Gap analysis for decision support tools, models and libraries

REFRESH D2.6

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Authors

Combining reports provided by:

Mari Wigham, Wageningen Food and Biobased Research

Seth Tromp, Wageningen Food and Biobased Research

Jennifer Wilson, Anthesis

Kate Bygrave, WRAP

With thanks to:

Anton Smeenk, Joost Snels and Nicole Koenderink (Wageningen Food & Biobased Research)

Project coordination and editing provided by WRAP.

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List of abbreviations

CFT	Cool Farm Tool
CoE	Community of Experts
CSR	Corporate Social Responsibility
DSL	Decision Support Library
DSM	Decision Support Model
DSS	Decision Support System
DST	Decision Support Tool
FLW	Food Loss and Waste
REA	Rapid Evidence Assessment
WP	Work Package

1 Executive summary

The REFRESH project investigates amongst other research Decision Support Systems (DSSs) that can help people, whether policy-makers, company CEOs or consumers, to make choices that help to reduce food waste. We want to develop systems that give people information, sometimes qualitative, sometimes quantitative, about the effects of their choices in terms of both food waste and the costs entailed. This helps them to make effective decisions.

One way to provide decision support is to model food waste using a Decision Support Model (DSM) or Decision Support Tool (DST)[1], making it possible to produce information on the likely effect of decisions on food waste. By making it easier for the target audiences to search for appropriate DSMs and DSTs and ensuring clear descriptions are provided the Decision Support Library (DSL) can help enable the provision of this advice.

This report provides the outcome of an assessment of the REFRESH DSL, DSTs and DSMs which included an assessment of the wider DSLs, DSTs and DSMs available from other providers.

It concludes that while the existing DSLs from other providers have a subset of the functionality, none of them provides the full range of support envisioned for the REFRESH DSL. The key gaps are the absence of a library for food waste DSMs; the lack of support for clear, structured, unambiguous model descriptions of models from a range of software environments; and the lack of support for finding compatible models or alternative models.

In relation to DSTs and DSMs it concludes that there are a considerable variety and scope of tools available for the target audiences to use. The benefit of the REFRESH DSTs and DSMs is that they share the same characteristics as the existing tools available, which confirms their appeal. However, this means that work may be needed to highlight and articulate the additional benefits and value of using the REFRESH outputs over other resources available.

There is an opportunity to develop DSMs and DSTs that are targeted for use by food businesses and the trade bodies that represent them rather than being targeted at academia and consultants. User feedback indicates they desire tools to cover a broad scope, and would prefer indicative tools which can be used to drive insights, rather than more detailed tools and models.

In terms of gaps in current provision of DSTs and DSMs, animal proteins (i.e. poultry, beef, lamb and fish) are a potential food type to extend into to increase market uptake. In addition, warehouse/chill house and logistics present gaps in the food supply chain that are currently not covered by DSTs or DSMs.

[1] As defined later in this document DSTs are aimed primarily at businesses, retailers, food manufacturers and trade associations. They tend to be easy to use with limited input options and guide the user through a number of steps in order to inform decision making. DSMs tend to be more complex and are typically used by technical consultants, academics and scientists to model specific situations help them produce tailored advise for decision makers.

There are two calculations that current tool offerings cannot undertake[2], which the REFRESH outputs could address:

- Estimate the carbon impacts of, and carbon offsets achieved, through food redistribution and how this differs within and between product categories;
- Look at the wider (true) costs of food waste reduction for a business i.e. procurement, labour, water, energy.

There are no 'functionality' requirements which are not met by existing DSTs and DSMs; clean modern interfaces for ease of use, smart search functions enabling easy and quick sourcing of data and insights, and simple and clear taxonomy for users to understand linkages of data are already included with the DST and DSM REFRESH work plans. Additional recommendations, such as housing the tools on an online platform etc. can be made to increase the uptake and use of the resources, such as hosting them on the REFRESH Community of Experts (CoE).

The on-going updating of the DSTs and DSMs poses a significant challenge which as yet, no other provider has managed to solve. Therefore, it is suggested that the longevity of the tools and models is carefully considered and a plan put in place to ensure that the resources created and shared will be updated and future proofed.

2 Background

REFRESH ("Resource Efficient Food and dRink for the Entire Supply cHain") is an EU research project taking action against food waste. 26 partners from 12 European countries and China work towards the project's goal to contribute towards Sustainable Development Goal 12.3 of halving per capita food waste at the retail and consumer level and reducing food losses along production and supply chains, reducing waste management costs, and maximising value from un-avoidable food waste and packaging materials. Backed by research to better understand the drivers of food waste, the project supports better decision-making by industry and individual consumers.

The work presented in this report was developed as part of Work Package 2 (WP2) on Business Engagement & Frameworks of Action of REFRESH. WP2 aims to establish evidence for a pan-European Framework for Action through the design and validation of national pilots so that Governments and other stakeholders can assess the potential of full scale national and EU-level frameworks in helping to deliver policy objectives on food waste, sustainable diets, food poverty, waste valorisation and oackagaing materials with high efficiency. Specifically WP2 seeks to design and pilot/test state-of-the art tools to facilitate effective decision making leading to actions that will prevent and valourise waste. WP2 identifies the need for a gap analyis of existing guidance and tools and what tools are required with the aim of helping to inform the development of DSSs by REFRESH. This report presents the outcomes of this work.

