 2015, UN country-members have agreed on acting, in accordance with their respective capabilities, to implement progressively the SDGs of the 2030 Agenda (United Nations, 2017), through a diversity of governmental and non-governmental good practices. The process of food upcycling to support low-income households, often implemented by civil society initiatives at local and micro level such as ReFood, transversally integrates several of the SDGs.

While other researchers have found that supplemental foods offered at food pantries are an important resource to improve the quality of food intake to populations in vulnerable situations (SDG 2.1), this is the first study in which there is food quantification of almost exclusively rescued fresh or freshly cooked products. In this study, it was possible to measure the contribution of donated food to a balanced diet of Portuguese low-income families, according to Portuguese guidelines, demonstrating that the process of up-cycling fresh food contributes to improve dietary patterns of low-income households.

The ReFood organization distribution process facilitates the promotion of good eating habits since processed and ultra-processed foods are not distributed, but only meals prepared in traditional restaurants, in addition to unprocessed and fresh foods from surplus distribution chains. The fact that sugary drinks and eventual alcoholic beverages are diverted to other institutions also promotes healthy dietary patterns.

Overall, despite the small beneficiaries' sample size, for clients who rely on organizations that redistribute perishable food such as our case-study, results in this study suggest that fresh rescued foods can contribute to a more balanced diet in terms of "Potato, Cereal and Cereal Products", "Vegetables", "Meat, Fish, Seafood and Eggs" and "Fruits". Thus, future research should evaluate the contribution of rescued fresh food to the dietary pattern of low-income families using a larger sample size. Furthermore, future

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research should also quantify nutritional intake and examine the effect of caloric/nutrient intake from recovered food donations on BMI/health status of food pantries' clients.

Upcycling food, besides from feeding needy populations, contributes to increase resource-use efficiency (SDG 9.4; SDG 12.5) and to substantially reduce waste generation, ensuring sustainable food consumption and production systems (SDG 12; SDG 2.4). In turn, global resource efficiency in consumption and production also helps maintaining ecosystems, lowers greenhouse gas emissions and fosters climate resilience (SDG 13.2.1). We found that the consumption of rescued and redistributed food contributes to a balanced diet and therefore improves health (SDG3) of families struggling with poverty (SDG1) and thus reduces inequalities (SDG10). This information is valuable to policymakers to better regulate the quantity and quality of donation of fresh and freshly cooked foods. This could be done transforming donation into mandatory post-harvest stage, reducing food waste to the unavoidable.

Limitations of this research were of different natures. Results show that a balanced amount of food is provided to families but there is no information about consumption frequency or diet pattern of the beneficiaries. A family unbalanced redistribution of types and amounts of foods per family member, could lead to an unhealthy diet pattern.

The amount of household food wasted or shared with others is unknown, thus the amount of food that is eaten is also unknown. In parallel to discarded or offered food, family's purchased food may also motivate unbalanced diets.

Comparing results of nutritional balance of hampers with the food general population results in comparing samples of different sizes and levels of representativeness specially in terms of the impact of their different socioeconomic situation. All beneficiaries are low-income families whose diet pattern depend partially on available food surpluses, while the general Portuguese population has differentiated socioeconomic situations whose diet patterns depend on their own choices. Conclusions drawn by comparing the eating patterns of these two populations may be biased.

The strengths of this study are direct weighing of around 1.721.642kg of food, representing 3500 items of exclusively food recovered products, in 3 weekly rounds over a period of 4 months, to assess how rescued and redistributed food can contribute to a balanced dietary intake of the recipients, according to the Portuguese food guidelines.

To our knowledge, this is the first study focusing on the contribution of exclusively recovered, and mainly fresh or freshly cooked food to a balanced diet of low-income population. However, inadequate financial resources and available time limited the geographic variety (and sample size), for the present research. For future studies, a better design could include a control group of families prior to being supported by the organization. In addition, conducting the research in other similar organizations should lead to more significant results.

Food waste rescue organizations are changes in local practices with the potential to contribute to food security of low-income populations, increase responsibility for societal change, decouple economic growth from environmental degradation (SDG 8.4), while endeavoring to accelerate the shift towards more sustainable food systems, all along the food value chain, from farm to fork.

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### **III- UPCYCLED NUTRIENTS**

## The Nutritional Content of Rescued Food Conveyed by a Food Aid Organization

*Nogueira A, Alves F, Vaz-Fernandes P. The Nutritional Content of Rescued Food Conveyed by a Food Aid Organization. International Journal of Environmental Research and Public Health. 2021; 18(22):12212. <https://doi.org/10.3390/ijerph182212212>*

**Abstract:** (1) Background: The number of food insecure families in the European Union has increased resulting in an increasing number of households depending on food assistance programs. The aim of this paper was to conduct research to evaluate the nutrient content of food rescued by a food aid organization which rescues and redistributes fresh or freshly cooked food to low-income households. (2) Methods: To determine the nutritional content of food hampers provided by our case study organization, we have weighed all items of food hampers in three weighing rounds over a period of four months. The Food Insecurity Experience Scale (FIES) was applied to measure households' food insecurity. (3) Results: Our results showed that, at our case study food aid organization, food donations substantially contribute for energy, macro, and micronutrient DRI (Dietary Recommendation Intake) intake. (4) Conclusions: When evaluating how these nutrients contribute to alleviate food insecurity of the beneficiary households, we found that perception of food insecurity is independent of the amount of nutrients served. To our knowledge, this is the first study that measures the nutritional content of fresh or freshly cooked rescued food conveyed by a food aid organization.

### III.1 Introduction

In 2017, the at risk of poverty rate in the European Union (EU-28) was 16.9% (European Commission, 2017). This means that the share of the European population with an equivalized disposable income below the at risk of poverty threshold (60% of the national median equivalized disposable income) was 16.9%. This means that of 119.1 million people, 42.5 million were not able to afford a quality meal every second day (European Commission, n.d.); meanwhile, the amount of European food waste is still around 88 million tons per year (Vittuari et al., 2017).

Low-income individuals are often viewed as being linked to poverty

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and social exclusion since insufficient resources may generate a reduced ability to purchase adequate quantities of healthy nutritious food (United Nations, 2016), resulting in situations of food insecurity (Leung, Epel, Ritchie, Crawford, & Laraia, 2014).

Food security is said to exist “when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meet their dietary needs and food preferences for an active and healthy life” (FAO, 2009). According to the Food and Agriculture Organization (FAO) (2009), the four pillars of food security are: (1) the availability of sufficient quantities of food of appropriate quality; (2) access by individuals to adequate resources for acquiring appropriate foods for a nutritious diet; (3) use of food through adequate diet, clean water, sanitation, and health care to reach a state of nutritional well-being; (4) stable access to adequate food at all times (FAO, 2006). The nutritional dimension is integral to the concept of food security (FAO, 2009).

To assess food insecurity at the household level, a psychometric scale for assessing food insecurity the Food Insecurity Experience Scale (FIES)) can be used. The FIES has been used to identify the following risk factors of food insecurity around the globe: low levels of education, weak social networks, less social capital, low household income, and being unemployed (A. Li, Dachner, & Tarasuk, 2009; Smith, Rabbitt, & Coleman-Jensen, 2017; Tarasuk & Mitchell, 2020). In 2020, the FIES was applied to investigate gender implications in food insecurity, showing that in every European area, women are more fragile in terms of food insecurity than men (Grimaccia & Naccarato, 2020). Furthermore, the same study suggested that the number of children in the household have a stronger impact on women’s food insecurity than on men’s, and the factor that most mitigates food insecurity for both men and women is higher education (Grimaccia & Naccarato, 2020).

As in other countries, the FIES was translated and validated into Portuguese (Instituto Brasileiro de Geografia Estatística - IBGE, Ministério do Desenvolvimento Social e Combate à Fome, & Ministério do Planejamento Orçamento e Gestão, 2004). In Portugal, it was applied by the General Directorate of Health in Portugal to monitor the food security of Portuguese households during the period of 2011–2014

(Gregório et al., 2017). The results showed that socio-economically vulnerable Portuguese populations appear not only to have diminished access to foods of high nutritional value but also, in some cases, show poor management of economic resources and family food. Women were found to be more susceptible to food insecurity than men, while elderly people were found to apparently be less food insecure, which might be explained by many of these elderly individuals having lived in a context of socio-economic precarity, and thus have developed adaptation and resilience mechanisms that lead to a lower perception of food insecurity. Furthermore, compensatory mechanisms to deal with isolation strongly influence the food consumption patterns of unemployed individuals and elderly people living alone. Gregório et al. (2017) also observed strong social cohesion in Portuguese society, which may be due to dense solidarity networks provided by social security, religious organizations, or civil society initiative (Gregório et al., 2017).

Several initiatives worldwide tackle the issue of food poverty of low-income individuals through different governmental and nongovernmental organizations, such as food banks, soup kitchens, and food recovery and redistribution organizations that donate food or sell it for a symbolic price (Arriola, 2015; Principato, 2018). To alleviate both food poverty and food waste, multiple hunger relief organizations connect people in need with food waste or surpluses (Brennan & Browne, 2021; Fan & Brzeska, 2016). In this case, surpluses, or products close to the best-by date, usually originating from the food industry sector, the distribution sector, or the food service industry, hotels, restaurants, and cafes (HORECA) channel, are rescued, and can be redistributed as-is or used to prepare meals at soup kitchens. Therefore, the nature and quantity of the food served by organizations that rely exclusively on donated food are not controlled by the organizations, as they depend on the nature and quantity of food donors' surpluses each day (Pettes, Dachner, Gaetz, & Tarasuk, 2016). The organizations face the daily challenge of both managing food sources with an everchanging nature and improving the nutrient intake of the recipients of the redistributed food (Garrone et al., 2014; Lindberg et al., 2014; Nair et al., 2017; Reynolds et al., 2015). Therefore, the nutritional quality of emergency food has been examined by researchers in different charitable

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organizations in several high-income countries such as Canada (Burston & Breton, 1990; Irwin, Ng, Rush, Nguyen, & He, 2007; A. Li et al., 2009; Tarasuk & Dachner, 2009; Tse & Tarasuk, 2008), France (Darmon, Coupel, Deheeger, & Briend, 2001), Germany (Langnäse & Müller, 2001), Italy (Maioli, Colosio, Muzio, & Cioni, 2016), the Netherlands (Neter et al., 2018), the U.K. (Fallaise, Newlove, White, & Lovegrove, 2020; Pelham-Burn, Frost, Russell, & Barker, 2014; Sprake, Russell, & Barker, 2014), the USA (Barone, Krummel, & Lee, 2020; Buttorff, Trujillo, Diez-Canseco, Bernabe-Ortiz, & Miranda, 2015; Hoisington, Manore, & Raab, 2011; Leung et al., 2012; Leung, Musicus, Willett, & Rimm, 2017; Lyles, Drago-Ferguson, Lopez, & Seligman, 2013; Mousa & Freeland-Graves, 2017, 2019; Simmet, Depa, Tinnemann, & Stroebele-Benschop, 2017), and Australia (Lindberg et al., 2014). In addition to the homeless, members of food-insecure households resort to food banks in emergencies (Greger et al., 2002; Irwin et al., 2007; Jun Zhang, Wang, & Yen, 2021) or use them as long-term food sources (Hegde et al., 2018). The longer low-income households depend on food assistance programs the more nutritional adequacy evaluations are crucial to determine if the programs meet the clients' (long-term) needs (Greger et al., 2002).

During the past decades, we have been assisting with the proliferation of charitable meal programs as well as with a shift in the assisted population (Tarasuk & Dachner, 2009), both of which may have been created due to the 2008 worldwide economic recession at first, and then were more recently exacerbated by the COVID-19 pandemic, which has led to increasing numbers of previously well-off families all over the world experiencing scarcity of resources. As such, many of them had no other choice than to feed themselves with the help of food banks, food pantries, soup kitchens, urban farms, and other charitable organizations (Dombroski et al., 2020; Fleetwood, 2020; Healy et al., 2020; Jablonski et al., 2020). The COVID-19 pandemic is directly affecting food systems through impacts on food supply and demand, as lockdowns have prevented small-scale food producers from supplying their products to consumers, and indirectly through decreases in purchasing power (UN, 2020).

The results obtained from research on European countries concur with those obtained in research in the North American continent (Buttorff et al., 2015; Lyles et al.,

2013). In these studies where the nutritional intake of beneficiaries of food aid services was evaluated, the amount of macro and/or micronutrients was considered inadequate for the following reasons: (1) the lack of availability of the amounts and types of food to ensure a balanced diet; (2) poor food choices; (3) beneficiaries not knowing how to cook certain foods.

Considering the previously mentioned at risk of poverty rate and the amount of wasted food in the EU and the EU policies to achieve the Sustainable Development Goals established by the United Nations (European Commission, 2015b), which include helping to eradicate hunger and malnutrition, food systems transformation, and saving nutritious food for redistribution to those in need, the research output on the nutritional value of upcycled food in the European continent has been unexpectedly low. This is precisely what we aimed to address in this study: (1) to quantify the nutrients of rescued and redistributed foods through a case study that involved the operations center of the Refood project in Leiria, Portugal (Refood, n.d.); (2) to evaluate how these nutrients contribute to alleviating the food insecurity of the beneficiary households. The Refood project is an independent, 100% volunteer-run organization that works to eliminate both food waste and hunger at the micro-local level (Refood, n.d.), rescuing food waste to support low-income households who receive food hampers 1–3 times per week. The novelty of this study concerns the nature of the rescued and redistributed food. Unlike other previously examined emergency food projects that rely mainly on dry staple foods or processed surpluses, most Refood-rescued and -redistributed food is freshly cooked (in restaurants, cafes, bakeries, and hotels) or is naturally fresh (fruit and vegetables).

### **III.2 Materials and Methods**

A cross-sectional study was conducted from November 2018 to March 2019 during three rounds of five consecutive working days in intervals of two months for food data collection, and over 8 consecutive working days of May 2019 for sociodemographic data collection and FIES application, in 59 adults using a food rescue and redistribution organization. The study case organization, Refood-Leiria, was visited 23 times within the mentioned months. During the data collection process, all items served to all families

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were weighed. After this process, the 27 families comprising 59 individuals (47 adults and 12 children) covered by all three weighing rounds were selected to ensure a significant amount of data per family. Thus, a total of about 3500 items were weighed, representing a total mass of 1,721,642 kg; tares were deducted, and edible percentages of foods were calculated whenever relevant (e.g., fruit, vegetables, certain meats, and fish) (Appendix C—Total Methodology Flow Chart).

The collected food data were analyzed and converted into nutrients using Food Processor SQL, a computer program developed from the 1980s by ESHA researchers (Salem, OR, USA), with nutritional information from tables of food composition of the United States Department of Agriculture (USDA), and successively improved by new generations of researchers in several countries, to increase the quantity and nature of food involved (ESHA Research, n.d.). In Portugal, this task has been performed since the beginning of the 1990s by researchers from the Department of Clinical Epidemiology, Predictive Medicine and Public Health of the Faculty of Medicine of the University of Porto and the Institute of Public Health to contain more and more culinary dishes that are typically Portuguese.

Whenever the food distributed did not correspond to one of the foods listed in the Food Processor SQL manual, the dishes were composed from existing data (e.g., 180 g of typical *migas* from the western region of Portugal was broken down into 60 g cornbread, 60 g of cabbage, 60 g of black-eyed peas, and one tablespoon of olive oil).

The collected data were then systematized and coded to be introduced in the Food Processor, which calculates the macronutrients (proteins, lipids, carbohydrates, and dietary fiber), micronutrients (vitamins and minerals), and caloric intake. The results were then exported to IBM SPSS® Statistics 27 (IBM Corporation, Armonk, NY, USA) to be statistically analyzed.

The following nutritional parameters were analyzed: total energy intake, proteins, total carbohydrates, free sugars (sugars added to food and drink), total fat, saturated fatty acids, monounsaturated fatty acids, total polyunsaturated fatty acids, trans fatty acids cholesterol, polyunsaturated fatty acids omega 3 and omega 6, dietary fiber, vitamin A, thiamine, riboflavin, niacin, pantothenic acid, vitamin B<sub>6</sub>, folate, vitamin B<sub>12</sub>, vitamin C, vitamin D, vitamin E, vitamin K, calcium (Ca), copper (Cu), iodine (I), iron (Fe), magnesium

(Mg), phosphor (P), potassium (K), sodium (Na), and zinc (Zn). The percentage dietary reference intake (DRI) of each studied nutrient provided by recovered food in our case study was calculated according to the following references: (1) for energy, macronutrients, dietary fiber, and micronutrients, we used values published by the Institute of Medicine (IOM, 2011); (2) for cholesterol, free sugars, saturated fat, monosaturated fat, polyunsaturated fat, trans fatty acids, we used the WHO recommendations (WHO, 2003); (3) for fiber, the American Heart Association recommended values were used (Van Horn, 1997).

After the process of weighing of the food items contained in the hampers, we preliminarily evaluated each hamper's content with respect to the relative mass percentage of each food group and no visible mass percentage differences were found (Nogueira et al., 2021a). Furthermore, the study case organization rescues and redistributes food surpluses from distribution, the HORECA channel, bakeries, and canteens, which means that from day-to-day, the nature and amount of the collected and redistributed food vary widely. The beneficiaries collect their bags, containing at least one meal (but very often more than one) plus snacks 1, 2, or 3 times per week according to their socio-economic situation or according to their availability to afford the trip to the operations center. When families have a very low income, the trip cost to the operation center may be a significantly high proportion of the family budget, so it is agreed with the family that the collection takes place fewer times each week, but the amount of redistributed food is as large as possible. Therefore, the sizes and contents of the collected bags are heterogeneous, even if the bag content is as balanced as possible (Nogueira et al., 2021a). Moreover, the same hamper may contain more than one kind of soup, main course, side dish, dessert, fruit, or snack, according to the daily assortment of rescued food. As a result, the percent DRI was calculated globally, considering the mean value of each nutrient provided per person and per collection day.

An appropriate instrument, the Food Insecurity Experience Scale (FIES), was developed in the 1990s by the United States Department of Agriculture (USDA), and has been translated to around 200 languages (Bickel, Nord, Price, Hamilton, & Cook, 2000; USDA, n.d.) and applied in several studies to measure food (in)security at the household level (Neter, Dijkstra, Visser, & Brouwer, 2014; Radimer & Radimer, 2002). In a global context, FIES was

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applied to a sample of 150 countries with results positively correlating with FAO data concerning the prevalence of undernourishment, national income, health, and well-being (Cafiero, Viviani, & Nord, 2018). The FIES scale was applied to the member of the beneficiary household who usually collects food at the ReFood-Leiria operations center, and who, complementarily, also responded to a survey for the sociodemographic characterization of their household. The objective of the study was explained to all beneficiaries as well as that their participation was voluntary and that there would be no retaliation for refusing to participate in the survey. Food insecurity using the FIES psychometric scale was categorized according to the scale validation report (Instituto Brasileiro de Geografia Estatística - IBGE et al., 2004).