[2] Note calculations fall out of scope of functionality

3 Introduction

As outlined Section 2 REFRESH is interested in DSSs that can help people, whether policy-makers, company CEOs or consumers, to make choices that help to reduce food waste. We therefore want to develop systems that give people information, sometimes qualitative, sometimes quantitative, about the effects of their choices in terms of both food waste and the costs entailed. This helps them to make effective decisions.

The scope, however, remains very large. There is a large difference between advising a government on the potential impact of abolishing best-before dates, and helping a caterer to decide how they can best dispose of their surplus product and different approaches are needed for each.

The three key aspects of DSSs identified by REFRESH that are considered in this report are Decision Support Tools (DSTs), Decision Support Models (DSMs) and Decision Support Libraries (DSLs). For the purposes of the report these can be described in the following way[3]:

- **DSTs:** Are aimed at decisions between options for which the effects and applicability are well understood. The scope is typically quite specific. The effects for a given user can be determined based on a specified set of information, which the user can easily fill in without assistance. Models may be used for calculations, but the choice of model can be determined by the tool itself according to a set of logical rules, and the inputs are also simple to fill in. For example, a dairy producer may wish to decide what they can do with their excess milk. A web-based DST guides them through a number of steps, in which they can select which options are relevant for them. The outcome is a list of instructions for them to follow, with links to relevant policies and guidelines. The audience for DSTs is primarily businesses, retailers, food manufacturers and trade associations and in relation to REFRESH examples of DSTs are the Animal Feed Tool and Quick Scan for retailers.
- **DSMs:** Are used by experts to assist them in producing tailored advice for the decision maker. An example that can be used is a supermarket that wishes to decide what their ordering policy should be in order to produce a minimum amount of waste. This involves a complex interplay between suppliers, transporters, shelf stockers and customers, which is specific for the given supermarket. The scientific consultant must obtain custom data on sales and ordering from the supermarket, and must model the specific supply chain situation, so that the consultant can advise on the best ordering policy. To do this, they can reuse existing data about the spoilage of the supermarket products, and individual models for elements such as cold stores, lorries etc. Reuse of existing data and models greatly speeds up the process. The audience for DSMs is primarily technical consultants, academics and scientists. In the course of modelling different scenarios, the consultant may develop a calculation model that is sufficiently well defined in inputs, scope

[3] Descriptions based on those provided in REFRESH (WageningenUR), What is a DSS, 2016

and applicability that it can be applied in a DST. In relation to REFRESH the key scope of DSMs is food waste measurement and management models widely available via open source means.

- **DSLs:** In order for users to effectively reuse existing data DSMs and DSTs, they must be able to quickly and easily find them, and evaluate whether and how they can be used. Ideally a DSL will provide support for finding and downloading models and datasets and will describe them accurately to help users judge their compatibility. The term 'library' can be misleading, as it tends to evoke different images for different people. The traditional image is of a building filled with books. Software developers, however, think of a library of specific software functions, which are used within their own code. We use the term 'library' to refer to a collection of items that are stored in an organised fashion, so that they can be stored and retrieved easily. We only consider a library in electronic format.

It should be noted that DSMs and DSTs are complementary to each other and can support each other. Knowledge developed with the DSM can specify calculation models for a DST, and models and data gathered for a DST can be added as building blocks to the DSM. Finally, the DSMs and DSTs together represent a pipeline of knowledge on food spoilage from scientists, government and industry to individual decision makers.

A summarised comparison of DSTs and DSMs is provided in Table 1.

Table 1: Comparisons of DSTs and DSMs[4]

	DSM	DST
Target group	Large companies or governmental organisations, that have sufficient resources to hire a scientific consultant	Companies, both large and small, policy-makers, consumers. Typically a specific target group per DST.
Users	Scientific consultants with relevant expertise	Anyone in the target group
Type of decision supported	Innovative decisions in complex environments	Decisions with well-defined, well-understood effects and applicability.
Inputs required	Custom data from target group, mathematical models, reference data	Well-defined data from user, straightforward calculation models, logical rules
Outputs given	DSM output is the set of models and data. The overall output is the advice which the scientific consultant gives	A piece of information – for example a text giving instructions, or a calculated cost

[4] Table extracted from REFRESH (Wageningen UR), What is a DSS, 2016

3.1 Assessment of DSMs and DSTs

The intention is for all REFRESH outputs to provide stimulus for other EU and third countries, including China, to take action on food waste. Therefore, ensuring project outputs are fit for purpose and appropriate for the target stakeholders is of considerable importance. To ensure the DSTs and DSMs provide such stimulus and have a lifespan longer than the length of the REFRESH project (June 2019) a gap analysis was conducted to gain insight into the potential to extend the DSTs and DSMs. Through a gap analysis undertaken by Anthesis we sought to understand:

- what is missing in the range of tools?
- what doesn't work so well in the existing tools? And;
- what potential improvements could make the offering accessible to more stakeholders?