Body mass index (BMI) was calculated according to reported values of weight and height. In the case of children, BMI was calculated using height and weight values reported by the parent, the sex and age of the child, together with the Centers for Disease Control and Prevention BMI Calculator for Children and Teen online tool (Centers for Disease Control and Prevention, 2020).

Statistical analysis was performed using IBM SPSS® Statistics 27. Descriptive statistics were used to summarize participant's characteristics and to examine the level of food insecurity in the study sample.

### III.3 Results

Table 1 summarizes the sociodemographic sample characterization. The 27 families in the sample consist of 59 individuals (34 female and 25 male), divided in 47 adults with a mean age of  $47.7 \pm 15.6$  years old (7 individuals are over 65), and twelve children with a mean age of  $9.6 \pm 4.3$  years old. Households consist of 1-4 members, of whom 1-3 are adults and 0-2 are children.

Among the adult members of the sample there are 16 active members, 17 unemployed, 1 is a student and 13 members are retired. All 12 children go to school at the appropriate year level. The academic qualifications of the adult vary from 2 school year to a bachelor's degree, with a mean value of  $8.0 \pm 3.4$  school years. In terms of nationalities, there are 50 Portuguese and 9 Brazilian.

Food Insecurity categories results (Table III.1), which were determined differently for households with children or without children, have been merged to evidence the totality of sample families experiencing each situation of Food Security (n=3), Low Insecurity (n=13), Moderate Insecurity (n=3), and Severe Insecurity (n=8).

**Table III.1:** Sociodemographic and Anthropometric Sample Characterization (n=59)

<b>Sociodemographic sample characteristics</b>		
	<b>n</b>	<b>%</b>
Families	27	
Households		
1	9	33.4
2	8	29.6
3	6	22.2
4	4	14.8
Households with Children		
Yes	8	29.6
No	19	70.4
Gender		
Female	34	57.6
Male	25	42.4
Occupational status		
Active members	16	27.2
Unemployed	17	28.8
Students	13	22.0
Retired	13	22.0
Highest Level of Education (adults n=47)		
1-4 years	12	25.5
5-6 years	7	15.0
7-9 years	12	25.5
10-12 years	15	31.9
>12 years	1	2.1
Nationality		
Portuguese	50	84.7
Brazilian	9	15.3
Food Insecurity		
Food Security	3	11.1
Low Insecurity	13	48.2
Moderate Insecurity	3	11.1
Severe Insecurity	8	29.6
Body Mass Index		
Underweight	1	1.7
Healthy weight	28	47.5
Overweight	17	28.8
Obese	13	22.0

To classify and quantify the foods distributed by ReFood in relation to the Portuguese food guidelines a 2200 Kcal reference diet was selected (Rodrigues, Franchini, Graça, & de Almeida, 2006) and one major assumption was made concerning the definition of a child. The UN Convention on the rights of children (1989) defined a child as “every human being below the age of eighteen years, unless under the law applicable to the child, majority is attained earlier”. The WHO defines adolescents as individuals in the 10–19 years age group (WHO, n.d.). However, for this study, we considered the volume of ingested food for a child over ten years old as similar to the food volume an adult ingests, remembering that the nutritional needs of a child/teenager are different from those of an adult (Koletzko, 2008; Mayo Clinic, n.d.).

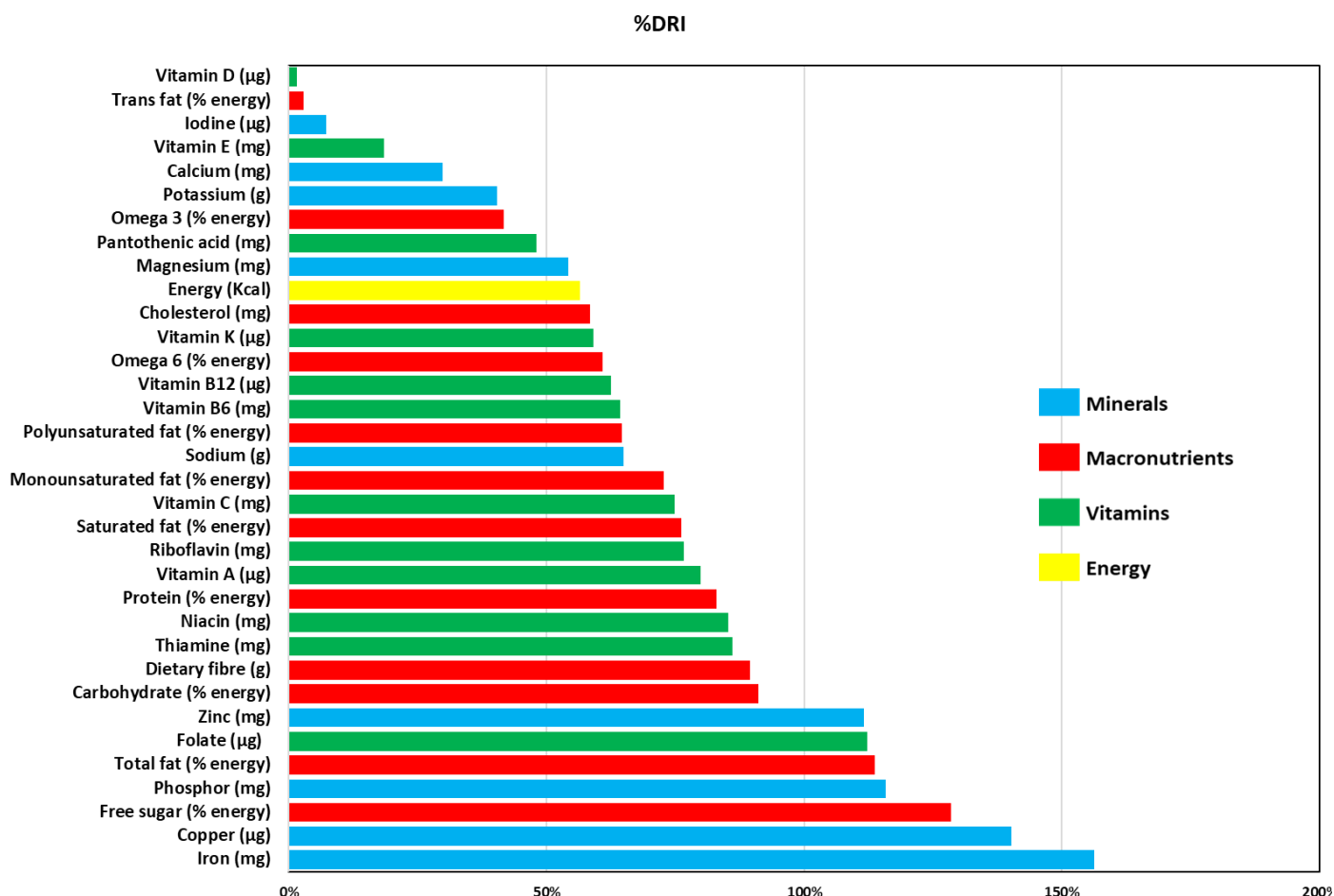
The daily mean macro- and micronutrients of redistributed food and the percentage of DRI (IOM, 2011; Van Horn, 1997; WHO, 2003) for beneficiaries are presented in Table III.2. The results show that the food hampers contributed to more than 100% of the DRI of Fe (156.3%), Cu (140.3%), total fat (133.7%), free sugar (128.5%), P (115.8%), folate (112.2%), and Zn (111.6%).

**Table III.2:** Mean Value of Nutrients Distributed per person and per day and percentage of the dietary reference intake (DRI)

Mean Value of Nutrients Distributed per person and per day		
Nutrients	Mean Value	% DRI
Energy (Kcal)	1244.4	56.6
Protein (% energy)	18.68	83.0
Carbohydrate (% energy)	50.08	91.1
Free sugar (% energy)	13.16	128.5
Total fat (% energy)	31.27	113.7
Saturated fat (% energy)	9.16	76.2
Monounsaturated fat (% energy)	12.74	72.8
Polyunsaturated fat (% energy)	5.17	64.6
Trans fat (% energy)	0.04	2.9
Cholesterol (mg)	175.50	58.5
Omega 3 (% energy)	0.38	41.7
Omega 6 (% energy)	4.57	60.9
Dietary fiber (g)	24.6	98.4
Vitamin A (µg)	638.7	79.8
Thiamine (mg)	0.99	86.1
Riboflavin (mg)	0.92	76.7
Niacin (mg)	12.8	85.3
Pantothenic acid (mg)	2.4	48.0
Vitamin B6 (mg)	1.03	64.4
Folate (µg)	448.9	112.2
Vitamin B12 (µg)	1.5	62.5
Vitamin C (mg)	61.7	74.8
Vitamin D (µg)	0.23	1.5
Vitamin E (mg)	2.76	18.4
Vitamin K (µg)	62.0	59.0
Calcium (mg)	328.4	29.9
Copper (µg)	1262.5	140.3
Iodine (µg)	10.9	7.3
Iron (mg)	12.5	156.3
Magnesium (mg)	200.7	54.2
Phosphor (mg)	810.7	115.8
Potassium (g)	1.9	40.4
Sodium (g)	1.3	65.0
Zinc (mg)	10.6	111.6

Figure III.1 shows that, although the redistributed food doesn't meet the DRIs for the remaining nutrients, the food benefits still provide for 91.1% of carbohydrate, 89.5% of dietary fiber, 86.1% of thiamine, 85.3% of niacin, 83.0% of protein, 79.8% of vitamin A, 76.7% of riboflavin, 76.2% of saturated fat, 74.8% of vitamin C, 72.8 % of monounsaturated fat, 65.0% of Na, 64.6.0% of polyunsaturated fat, 64.4% of vitamin B<sub>6</sub>, 62.5% of vitamin B<sub>12</sub>, 60.9% of omega 6, 59.1% of vitamin K, 58.5% of cholesterol, 56.6% of energy, and 54.2% of Mg.