3.2 Assessment of DSLs

For consultants to effectively reuse existing data and models, they must be able to quickly and easily find them, and evaluate whether and how they can be used. This task is hard enough for one particular discipline, but is made harder by the fact that food waste is a problem that spans many disciplines, from logistics, to biology, to psychology. For this reason, REFRESH is developing a library of models and datasets related to food spoilage. This library will provide support not only for finding and downloading models and datasets, but also for accurately and unambiguously describing them and judging their compatibility. The library will not contain an engine for running the models, the user is expected to download them and run them using their own installed software.

The library will be capable of storing both DSMs and DSTs. It is useful to have a collection of available DSTs, and support in finding the most appropriate tool. However, the main focus of the library will be on DSMs, as these are the building blocks with which new DSMs and DSTs can rapidly be built.

An initial version of the REFRESH DSL already exists, built by data science experts from Wageningen Food & Biobased Research during a previous project. This version has a number of features that make it possible to store and find models. We have identified a further set of features that we consider necessary to provide more advanced support in describing (and hence understanding) the models, and judging their compatibility.

A gap analysis has been undertaken by Wageningen Food and Biobased Research to compare the REFRESH DSL to existing libraries, in order to determine:

- whether an existing library already fills the need;
- which unique functionality our library possesses;
- and whether our library is missing useful functionality that is present in other libraries.

Further development of this library is foreseen in both the REFRESH project and the Wageningen University and Research GFNS project. Therefore, the domain scope of the library will be broadened to cover sustainable food supply chains.

Not only waste models but also models in the field of food security and the circular economy will be of interest.

4 Approach

4.1 Approach to the assessment of DSTs and DSMs

To identify other similar offerings to the DSTs and DSMs Anthesis conducted a Rapid Evidence Assessment (REA). We (Anthesis) conducted the REA for comparable library and tool offerings, and evaluated to what extent these offerings were different and went beyond the distinctive aims and ambitions of the REFRESH outputs so far. After the REA was complete, we drew conclusions about the opportunity for plugging existing gaps in provision and improving the use and uptake of specific tools.

4.1.1 Search process

The search was conducted in two ways:

1. **Informal stakeholder interviews:** Utilising the Anthesis network of businesses within the food supply chain, informal interviews were conducted using a series of open ended questions to gain insights (see below for more detail).
2. **Desk-based research:** A large number of DSTs and DSMs were assessed. They were identified via the original 'Inventory of business change tools'[5] supplemented with a traditional internet search using Google and a review of the work undertaken to assess DSLs (described in this report). Following identification of the DSMs and DSTs for this research the Inventory of business change tools was updated. Section 6.1 of the Inventory provides a summary of the DSMs and DSTs that were assessed in this research.

Informal stakeholder interviews

As Anthesis has a solid network of UK and EU food manufacturer and retailer clients, a series of short face to face and telephone interviews were conducted to gain insight into the market value and opportunity that the DSTs and DSMs have.

To frame these discussions the following process was adhered to:

Approach to Interview

1. Introduction to REFRESH project, its aims and the purpose of the discussion (i.e. gaining stakeholder insight)
2. Overview of the decision support library and its contents

[5] An inventory of tools available to stakeholders in the food supply chain to support them in tackling food waste.

3. Discussions on their opinion using the following questions as a guide:
    - Do you use any food waste decision tools to inform your business approach?
    - If so are they any improvements you'd like to see in your tool?
    - Is there a tool that you wish existed (re food waste) that would help your business?
    - Are there certain types of food not covered by the tools you use or are aware of?
    - Are there tools that cover different areas which you use to inform your decision making?
4. Thanks and close out

For the purpose of this gap analysis six food manufactures and two food retailers were contacted for their insights. None of the participants will be named and their thoughts and insights are shared as part of the body of the findings outlined below.

Desk-based research

The traditional aspects of the REA search process were conducted as part of the desk-based research. Utilising our own search terms in addition to those used in the assessment of DSLs, the team reviewed existing resources available and then conducted a deeper review into the tools and models that were available. The search terms used were as follows:

Table 2. Search terms used

Search Terms Used		
Food waste tool	Food model library	Food waste resource library
Animal feed decision tool	Food waste library	Food waste reduction insights
Food waste valorisation tool	Food waste data library	

Assessment of tools

The tools identified by the search were then prioritised for further review using judgement of:

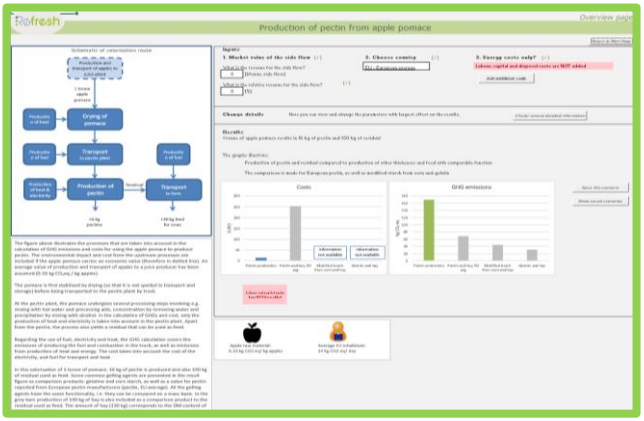
1. Applicability of content: How well the content of the tool fits with the objectives of REFRESH
2. Audience applicability: The target audience for the tool and whether it was targeted at the same audience as the REFRESH tools

Scores of 1 to 5 were given for each applicability criteria allowing those with the highest overall applicability score to be identified and assessed in more detail.