Furthermore, the food donations supplement recipients' dietary intake with additional pantothenic acid (48.0%), omega 3 (41.7%), K (40.4%), Ca (29.9%), vitamin E (18.4%), I (7.3%), trans fat (2.9%), and vitamin D (1.5%).



**Figure III.1:** The percentages of the daily contribution of the food donations to the dietary reference intake (DRI) of Refood- Leiria beneficiaries. Institute of Medicine dietary reference intakes for energy, macronutrients, fiber, and micronutrients (IOM, 2011) ; World Health Organization (WHO) dietary reference intakes for cholesterol, free sugars, saturated fat, monosaturated fat, polyunsaturated fat, trans fatty acid (WHO, 2003); American Heart Association dietary reference intake for fiber (Van Horn, 1997).

Reported values of weight and height were used to calculate BMI of all beneficiaries. Mean adult BMI value is 25.9±4.62, with one individual underweighted, 22 having a healthy weight, fifteen overweight and nine obese. For children, BMI was calculated using height and weight values reported by parent, the sex and child's age, together with the Centers for Disease Control and Prevention BMI Calculator for Children and Teen online tool (Centers for Disease Control and Prevention, 2020), which also

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provides the BMI categorization, considering the child's age and sex. No child fell in the underweight category, six have a healthy weight, two are overweight and four obese. For children, because according to the child's age and sex the same BMI value may fall into different categories, no mean BMI value was calculated.

This study was carried out focusing on families and not on individuals. Food (in)security was found to be directly related to the mean amount of energy contained in each family hamper. However, two of the four food (in)security category frequencies showed  $n < 5$  and therefore the four categories of food (in)security (Food security, Low Insecurity, Moderate Insecurity, and Severe Insecurity) were regrouped into two, "Food security and Low Insecurity" and "Moderate and severe Insecurity", to homogenize the distribution. Thusly, the distribution of macro and micronutrient mean values into the two new food insecurity categories, was found to not be a normal distribution. As a result, two non-parametric tests, the median test, and the Mann-Whitney U test, were applied (Table III.3), showing no statistic differences ( $p < 0.05$ ) except for polyunsaturated fat and omega 6.

**Table III.3:** Mean Value and standard deviation of Nutrients Distributed per person, per day and per two Food Insecurity categories, and Results of Median Test and of Mann-Whitney U Test per nutrient

<b>Mean Value and standard deviation of Nutrients Distributed per person and per day per food category</b>				
<b>Nutrients</b>	<b>Food Security and Low Insecurity</b>	<b>Moderate and Severe Insecurity</b>	<b>Mann-Whitney U Test</b>	<b>Median Test</b>
Energy (Kcal)	1540.7 ± 1810.5	813.6 ± 344.0	0.394	1.000
Protein (% energy)	18.44 ± 2.679	18.84 ± 4.755	0.394	0.440
Carbohydrate (% energy)	52.43 ± 8.291	46.84 ± 7.756	0.481	0.704
Free sugar (% energy)	12.97 ± 2.105	13.43 ± 2.819	0.394	0.704
Total fat (% energy)	29.35 ± 6.689	34.03 ± 4.184	0.099	0.252
Saturated fat (% energy)	8.564 ± 2.184	9.978 ± 1.554	0.148	0.252
Monounsaturated fat (% energy)	11.96 ± 3.171	13.87 ± 1.811	0.195	0.704
Polyunsaturated fat (% energy)	4.807 ± 0.9055	5.708 ± 1.075	0.030	0.252
Trans fat (% energy)	0.0556 ± 0.1305	0.1000 ± 0.0205	0.342	0.183
Cholesterol (mg)	187.3 ± 152.5	158.4 ± 103.0	0.865	0.704
Omega 3 (% energy)	0.3590 ± 0.162	0.3987 ± 0.1294	0.544	0.704
Omega 6 (% energy)	4.252 ± 0.859	5.032 ± 1.015	0.023	0.252
Dietary fiber (g)	34.81 ± 78.76	9.642 ± 9.998	0.089	0.120
Vitamin A (µg)	707.4 ± 537.0	538.7 ± 312.7	1.000	1.000
Thiamine (mg)	1.26 ± 1.29	0.614 ± 0.249	0.110	0.440
Riboflavin (mg)	1.087 ± 0.853	0.666 ± 0.284	0.318	0.440
Niacin (mg)	14.64 ± 9.802	10.25 ± 7.318	0.342	0.440
Pantothenic acid (mg)	3.082 ± 3.457	1.513 ± 0.757	0.121	0.440
Vitamin B6 (mg)	1.342 ± 1.742	0.565 ± 0.315	0.342	0.440
Folate (µg)	656.6 ± 1756.8	146.9 ± 57.23	0.178	0.440
Vitamin B12 (µg)	1.674 ± 1.331	1.321 ± 0.8019	0.827	1.000
Vitamin C (mg)	77.54 ± 55.70	38.37 ± 13.42	0.121	0.440
Vitamin D (µg)	0.2417 ± 0.2356	0.2060 ± 0.2813	0.368	0.440
Vitamin E (mg)	3.486 ± 4.169	1.698 ± 0.9425	0.544	1.000
Vitamin K (µg)	73.60 ± 51.83	45.08 ± 19.44	0.195	1.000
Calcium (mg)	422.8 ± 552.7	191.14 ± 73.89	0.099	0.440
Copper (µg)	1.819 ± 3.654	0.4256 ± 0.1861	0.162	0.440
Iodine (µg)	13.27 ± 11.87	7.499 ± 3.334	0.212	0.120
Iron (mg)	16.52 ± 30.10	6.551 ± 2.555	0.212	1.000
Magnesium (mg)	280.28 ± 511.77	97.31 ± 44.68	0.121	0.440
Phosphor (mg)	1061.5 ± 793.3	445.9 ± 194.9	0.394	1.000
Potassium (g)	2526.9 ± 3433.3	1035.5 ± 399.5	0.272	0.440
Sodium (g)	1528.8 ± 863.5	1063.3 ± 485.5	0.272	1.000
Zinc (mg)	13.13 ± 16.31	6.855 ± 2.372	0.610	0.704

### III.4 Discussion

The nutritional results showed that rescued and redistributed fresh or freshly cooked food can contribute to low-income households' DRI of energy, and macro- and micronutrients. As we were unable to find parallel studies that examined DRI of exclusively rescued and redistributed fresh or freshly cooked food, we could not extrapolate beyond this case study. Moreover, the results in the previously mentioned literature are often

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expressed in other units other the dietary reference intake (DRI). Still, we used the results from other researchers who studied food provided to low-income households by emergency food organizations for discussion purposes, regardless of their nature or national nutritional guidelines.

The estimate of energy provided by the food donation in the present research is 1244.4 Kcal, which is 56.6% of the DRI, higher than that reported Sparke et al (Pelham-Burn et al., 2014; Sprake et al., 2014) but lower than those found by other researchers (Leung et al., 2012), which, in some cases, exceeded the recommendations (Fallaize et al., 2020; Greger et al., 2002; Irwin et al., 2007). As food hampers offered by ReFood-Leiria are supposed to provide for at least one full meal, plus snacks, this caloric intake is adequate with respect to the Portuguese food guidelines of 2200 Kcal for the reference diet selected (Rodrigues et al., 2006).

The mean supply of macronutrients in this case study not only almost met the DRI for protein and carbohydrates but exceeded the DRI with respect to total fat (Table 1). This concurs with the organization providing for at least one meal per day but, whenever possible, more than one meal is served to improve beneficiaries' nutrition on days when they do not collect food from the organization. Other researchers found food-aid organizations supplying larger portions (>%DRI) of protein (Akobundu, Cohen, Laus, Schulte, & Soussloff, 2004; Fallaize et al., 2020; Greger et al., 2002; Leung et al., 2012), carbohydrates (Fallaize et al., 2020; Leung et al., 2012), and total fat (Lyles et al., 2013; Pelham-Burn et al., 2014). Still, some studies found insufficient amounts (<%DRI) of protein (Hoisington et al., 2011; Irwin et al., 2007; A. Li et al., 2009; Mousa & Freeland-Graves, 2019), carbohydrates (Mousa & Freeland-Graves, 2019), and fat (Irwin et al., 2007; Mousa & Freeland-Graves, 2019) being served by emergency food programs.