4.1.2 REFRESH DSMs and DSTs

The DSMs and DSTs identified from other providers were assessed in the context of the REFRESH DSTs and DSMs which are described below.

FORKLIFT

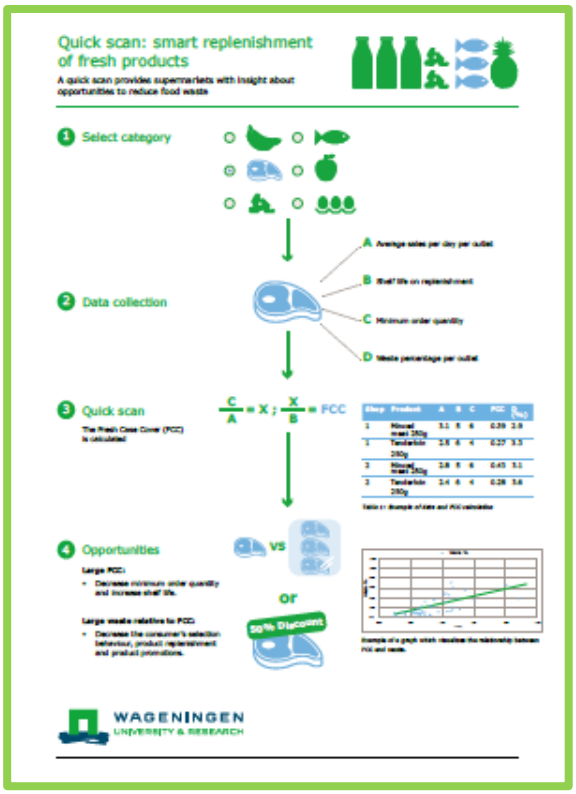


FORKLIFT: FORKLIFT (FOod side flow Recovery LIFe cycle Tool) provides stakeholders with a hands-on tool helping to gain a general understanding and highlight the environmental impacts and costs for selected valorisation routes, focusing on selected parameters. The food side-flows covered in the tool (WP6) are:

- Apple pomace
- Blood from slaughtering
- Brewers' spent grain
- Tomato pomace
- Whey permeate
- Rapeseed press cake

It uses an approach that pinpoints hotspots considering environmental impacts and costs in a given context for valorising food losses and secondary resources. FORLIFT allows quantitative data to be gathered and streamlined to make LCA and LCC approaches more accessible. It provides a framework which allows new models to be developed for other side flows in the future.

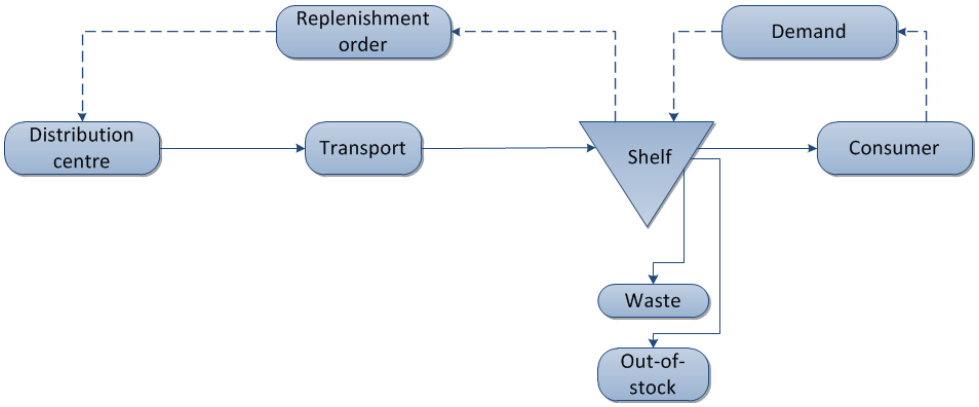
Quick Scan



Quick Scan: Quick Scan focusses on helping retailers to reduce in-store[6] food waste. In-store food products are wasted for different reasons. For example, due to expiration date labels, unacceptable quality decay or product/packaging damage. Some retailers lack a understanding of how food in the stores is wasted and how wastage can be controlled (e.g. via understanding of data with KPI's and SMART targets being set). Quick Scan is a four-step approach that gives retailers, based on their own historical data, a thorough insight in their food waste and opportunities to reduce it. The technique used is the so called Fresh Case Cover (FFC). This is an indicator with which problem areas (categories, products) can be identified in terms of loss. Depending on the FCC value and the measured loss, various prevention options are proposed.

[6] Food waste at retail outlets can be divided into pre-store and in-store food waste. Pre-store waste consists of items rejected by the retail outlet at delivery due to non-compliance with quality requirements. This proposal focusses on in-store food waste.

Fresh Case Cover[7]



Once the Quick Scan methodology has been used the next recommended step is Fresh Case Cover[8], a scientifically grounded methodology for simulation of a number of interventions at retail level that show the effects on spoilage (in weight and financial terms). Bottleneck outlets, categories and products are defined as outlets, categories and products that are responsible for a relatively large amount of waste compared to other outlets, categories and products. Finding these bottlenecks is done by benchmarking all products according to the performance indicator Fresh Case Cover index (FCC). Commonly retail outlets order new products according to a certain replenishment policy; a formal rule by which it is calculated how many new products should be ordered. The lower the predefined replenishment level, the lower the replenishment, and the lower the resulting stock level, implying less risk of having waste but also implying more risk of running out-of-stock. The method of calculating the specific value of the predefined replenishment level varies per retailer but is commonly based on factors such as a forecast of the future consumer demand based on historic sales, and a safety stock, sometimes called a 'display stock'. The FCC of a product is calculated by dividing the product's case pack size by its average regular daily demand and its store shelf life. Benchmarking of outlets, categories and/or products is possible using FCC.