In addition to total fat, other types of conveyed fat were examined. The findings showed that the provision of each fat type was lower than the DRI. For saturated fat (DRI < 10% energy), trans-fat (DRI < 1% energy), and cholesterol (<300 mg, the equivalent of 58.8% DRI), all three results were adequate. Cholesterol-adequate food was also documented in a soup kitchen in the USA (Lyles et al., 2013). Similar results of lower-than-recommended polyunsaturated fat (Mousa & Freeland-Graves, 2019) and monounsaturated fat (Leung et al., 2012) have been found by other researchers.

Conversely, saturated fat was found to be significantly higher than recommended in food aid organizations in the U.K. (Fallaize et al., 2020; Sprake et al., 2014). Omega 3 (41.7% of the DRI) and omega 6 (60.9% of the DRI) provisions were considerable, unlike reported in a study in the USA (Leung et al., 2012), which reflects the amount of fish present in food rescued by the organization.

Our findings showed that the percentages of free sugar were higher than the DRI. The same result was found by researchers who examined the nutritional content of foods distributed by the Supplemental Nutrition Assistance Program in the USA (Leung et al., 2012, 2017), and by a food bank and a charitable meal service in the U.K. (Fallaize et al., 2020; Sprake et al., 2014). Even though nearly no sugary drinks are rescued and redistributed by our case study organization, they rescue a large amount of bakery products. These bakery products often contain free sugar as a part of the recipe or even as a leavening aid; therefore, a considerable quantity of these products is diverted to other organizations to avoid sugar-unbalanced dietary patterns in beneficiaries. Nevertheless, bakery products are served to be consumed as breakfast and mid-morning or mid-afternoon snacks in amounts appropriate for more than one day.

Figure 1 shows that the dietary fiber provided by the food donation was 89.5% of the DRI, an adequate provision. Even if adequate provisions of fiber were found in two studies (Akobundu et al., 2004; Fallaize et al., 2020), most researchers reported inadequate amounts of served fiber (Leung et al., 2012; Lyles et al., 2013; Mousa & Freeland-Graves, 2017; Sprake et al., 2014; Tse & Tarasuk, 2008). One of the reasons that may explain the large amount of fiber served by the ReFood-Leiria organization is the Portuguese tradition of vegetable soup consumption at nearly every meal, as well as of vegetable side dishes (usually salads or boiled vegetables). Hence, it is not surprising that these products are constantly present in food rescued from different food sources (the HORECA channel, the distribution sector, and canteens) and are thus served by the organization.

The redistributed mineral micronutrients depicted in Figure 1 have DRIs for Fe, Cu, P and Zn, all above 100%, mirroring the redistribution of meat and green-leaved vegetables. Adequate (Akobundu et al., 2004; Lyles et al., 2013; Tse & Tarasuk, 2008) and high (Greger et al., 2002) provision of Fe, and insufficient Zn (Irwin et al., 2007; Maioli et

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al., 2016; Pelham-Burn et al., 2014; Sprake et al., 2014; Tse & Tarasuk, 2008) have been documented. The Na and Mg DRI provisions were >50% but lower than 70%, consistent with the small amounts of salt in cooked rescued food. The Na results are consistent with those from research of two food aid organizations (Lyles et al., 2013; Maioli et al., 2016), but Mg was found to be lower than in other organizations (Irwin et al., 2007; Sprake et al., 2014; Tse & Tarasuk, 2008)(Mousa & Freeland-Graves, 2019; Pelham-Burn et al., 2014). The pattern of low amounts fresh fruit and vegetable donations in many organizations is consistent with findings of the inability to meet K nutritional requirements (Darmon et al., 2001; Lyles et al., 2013; Mousa & Freeland-Graves, 2019; Pelham-Burn et al., 2014; Sprake et al., 2014). However, the ReFood-Leiria organization conveys large amounts and a wide variety of fresh fruit and vegetables, which, due to their nature, met 40.4% of the total K DRI, consistent with usually redistributed items such as jacket potatoes and bananas. Because few dairy products are rescued and redistributed by the ReFood-Leiria organization, it is not surprising that the DRI for calcium is lower than 50%. However, this is evidence of how vegetables such as kale, a typical Portuguese soup ingredient or side dish, are good sources of calcium. The scarcity of donations of dairy products, fruit, and vegetables, causing the lack of Ca, has been reported in American and European research quantifying the nutritional content of food provided by charitable services (Akobundu et al., 2004; Darmon et al., 2001; Greger et al., 2002; Irwin et al., 2007; Lyles et al., 2013; Maioli et al., 2016; Mousa & Freeland-Graves, 2019; Pelham-Burn et al., 2014; Simmet et al., 2017; Tse & Tarasuk, 2008). The provision of I was found to be much lower than the DRI, unlike results documented in British food banks (Fallaize et al., 2020). However, our results concur with the European iodine deficiency identified by the World Health Organization (Andersson, De Benoist, Darnton-Hill, & Delange, 2007).

Food hampers distributed by our case study organization always contained fresh fruit and vegetables. As such, it is not surprising that the percent DRI of the calculated vitamin content was high, unlike most reported findings. Rescued and redistributed foods' folate provision exceeded 100% DRI, a result previously documented in the USA (Akobundu et al., 2004; Greger et al., 2002). Vitamin A, thiamine, riboflavin, niacin, and vitamin C were provided in amounts ranging from 75% to 100% of the DRI. Vitamin B<sub>6</sub>, vitamin B<sub>12</sub>, and vitamin K percent DRI provisions were lower than but still over 50%.

The previously mentioned researchers observed a low or very low percent DRI of vitamin A (Akobundu et al., 2004; Fallaize et al., 2020; Irwin et al., 2007; Lyles et al., 2013; Mousa & Freeland-Graves, 2019; Pelham-Burn et al., 2014; Simmet et al., 2017; Sprake et al., 2014; Tse & Tarasuk, 2008), thiamine (Darmon et al., 2001; Tse & Tarasuk, 2008), riboflavin (Darmon et al., 2001; Irwin et al., 2007; Tse & Tarasuk, 2008), niacin (Darmon et al., 2001; Irwin et al., 2007), vitamin C (Akobundu et al., 2004; Irwin et al., 2007; Mousa & Freeland-Graves, 2019; Pelham-Burn et al., 2014; Simmet et al., 2017), vitamin B<sub>12</sub> (Irwin et al., 2007), and vitamin K (Mousa & Freeland-Graves, 2019), consistent with the identified insufficient provision of fruit and vegetables. Our findings of a DRI lower than 50% for pantothenic acid and vitamin E are consistent with the small amounts of rescued and redistributed seeds and nuts. Finally, vitamin D, seldom present in food, was expectedly found in very small amounts, and thus also in other food aid organizations (Fallaize et al., 2020; Irwin et al., 2007; Maioli et al., 2016; Mousa & Freeland-Graves, 2019). Vitamin D, needed for human metabolism, is mainly synthesized by the human body when in contact with solar radiation (Bogh, Schmedes, Philipsen, Thieden, & Wulf, 2010; Holick, Chen, Lu, & Sauter, 2007).

The results of nutrient distribution between the two food insecurity categories were non-normal, with high standard deviation values, even after efforts to normalize the distribution through the application of conversion factors such as dividing each hamper's contents by the number of individuals per household and the number of weekly collection days. A second strategy to normalize the distribution involved removing outlier households from the sample. None of the attempts to normalize the distribution were successful due to the everchanging nature and quantity of daily rescued food requiring the organization to redistribute the majority of what is collected within 24 h. Thereby, adequate nonparametric tests, the Mann–Whitney U-test and median test, were applied. The results identified no statistical difference for nutrients provision between the two food insecurity categories, except for two nutrients. The Mann–Whitney U-test, with a significance of 5%, showed significant differences only for polyunsaturated fat ( $p = 0.030$ ) and omega 6 ( $p = 0.023$ ), suggesting that the beneficiaries' perception of food insecurity is independent of the amount of nutrients provided by the organization. This finding also suggested that the source of food insecurity might be related to other socio-economic factors, similar to other

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researchers' findings (Smith et al., 2017; Tarasuk & Mitchell, 2020). Moreover, no significant differences were found when correlating households' occupational status—steady income (active and retired) and unsteady income (unemployed and part-time workers)—with the two food (in)security categories with an exact Fisher's test ( $p = 0.391$ ).

This research's limitations may have been due to the non-normal nature of the distribution of the data, preventing the establishment of causal associations between food insecurity and the provided macro- and micronutrients and socioeconomic outcomes. One different limitation is related to assessing food insecurity based on the individual self-perception of the respondent, and the tool used does not allow the identification of how food insecurity affects each member of the household. Another limitation is that no measure of food intake was possible, and thus there was no possibility of evaluating the contribution of donated food to the total diet. Finally, the reported values of height and weight are another acknowledged limitation.

Several strengths should also be noted related to the data collection process, which involved weighing of more than 3500 items. This study design captured the mean amount of 33 nutrients and energy, allowing the calculation of each nutrient's percentage of DRI provided by rescued and redistributed food to low-income families. Furthermore, this was a pilot study on the contribution of upcycled freshly cooked food considering larger issues concerning food security, not only in Portugal, but from an international point of view. One key issue is that upcycled food, especially prepared food, is likely to be culturally appropriate and more likely eaten, providing quantities of food of appropriate quality for a nutritious diet. Secondly, the barriers to food security presented by a lack of cooking time, tools, or knowledge are avoided to some degree, allowing the use of food in all circumstances. Finally, our results challenge prior work showing low nutrition quality in many traditionally distributed shelf-stable or bulk food foods, which may contribute to changing the direction of research to more sustainable food security paths.