[7] Details taken from: A methodology for food-waste prevention at retail outlets, Wageningen Food and Biobased Research, 2017

[8] At the time of writing, the report related to this deliverable is still in development (D2.7 a report of the method and results of testing the DSS within pilots)

Animal Feed Tool

Animal Feed Tool: It is estimated that if farmers all around the world fed their livestock on the food we currently waste and on agricultural by-products, enough grain would be liberated to feed an extra three billion people, more than the additional number expected to be sharing our planet by 2050[9]. The Animal Feed Tool is a decision making support tool developed by REFRESH for using former foodstuffs as farm animal feed. It allows producers to see if their waste could be used as animal feed and describes the relevant EU regulations for farmers and others in the food chain. The specific target audiences for the tool are:

- Catering/hospitality sector
- Farmers
- Food manufacturers / processors
- Retailers
- Dairy processors

4.2 Approach to the assessment of DSLs

The approach taken by Wageningen Food and Biobased Research to the gap analysis for DSLs was undertaken in three steps as follows.

1. **Defined functionality:** We (Wageningen Food and Biobased Research) defined the key functionality of our library.
2. **Web-search:** We searched the web for comparable libraries, and evaluated to what extent these libraries share the distinctive features of our library.

[9] United Nations Environment Programme (2009), The Environmental Food Crisis – The Environment's Role in Averting Future Food Crises, A UNEP Rapid Response Assessment, ed. C. Nellemann et al., February 2009, p. 19

3. **Conclusions:** We drew conclusions about the gap between our library and the existing ones: which gap do we fill, and which gaps still exist?

Defining functionality

Because the REFRESH DSL was still in development at the time of the research, Wageningen Food and Biobased Research made a distinction between actual features and features under development when defining the functionality of the DSL. The features under development are part of the research plan within the REFRESH project.

Web-search for comparable libraries

We (Wageningen Food and Biobased Research) considered comparable libraries to the REFRESH DSM library as being libraries that:

- Contain descriptions of mathematical or software models
- Allow the models to be searched
- Allow implementations of the models to be downloaded
- Can contain models relevant to food waste

When looking for comparable libraries, we considered three types of library:

- Libraries for model developers
- Libraries of models in a particular domain
- Generic libraries for sharing research

The search for the first two types was conducted via Google, using the search terms 'model library', 'food model library' and 'food waste library'. We limited our analysis to libraries that contained mathematical models, therefore excluding libraries of physical or CAD models. We also excluded libraries such as GAMS[10] that offered very basic support and/or were only marginally related to the type of models needed for modelling food waste.

We paid particular attention to searching for libraries related to food waste but did not find any. The closest results were resources libraries such as the EU food waste resources library[11], and the WRAP resources library[12]. These contained useful information such as guidelines and logos, but no mathematical models. There are therefore, to the best of our knowledge, no libraries that make models available to assist in modelling food waste.

Generic libraries for sharing research are very difficult to find via an internet search, as many different terms are used to describe them. Therefore we have

[10] https://www.gams.com/
[11] http://ec.europa.eu/food/safety/food_waste/library_en
[12] https://partners.wrap.org.uk/

relied on our experience from conferences and presentations in the eScience area to identify a shortlist. We concentrated on libraries whose main aim is to share research and make it reusable, and therefore have not included systems such as Pegasus[13] that concentrate mainly on running scientific workflows. Trident[14] was examined but is not included in the table of results, as the project has been archived, and also offered no distinctive features relative to the other libraries tested.

5 Outcomes

5.1 Outcomes of assessment of DSTs and DSMs

To help inform the next phase of the REFRESH DSTs and DSMs Anthesis has structured the findings the gap analysis of DSTs and DSMs into short sections, each addressing a different consideration related to the market opportunity available from the extension of REFRESH outputs.

5.1.1 Audience

One of the first fundamental questions regarding the potential scope of market opportunity for the DSTs and DSMs is whether they are applicable to a wider audience than that which they are intended? Currently the resources provided by REFRESH are aimed at a wide cross section of users, from food businesses, retailers, policy makers and academics – a good broad stakeholder base. The DSTs and DSMs then focus at separate cross sections of these stakeholders, with DSTs at decision makers in food businesses, and policy makers and DSMs at academics and consultants.

As such a broad audience has already been scoped out, to find opportunities to reach new audiences the above audience base needs to be segmented further to develop a richer and multi-tier audience map. Outlined below is an analysis of the sub-audiences that could be reached if the content and positioning of DSTs and DSMs were updated.