For future studies, a recommended design would include having a control group of families prior to being supported by the organization as well as conducting the research in other Refood operation centers, or in other similar organizations. The case study organization, Refood-Leiria, is one operation center of the national Refood organization that comprises 51 operation centers spread from North to South Portugal, one in Spain

(Madrid), one in Italy (Milan), and one developing in the USA (Richmond, Virginia). All operation centers conduct similar activities at the micro-local level, consisting of rescuing fresh or freshly prepared food, mainly from the HORECA channel and the redistribution sector, to redistribute it to low-income families. Thus, despite the sample size, the generalization of the results may be possible in the Portuguese context. To confirm the national generalization, the next round of research may focus on a Refood operation center in another context such as a larger Portuguese city (Lisbon or Porto). Another line of research should focus on Refood's activity in international contexts.

Another method of improving the research design would be to evaluate the beneficiaries' total food intake, so that the contribution of donated food to the total diet could be calculated.

### **III.5 Conclusions**

During the past decades, the food insecurity situation of the Portuguese population has been tackled by the public welfare system, but more recently, other governmental and some nongovernmental organizations such as the Refood project have emerged to support low-income households.

To the best of our knowledge, this is the first study to measure the nutritional content of fresh or freshly cooked rescued food by a food aid organization. Whereas other researchers have found that supplemental foods offered from food pantries are an important resource, a lack of sources of macro- and micronutrients provided by nonindustrial meals and fresh fruit and vegetables has been frequently documented. Conversely, our results showed that, for our case study, food aid organization, food donations substantially contributed to energy, and macro- and micronutrient DRI intake. When evaluating how these nutrients contribute to alleviating the food insecurity of the beneficiary households, we found that the perception of food insecurity was independent of the amount of nutrients served one to three times per week to each vulnerable household. Increasing the weekly frequency of hamper distribution requires food sources, physical space, refrigerating equipment, and human resources.

Food aid organizations require local cross-sector collaboration to achieve

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increased participation in food surplus donations from the HORECA channel and the distribution sector, to encourage volunteerism from university students, or to enact corporate social responsibility including volunteerism in continuing professional development.

The COVID-19 pandemic served as an example of a crisis that has posed unprecedented challenges to food loss and waste in the global food supply system as well as an increasing food insecurity risk to the population. We learned that, instead of resuming life as normal, life should transition to a new, more sustainable kind of normality where food recovery and redistribution to low-income families is a widespread practice of urban mining, fostering positive outcomes for biodiversity, human well-being, and climate.

Data from this study provide valuable information to increase the awareness of the nutritional value of food diverted from landfills. The findings also provide a strong argument to encourage policymakers not only to increase the resources allocated to organizations that both rescue food surpluses and fight food insecurity but also to implement policies that increase access to stable and sufficient quantities of adequate food to the food insecure.



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## **FINAL REFLECTIONS AND CONCLUSIONS**

## **ii. Overview**

The study was set out to explore what is being done to up-cycle food, especially for human consumption, and what are the benefits of this process. The initial research questions were:

- a) How is food waste being up cycled?
- b) How can up-cycled food contribute to the balanced diet of low-income households?
- c) What is nutritional content of rescued and redistributed food conveyed by a food aid organization, with respect to the dietary recommend intake values?
- d) How can the process of up-cycling and redistributing food contribute to achieving the SDGs?

First, the general research process and the consulted bibliography are reflected to demonstrate how the totality of the research process evolved along with the study. This research having been carried out during five years, going through the COVID-19 pandemic, a reflection is important for this pilot study to discuss how the researcher's lens evolved over time and may have impacted the research development. This reflection can be regarded as a second order learning exercise and offers a new perspective on how this research is framed in the situation of ecological crisis in which we live. Next, the research questions are answered and followed by discussing the limitations of the work. In the final section, future research paths are outlined.

### **ii.1 Reflection on the research process**

We are facing the 6<sup>th</sup> extinction of biodiversity. Even the loss of some endangered or vulnerable species could accomplish the 6th mass extinction only in centuries due to a domino effect, adding multiple ecological stressors, unusual climate change and high atmospheric CO<sub>2</sub> (Ceballos, García, & Ehrlich, 2010; Eldredge, 2009).

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According to WHO, it is likely that the COVID-19 originated in the loss of ecosystems, putting humans in presence of a virus present in wildlife (WHO, 2021). The more wildlife is destroyed, the more the conditions for the development of new future infections are generated. In fact, if the WHO hypothesis is proved correct, the humanity brought to itself this virus, by destroying natural ecosystems, which forced animals who live with the virus, to seek other spaces where the humans live.

This crisis revealed our excesses and the frailty of our society. If we don't change our behavior, we will lose the ecologic fight, having lost our capacity to adapt to our environment and therefore we must make the right choices before they are imposed to us by circumstances.

Several these choices are already being made and implemented around the globe and in very different activity sectors. Ecological corridors have been created to mitigate negative effects from transport/energy infrastructures in wild fauna (European Commission, 2016a; Instituto de Pesquisas Ecológicas, 2020; Lifelines Project- Universidade de Évora, n.d.). Farmers have decided to revolutionize current vegetable production practices by creating new systems inspired by nature (Centre de Développement de L'Agroécologie, n.d.; Frost, 2021; Maraîchage Sol Vivant, n.d.). During 2020 spring lockdown, the European and Chinese skies ones were clean and clear, CO<sub>2</sub> emissions curves dived, due to the decrease of industrial activity and air transportation (Liu et al., 2020). The Solar Impulse Foundation, and particularly Bertrand Picard, have developed a solar power powered airplane, raising the interest in profitable solutions to reconcile economy and ecology (Solar Impulse Foundation, n.d.).

New technologies are no panacea and they do not replace an examination of conscience that leads to consumption options involving less materials, less energy and less goods taken from nature. Sobriety is no option, nor is circular economy.

The environmental burdens of food waste are originated at all stages from production to distribution, storage, cooking, and disposal. These burdens concern water use, land use, deforestation, and loss of biodiversity at production, fertilizer impacts, GHG production during all transportation, storage, cooking and land fill processes, landfill use,

and other solid and liquid pollutants production. Upcycling food for human consumption contributes to alleviate both environmental burdens of food waste and food insecurity.

Post COVID-19 economy also showed that we produce less and less what we consume but consume less and less what we produce. United Nations' data show that, in 2018, 55% of the population lived in urban areas and that this number will rise up to 68% by 2050 (United Nations- Department of Economic and Social Affairs, 2018). Cities must, therefore, be able to self-provide and the process urban mining for food, up-cycling it, is one sort of response to the need of acting differently that was made clearer by the pandemic.

Even if this research is a limited case study from Portugal it speaks to the larger issue. It showed that upcycling fresh and freshly cooked food is possible, at micro-local level, can support low-income households, providing culturally appropriate meals, while avoiding the barriers presented by lack of cooking time, tools, or knowledge. This surprising result challenges prior work showing low nutrition in many traditional shelf-stable or bulk food distributed foods, at food aid organizations.

## **ii.2 Conclusions**

Deriving from the research questions outlined at the beginning of this thesis, six objectives were set up. This section is divided into six subsections, using a separate section for each objective.

### **ii.2.1 To provide an update on what has been found to upcycle FLW as a material or energy source, but also to find about solutions of using FLW for human consumption.**

This objective was addressed twofold: from the point of view of food waste reuse as a raw material, and as a resource to tackle food insecurity.

Food waste as a raw material research, focuses on the fields of chemical engineering, energy fuels, environmental engineering, biotechnology, and microbiology applied to engineering. Valorization of food waste turning it into a material or bioenergy

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source requires know-how and are more time, energy and other material consuming than the process of upcycling food as is. To reduce the environmental burdens of food waste reuse as a raw material, we advocate that FW upcycling, through technologic innovation should be sponsored towards the development solutions for inevitable and non-edible parts of FW.

Conversely, to avoid landfill environmental and economic burdens of disposing of edible food waste, as well as environmental and economic burdens of producing new food, the up-cycling process is still the most sustainable option, even if it also has its costs (EPA Environmental Protection Agency, n.d.). Hence, the pertinent second FLW research field, which focuses on food security, through FW upcycling for human consumption improvements in terms of humanitarian logistics, concerning supply, transportation, conservation, and volunteerism. At this research stage we also found there is a lack of research focusing on measuring the potential of rescued and redistributed perishable FW as a way of tackling food insecurity.

**ii.2.2 To evaluate the contribution of fresh and freshly cooked rescued and redistributed food to supplement low-income household diet, according to the Portuguese guidelines, using the Refood-Leiria organization as a case study.**

In this study, it was possible to measure the contribution of donated food to a balanced diet of Portuguese low-income families, according to Portuguese guidelines, demonstrating that the process of up-cycling fresh food contributes to improve dietary patterns of low-income households. Overall, for clients who rely on organizations that redistribute perishable food such as our case-study, the results in this study suggest that fresh rescued foods can contribute to a more balanced diet in terms of “Potato, Cereal and Cereal Products”, “Vegetables”, “Meat, Fish, Seafood and Eggs” and “Fruits”.