Table 3. Analysis of sub-audiences

Top Level	Sub – levels			
Food businesses	Primary producers	Manufacturers	Importers	Exporters
Retailers	Discounter	Top 5 by market share	Small/ local	Regional
Policy makers	Government	Trade Associations		
Other	Consultancies	Academics	Scientists	Catering/ hospitality

[13] https://pegasus.isi.edu/
[14] https://tridentworkflow.codeplex.com/

As presented above, it is felt that at a top level the majority of relevant audiences are correctly targeted, but that digging deeper into the tiers of each 'audience' the appropriateness and accessibility of the tools and models on offer begins to lessen as they become too niche (e.g. animal feed etc.). The yellow segments in the above table are highlighted as potential 'audiences' to target. These audiences have been identified for the following reasons:

1. There is scope for DSTs and DSMs to cover more topic areas than currently planned as part of the REFRESH outputs.
2. These stakeholders are often overlooked, whether because their business model is not straightforward, or they are not a highly influential stakeholder group in relation to food waste reductions.

Primary producers are the exception to the rule above as there are currently a significant proportion of tools and models available, however those try to be applicable to a variety of crops, livestock etc. Therefore these can often be perceived to be 'too high level/broad' to be seen as valuable to the primary audience and as such do not get used. If tools and models were developed to delve deeper into particular topics, on the understanding that the scope of audience will be smaller but the value to those who use it will be higher, this audience could be unlocked – however it would require significant investment in both time, resource and tool development.

Currently the planned focus by REFRESH for content is on DSMs whose target audience is academia and consultants, whereas the biggest market opportunity lies with food businesses that will utilise the two DSTs available (animal feed and waste valorisation). It is therefore suggested that the REFRESH outputs need to be more focused on food businesses and trade bodies who operate on their behalf, to optimise the use of the resources.

5.1.2 Functionality

With a secondary tier of target audience identified, the next step in understanding the scope for extending the REFRESH outputs is to look at existing functionality; specifically, are there any key functions not yet supported in existing tools?

Our review confirmed the REFRESH DSTs and DSMs are unique in their focus (i.e. food waste) and that much of the planned functionality will address existing functionality gaps identified by tool and model users such as:

- Clean modern interfaces for ease of use
- Smart search function enabling easy and quick sourcing of data and insights
- Simple and clear taxonomy for users to understand linkages of data
- Recommandations for alternative models etc.

However, there is a potential feature which may improve the uptake and use of the DSTs and DSMs; a website or platform to house and run the tools and models, without a user needing to download and run them individually. This functionality recommendation currently extends the planned scope of the REFRESH tools and models and for good reason, as having the DSTs and DSMs predominantly software agnostic (some will still be online – e.g. Animal Feed

Tool) means that users are not limited by software selection therefore making content more accessible.

However, adopting a 'download and take away' approach presents a series of limitations that the target audience may find difficult to overcome:

- In recent years there has been a trend which moves away from Excel based outputs to online versions of tools and resources (see Cool Farm Tool below), the 'download and takeaway' approach goes against this;
- Most of the users identified within the audience review (described in section 4.1) expect tools and models to be able to be run online with a specific platform that houses them, with a free/paid for access model in place if entering sensitive data. Businesses especially are looking for managed services rather than standalone desktop tools;
- The job roles predominantly targeted within the biggest audience segment (food businesses) may not be technical enough to download and run tools and models in excel, as external help is often put in place to do this type of work. Therefore, the approach adopted doesn't directly provide added value to this audience segment; and
- Excel based tools and models can break, macros can stop working and built in calculations can often be interfered with – all of which can in some instances lead to erroneous outputs which may present a reputational risk for REFRESH.

In summary there are no 'functionality' requirements which are not met by the DSTs and DSMs. Additional recommendations can be made to increase the uptake and use of the resources however these go considerably beyond the scope and scale of the REFRESH project.

5.1.3 Gaps within other tools

To ensure that the REFRESH DST and DSM offering remains unique and valuable, a review beyond audience applicability and technical functionality to content related gaps was conducted. This is a critical part of the review process as without the right level and direction of focus, the target users will not use the tools and positive actions towards food waste reductions will not be made.

What are the most important gaps?

Within the food sector there are an infinite number of food waste related areas to focus on with both tools and models. However, to provide a cross section which is appropriate to as broad an audience as possible, the following topics should be addressed in some shape or form.

Tools which can accurately record food waste: To access food businesses (specifically suppliers, manufacturers and primary producers) tools which can support in the accurate reporting and accounting of food waste, both within own operations and the supply chain, are needed. More and more food businesses are being requested to account for their waste in line with the Food Loss and Waste (FLW) Standard, therefore an online tool which is aligned to the standard and supports suppliers in accounting for their food waste would be very popular. Winnow, Leanpath and Wastewatchers all provide technological solutions to dramatically reduce food waste and operate more sustainable facilities; however

these are very much focused on the hospitality sector, with commercial kitchens as their target audience.

Tools and guidance to help businesses embed and support food waste reductions into their sustainability agenda: Following on from the above many businesses understand why food waste reductions are important and that they should align themselves with industry best practice (i.e. the FLW standard), however they struggle to go beyond articulating its 'the right thing to do' and the commercial savings associated with waste reductions. A tool which enables users to link food waste reductions to their own corporate social responsibility (CSR) agendas would support businesses in creating a long-lasting link to food waste reductions and embedding reduction activities into their organisation's sustainability agenda.