Moreover, when comparing foods redistributed at the food aid organization with the eating patterns of the general Portuguese population, the most significant differences are related to the consumption of Non-Food wheel products. In fact, the Refood organization distribution process facilitates the promotion of good eating habits, since

processed and ultra-processed foods are not distributed, but only meals prepared in traditional restaurants, in addition to unprocessed and fresh foods from surplus distribution chains. The fact that sugary drinks and eventual alcoholic beverages are diverted to other institutions also promotes healthy dietary patterns.

### **ii.2.3 To quantify the nutritional content of rescued and redistributed food conveyed by a food aid organization, with respect to the dietary recommend intake values (DRI)?**

Nutritional results show that rescued and redistributed fresh or freshly cooked food can contribute to low-income households' DRI of energy, macro, and micronutrients.

The estimate of energy provided by the food donation in the present research is 1244.4 Kcal, 56.6% of DRI. Considering that food hampers offered by ReFood-Leiria are supposed to provide for at least one full meal, plus snacks, this caloric intake is adequate, with respect to the Portuguese food guidelines 2200 Kcal reference diet selected.

The mean supply of macronutrients found in this case study not only almost met DRI recommendations for carbohydrates, dietary fibre, niacin, thiamine, and protein but exceeded recommendations with respect to iron, copper, free sugar, phosphor, total fat, folate, and zinc.

Riboflavin, Niacin, Pantothenic acid, Vitamin B6, Vitamin B12, Vitamin C, Vitamin E, Vitamin K, Calcium, Magnesium, Potassium, and Sodium were provided in amounts ranging from 79,8% and 18,4%.

### **ii.2.4 To evaluate how nutrients from rescued and redistributed food can contribute to alleviate food insecurity of the beneficiary households.**

Results of nutrient distribution between the two food insecurity categories showed a non-normal distribution. Thereby, adequate non-parametric tests, Mann-Whitney U test, and Median test, with a significance of 5% were applied. Results showed that no statistic difference was identified for nutrients provision between the two food insecurity categories, except for two nutrients, suggesting that the beneficiaries' perception of food

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insecurity is independent of the amount of nutrients provided by the organization. This fact also suggested that the source of food insecurity might be related to other socio-economic similarly to other researchers' findings (Smith et al., 2017; Tarasuk & Mitchell, 2020). Moreover, no significant differences were found when correlating households' occupational status – steady income (active and retired) and no-steady income (unemployed and part-time worker) – with the two food (in)security categories with an exact fisher test ( $p=0.391$ ).

#### **ii.2.5 To evaluate the ways in which the process of upcycling fresh food can contribute to achieve SDGs.?**

Upcycling food, besides feeding malnourished populations (SDG 2.1), contributes to increase resource use efficiency (SDG 9.4; SDG 12.5) and to substantially reduce waste generation, ensuring sustainable food consumption and production systems (SDG 12; SDG 2.4). In turn, global resource efficiency in consumption and production also helps to maintain ecosystems, lowers greenhouse gas emissions, and fosters climate resilience (SDG 13.2.1). We found that the consumption of rescued and redistributed food contributes to a balanced diet and therefore improves the health (SDG3) of families struggling with poverty (SDG1) and thus reduces inequalities (SDG10). The whole food rescuing process requires the involvement stakeholders, such as food sources, volunteers, and multiple community partners contributing in different ways (from plastic containers to vehicles and petrol) to support the beneficiaries (SDG 17.2; 17.17).

#### **ii.2.6 To propose a strategy to make the food rescue and redistribution process a perennial activity, naturally integrated into citizens' lives.**

This objective had no direct place in any of the previous thesis parts and derives from constant reflection during the doctoral course. All strategies mentioned were already successfully implemented during the past six years, to make the food rescue and redistribution process a perennial activity.

The process of upcycling food to support low-income households requires various stakeholders: food sources, volunteers, beneficiaries, and a diversity of other stakeholders who are involved in different ways. The challenges presented involve having a steady number of volunteers, food sources, beneficiaries and sponsorships which requires constantly endeavoring in contacts and innovative strategies.

It may seem odd to consider finding beneficiaries a challenge. In fact, most households either seek help by their own initiative, through friends already supported by the Refood organization, or are referred by a partner governmental or non-governmental organization. Nonetheless, these governmental and non-governmental organizations are, in turn, also beneficiary-partners, being the recipients of daily collected foods in such large amounts that, if provided to households, would result in extremely unbalanced diets (*e.g.* bakery products). To optimize the concertation of efforts and resources for the redistribution of food surpluses to needy populations, promoting meetings with the participation of the other social aid organizations, can increase interconnectedness.

Food sources may be searched by direct personal contact, email etc, or through other indirect initiatives, such as participating locally in conferences, colloquia, and seminars where different sorts of stakeholders and decision makers can be found in a situation conducive to dialogue.

To tackle the need of a constant number of volunteers, volunteering can be promoted at secondary school level and especially at university, when students are mature enough to understand how important it is to upcycle food waste, to support low-income households, to alleviate environmental burdens of food waste, and to give back to the community. To provide a meaningful learning experience at secondary level, and even junior high school, as a part of citizenship formation, students could participate in sorting food for donation at the school canteens, contributing actively for the process, raising the awareness of the whole school community for food waste versus malnourishment in local community. As living labs universities provide the perfect opportunity to commit meaningfully to sustainability. The participation in food donation should be encouraged by educators, through volunteering subjects inserted in the curriculum, and as a part of training, for students of all courses. Transformative learning may be implemented in

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another context and to another generation, included in corporate social responsibility in terms of actions (allowing employees to participate in food up-cycling during work time) or in the curriculum of continuing professional development.

### **ii.3 Limitations of the study**

The non-normal nature of the distribution data caused an impossibility of establishing causal associations between food in-security and provided macro and micronutrients, and socioeconomic outcomes, which represented a limitation of this research.

One different sort of limitation is related to the fact that food insecurity was assessed based on individual self-perception of the respondent, and the tool used does not allow the identification of how food insecurity affects each member of the household.

Another sort of limitation is the fact that no measure of food intake was possible, and thus there was no possibility of evaluating the contribution of donated food to the total diet. Finally, reported values of height and weight are also an acknowledged limitation.

### **ii.4 Future research**

Future research should evaluate the contribution of rescued fresh food to the dietary pattern of low-income families using a larger and more diverse sample.

For future studies, a recommended design would include to have a control group of families prior to being supported by the organization as well as conducting the research also in other ReFood operation centers, or other similar organizations. The case study organization, ReFood-Leiria, is one operation center of the national ReFood organization that comprises 51 operation centers spread from north to south of Portugal, one in Spain (Madrid), one in Italy (Milan), and one developing in the USA (Richmond, Virginia). All operation centers have a similar activity at micro local level, consisting of rescuing fresh or freshly prepared food, mainly from the HORECA channel and the redistribution sector, to redistribute to low-income families. Thus, despite the sample size, the generalization of

results may be possible in the Portuguese context. To confirm the national generalization, the next round of research could focus on a ReFood operation center in another context such as a larger Portuguese city (Lisbon or Porto). Another round of research should focus on ReFood's activity in international contexts.

Another way of improving the research design would be to evaluate the beneficiaries' total food intake, so that the contribution of donated food to the total diet could be calculated.

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## **APPENDICES**

## Appendix A – World food redistribution organizations

Organization	Countries	Self-reported activity	Distribution
Alimento para Todos(BA)	<a href="#">Mexico</a>	Collects and redistributes food, clothes, and other items,upcycled or not.	Global Food Banking Network member
Annakshetra	<a href="#">India</a>	Collects surplus food and distributes to the people at thebottom of the pyramid.	Soup kitchen
ANDES	<a href="#">France</a>	Solidarity groceries’ network based on the revalorization ofunsold products, to support low-income households.	Solidarity grocery
Boulder Food Rescue	<a href="#">USA</a>	Rescues and delivers healthy food such as uncut fruits andvegetables, to no-cost grocery programmes reducing food waste.	Solidarity grocery
Buon Samaritano	<a href="#">Italy</a>	Recover food surpluses from multiple donors in the foodsupply chain, reducing waste and giving food that is stillgood new value.	Global Food Banking Network member
City Harvest	<a href="#">USA</a> <a href="#">UK</a>	Collects good, nutritious food from farms, restaurants, grocers, and manufacturers to help feed people strugglingto put food on their tables.	Solidarity grocery
Comissão Nacional de Combate ao Desperdício Alimentar	<a href="#">Portugal</a>	Promotes the reduction of food waste through an integratedand multidisciplinary approach	Awareness programme
DC central kitchen	<a href="#">USA</a>	Volunteers transform wasted food into balanced meals for the community.	Soup kitchen

## Appendix A – World food redistribution organizations (Cont.)

Organization	Countries	Self-reported activity	Distribution
FareShare	<a href="#">UK</a> <a href="#">Australia</a>	Redistributes surplus food to charities that turn it into meals.	Soup kitchen
Feeding America	<a href="#">USA</a>	The largest hunger-relief organization in the United States, Feeding America connects people with food through donations, volunteers, and staff.	Global Food Banking Network member
Feeding Forward	<a href="#">USA</a>	Feeding Forward is an APP that connects businesses with excess edible food to feed those in need.	App
Food cycle	<a href="#">UK</a>	Improves nutrition and reduces hunger by cooking healthy meals using food surplus for those in need.	Soup kitchen
Foodforward	<a href="#">USA</a>	Volunteer project that recovers (from fruit trees, farmers markets and the Los Angeles Wholesale Produce Market) and distributes food surplus across 8 counties of southern California	Food hampers
Food Recovery network Food Sharing	<a href="#">USA</a> <a href="#">Germany</a> ; <a href="#">Austria</a> <a href="#">Switzerland</a> ; <a href="#">Denmark</a>	Student movement fighting against food waste and hunger. Food surplus from households is shared through a digital platform, to avoid food waste.	Food hampers App
Grow Sheffield's Abundance project	<a href="#">UK</a>	The Abundance Project aims to stop food waste by helping people harvest their fruit, then helping either re-distribute it to worthy food bank projects or helping to run workshops.	Food hampers