Cost benefit analysis of investing in food waste prevention: Although some work has been done in this area (see WRAP tool for local authorities) there has yet to be a widely accepted tool for food businesses to use which helps them weigh up the costs and associated benefits of implementing food waste reduction activities and interventions within their business.

Packaging optimisation: There are many case studies available, but no tools or models which can be used by retailers or food manufacturers to inform packaging optimisation. Looking beyond simple packaging waste, a tool which looks to support shelf-life extension and optimise material choice would be highly covetable. Currently there is no singular tool which offers scenario based assessments.

Plastic alternatives: Following on from the point on packaging optimisation, a focused plastics and plastics alternative tool would support the growing agenda within the UK and Europe which is moving towards plant and paper based alternatives. If a tool could provide recommendations for alternatives and provide guidance on how this could impact food waste, it would be the first of its kind.

Product life extension (category specific): There is ample research which suggests that extending the shelf life of products can save upwards of 1,000 tonnes of food waste each year. However, to date these findings and insights have mainly been captured through case studies. A tool which can take users through product category examples and direct them on the correct path for packaging optimisation would be highly valuable.

Outlined above are some hot topic areas which currently are not addressed in significant detail via tools or models, or if they are (i.e. WRAP tools), the resources available are only available in case study or guidance document format.

Overall it seems that users desire tools to cover a broad scope, and that they would prefer indicative tools which can be used to drive insight in the right direction – rather than fewer more detailed tools and models. This finding is somewhat at odds with the purpose of the REFRESH tools and models and the available tertiary audience segmentation which directs the on-going development of the DSTs and DSMs into niche more depth extension routes.

5.1.4 Are there certain types of food not covered?

On review it seems that fresh produce and ambient packaged foods are well covered but that livestock (i.e. poultry, beef, lamb and fish) have less coverage. This seems principally due to the more challenging nature of animal protein supply chains. Similarly to the findings on missing topics, there is guidance available for all product categories however the resources available vary in scope, availability and age depending on the specific product category.

In summary it appears there are no market opportunities for expanding the DSTs and DSMs into specific food and product category types.

5.1.5 Are there stages in the food chain that are missing?

Each of the 'traditional' supply chain stages are covered, however there are some gaps relating to the audiences currently not yet targeted. As illustrated below; those highlighted in green are the aspects of the food supply chain that are currently represented to a significant degree, whereas those highlighted in yellow are not.

Table 4. Supply chain coverage

Production	Processing	Distribution	Retail	Consumer
On-farm	Manufacturing/ processing	Delivery to store	In-store	In-home preparation & consumption
	warehouse/ chill house	Import/export	Hospitality/ catering	Restaurant consumption

The less represented aspects of the supply chain are those which are associated with import/export business models, the transportation of food to its designated retail destination and consumption in a non-home-based setting.

Warehouse/chill house and logistics are the most interesting gaps in the food supply chain that are currently not covered. It is not unsurprising that logistics is not readily covered; this is in part due to the 'black box' and competitive nature of the savings and efficiencies that can be gained in this area. Therefore, there is little open industry insight into these elements of the supply chain and so limited insights and resources to share which could significantly drive improvements. Warehouse/chill house and import/export models are an aspect of the supply chain that could be explored in more depth as food waste still occurs and can be prevented within these stages.

5.1.6 Are there country specific tools?

Similar to the scope of the REFRESH partners, the tools available to tackle food waste vary from country to country. However, it is important to note that these tools are not positioned as country specific; rather they are agnostic of geographical location.

The tools that are available appear to be focused on downloadable toolkits on keeping food waste out of landfill, how to overcome challenges faced with redistribution, and apps which are available for a range of food businesses to redistribute food which is fit for human consumption to charity partners. Some examples of the tools which are available are below:

- (EU) Think.Eat.Save Global Anti-food waste campaign toolkit
- (EU) Reducing the food wastage footprint toolkit
- (EU) WASP Tool – Development and demonstration of a waste prevention support tool for local authorities
- (EU) A decision support tool for sustainable bioenergy
- (USA) Food Waste Alliance: Best practices and emerging solutions toolkit

As evidenced from the examples above, the spread of tools available from different countries is varied however they all share the following characteristics:

- Focused on preventing food waste;
- Sharing best practice;
- Address food waste challenges in a business, home and retail setting;
- Not country specific; and
- Are all downloadable and take-away documents.

The benefit of the REFRESH DSTs and DSMs is that they share the same characteristics as the existing tools available which confirms their appeal. However, the same benefit is also a considerable challenge as it may be difficult to highlight and articulate the additional benefits and value of using the REFRESH outputs over other resources available.

5.1.7 Is there a type of calculation/simulation/prediction that can't be done yet?

On review of the tools available and feedback provided by stakeholders there are seemingly two calculations that current tool offerings cannot do.

1. Estimate the carbon impacts of, and carbon offsets achieved, through food redistribution and how this differs within and between product categories;
2. Wider costs of food waste reduction for a business i.e. procurement, labour, water, energy.

The above calculations have been highlighted as these were commonly mentioned as bug bears or challenges for stakeholders within food businesses who are frequently asked to go beyond a singular figure (i.e. tonnes of food redistributed or saved) to present a more holistic figure of the environmental, financial and social savings made.