## Appendix A – World food redistribution organizations (Cont.)

Organization	Countries	Self-reported activity	Distribution
Hands for hunger	<a href="#">Bahamas</a>	Fresh surplus food rescue, non-perishable food storage, education, and awareness activities.	Food hampers
L.A. Kitchen	<a href="#">USA</a>	Uses rescued food for job training and distribution of healthy meals and snacks to areas with low food security	Soup kitchen
Last Minute Market	<a href="#">Italy</a>	Assists companies in the large-scale retail trade in the recovery of food surpluses.	App
Mesa Brazil do SESC	<a href="#">Brazil</a>	A national network of food banks that fights against hunger and waste.	Global Food Banking Network member
Unidos Contra o Desperdício	<a href="#">Portugal</a>	A civic and national movement, that unites several stakeholders in an active and positive fight against food waste.	Awareness programme
OLIO	<a href="#">UK</a> + 32 countries	Olio is a mobile app for sharing food, with the goal of reducing food waste, by connecting those with surplus foods to those who need or want to consume those foods.	App
OzHarvest	<a href="#">Australia</a>	Food rescue charity that collects quality surplus food to distribute it to people in need and divert food waste from landfill.	Solidarity grocery
Refood	<a href="#">Portugal</a>	Rescues and redistributes food to needy population	Food hampers

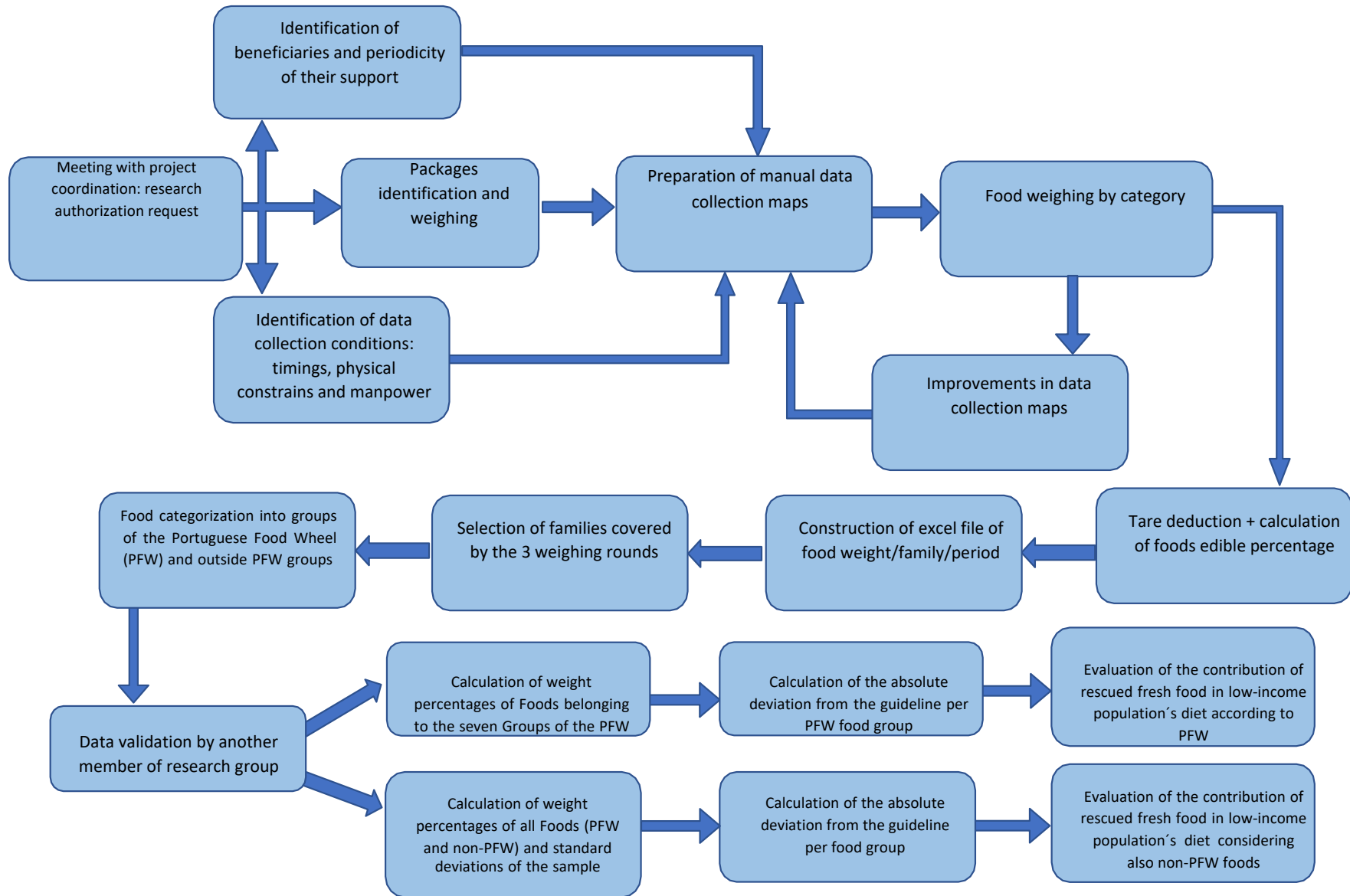
## Appendix A – World food redistribution organizations (Cont.)

Organization	Countries	Self-reported activity	Distribution
Rock e Wrap It Up!	<a href="#">USA</a>	Recovers all the prepared and unserved excess catered food.	App
SecondBite	<a href="#">Australia</a>	We rescue surplus food from across the retail network and redistribute it - free of charge.	Food hampers
Siticibo	<a href="#">Italy</a>	Rescues food to feed the needy.	Global Food Banking Network member
Society of St Andrew	<a href="#">USA</a>	Truckloads of surplus produce, donated by the agricultural community, are delivered to agencies serving the poor. + Gleaning	Food hampers
Solidarity Fridge	<a href="#">Brazil</a> ; <a href="#">France</a> ; <a href="#">India</a> ; <a href="#">New Zealand</a> <a href="#">Saudi Arabia</a> ; <a href="#">Spain</a> ; <a href="#">Sweden</a> ; <a href="#">United Arab Emirates</a> ; <a href="#">United Kingdom</a> <a href="#">Sweden</a> <a href="#">Argentina</a> ; <a href="#">Portugal</a> ; <a href="#">USA</a>	Fights against food wasted due to food trends or being too close to the sell by date.	Solidarity grocery
Stop spild af mad	<a href="#">Denmark</a>	Since 2011, Stop Food Waste, partners and volunteers collect and distribute free surplus food in hostels, shelters, women's homes, and other aid organizations for the homeless and socially disadvantaged.	Food hampers
The Daily Table	<a href="#">USA</a> (Massachusetts)	Founded by a veteran of the grocery industry, The Daily Table is a non-profit grocery store that opened in June 2015 in Dorchester, Massachusetts, with a goal of using rescued and donated food from a variety of sources to offer low-cost food in underserved neighborhoods.	Solidarity grocery

## Appendix A – World food redistribution organizations (Cont.)

Organization	Countries	Self-reported activity	Distribution
<a href="#">The Global FoodBanking Network</a>	<p><b>GFN Certified Members:</b> Argentina; Australia; Botswana; Brazil; Bulgaria; Canada; Chile; China; Colombia; Costa Rica; Dominican Republic; Ecuador; El Salvador; Guatemala; Honduras; Hong Kong; Israel; Mexico; Panama; Paraguay; Peru; <a href="#">Portugal</a>; Russia; Singapore; South Africa; South Korea; Taiwan; Turkey; United Kingdom.</p> <p><b>GFN Network members:</b> Botswana; Bhutan; India; Jordan.</p> <p><b>European Food Banks Federation (partner):</b> Austria; Belgium; Czech Republic; Denmark; Estonia; Ukraine; France; Germany; Greece; Hungary; Italy; Ireland; Lithuania; Luxemburg; Netherlands; Norway; Poland; Portugal; Russia; Serbia; Slovakia; Spain; Switzerland.</p> <p><b>Feeding America (partner)</b></p>	An international non-profit that works towards a hunger-free future in more than 40 countries by creating, sustaining, and strengthening food banks. Food banking systems capture surplus food and deliver it to the people who need it most, engaging all sectors of society (governments, business, and civil) in the process. Food banks acquire donated food, much of which would otherwise be wasted, from farms, manufacturers, distributors, retail stores, consumers, and other sources, making it available to those in need through an established network of community agencies. (GBN)	Global Food Banking Network member
Zero Desperdício	<a href="#">Portugal</a>	ZERO DESPERDÍCIO's focus is combating waste, in all its dimensions and aspects, from production to consumption, from oceans to energy, from resources to knowledge, associating with innovation, new approaches and possibilities for building a future and a more sustainable society.	Awareness programme

**Appendix B: Part II Methodology flow-chart**



**Appendix C: Part III Methodology flow-chart**