In regards to point one, the desire for this calculation is linked to an earlier point which is supporting businesses to embed food waste reduction activities into wider business sustainability strategy. A simple way to do this is to relate food waste impacts and savings to other measured and easily understood impact areas such as carbon, water and energy. Connecting food waste reduction

activities to a business's carbon strategy effectively future proofs the longevity of the activities and creates a narrative which is more accessible to a wider range of roles and internal stakeholders.

Some work on capturing data and figures for point two – wider costs of food waste – is evident in the hospitality sector with software such as Winnow and Lean Path which is available for commercial kitchens to support them in financially accounting and tracking food waste. However, such technology is not open source and is costly to acquire and install; it is also aimed at hoteliers and chain restaurants who want to track progress against multiple sites, therefore not appropriate for small restaurants or businesses. It should also be noted that both software solutions although best in class do not measure the indirect cost of waste such as labour, procurement etc.

Potentially DSMs could be produced as part of the REFRESH project which could create a framework or method to calculate the above and address these on-going challenges.

5.1.8 Examples of wider sector best practice

To put some of the information from the gap analysis into context a brief summary of two different tools in other disciplines is outlined below:

Cool Farm Tool

Cool Farm Tool (CFT): The CFT is a free to use online greenhouse gas, water and biodiversity calculator for farmers. Previously a downloadable excel tool the CFT went online approximately two years ago and broadened its remit from purely GHGs to water and biodiversity with great success.

Factors which have enabled the tool to be successful with its target audience are as follows:

- Geared towards managing, monitoring and understanding issues at the heart of its audiences (primary producers) business (i.e. cost, productivity etc.);
- Has difficult calculations built into the online tool taking accounting/technical expertise burden away from users (i.e. fertilisers, soil tillage);

- It is positioned as a scoping and hotspotting tool – not a silver bullet catch all solution – farmers have embraced this open and transparent positioning;
- Takes less than 15mins to get an assessment making it an efficient and simple investment in time; and
- Has been tried and tested by other retailers and food businesses providing credible industry endorsements.

Muddy Boots

Muddy Boots: Muddy Boots is a paid for cloud based software for growers/agronomists, suppliers and processors, and retailers connecting everyone in the supply chain together to measure and monitor quality and compliance. Through collaborative online software, users get immediate visibility of the performance of their sites, suppliers and products. Equipped with this insight, they can make more informed decisions on how to improve quality, drive efficiency and mitigate risks more effectively.

Unlike the CFT, Muddy Boots is an example of a commercial offering of a DSM. Success factors that have led to its established use by primary producers are:

- Web and app based which means data is accessible in the field easily;
- Data moves quickly both ways ensuring everyone is engaged and updated regardless of their status in the supply chain;
- Simple and easy design which makes it accessible for everyone from the farmer to the technical manager; and
- Covers off challenges associated with working at scale and volume – i.e. traceability.

The tools above are very different in their focus and scope in comparison to the REFRESH DSTs (animal feed and valorisation), however there are characteristics that are transferable to the REFRESH outputs. Notably:

- Simple and easy user interfaces;
- Online and app based where possible;
- Movement of data within the tool itself reducing the need for technical expertise; and
- Links and recommendations for improvements.

5.1.9 Tool longevity

The final question for review as part of the assessment of extending the DSTs and DSMs is that of longevity. With information, technical models and ways of thinking changing all the time, a significant challenge for the future of the REFRESH tools will be how to keep tools up to date.

It is clear from the findings that this is a significant challenge for other tool and resource library providers with many tools and models published between 2013 – 2016. It was not clear during the review if any of the older tools and resources had been superseded, as version control and updates were not documented clearly.

However, a clear trend that was identified is that many tools and resources have been developed as outputs of international projects similar to REFRESH (e.g. Fusions) and that because of this the tools have not been updated or continued due to lack of funding. Therefore, it is suggested that the longevity of the tools and models is carefully considered and a plan put in place to ensure that the resources created and shared will be updated and future proofed.

5.2 Outcomes of assessment of DSLs

5.2.1 Features of the REFRESH DSL

Explanatory context

The key concept of the DSL is that it has the theoretical model as its central focus. Models have an underlying theory that is independent of how they are implemented. A model can be described in terms of the real life domain concepts that it models. For example, a model can calculate the force ***F*** required to induce an acceleration of ***a*** metres per second squared in an object of mass ***m*** kilograms. This model can be represented mathematically by the equation ***F=ma***. These descriptions, the domain description and the mathematical description, are completely independent of how the force is calculated in software. As such, several different implementations can be created – the equation can be calculated in Excel, in Matlab, in Java etc. In all the implementations, the underlying model is the same. Describing this model accurately makes it easy for people to understand what it does, and as a result makes it easier to use the implementation correctly, or to adapt it for another purpose.

This is an inversion of the more common approach, where the implementation, the software code, is central, and the underlying model may be described in documentation, or not at all. The reason for this inversion is that the library is aimed at helping its users to achieve a particular purpose, to model a real life situation to answer a question about food waste. ***How*** this is achieved, with which software and which technology, is a secondary issue. Food waste is also a complex issue, involving many different factors, from bacterial growth, to logistics, to the psychological aspects driving consumers. It is therefore highly unlikely that all these models will be developed in the same software environment. What is important is to understand exactly what model implementations do, and to have a very clear description of their inputs and outputs, to allow model implementations to be linked together. The DSL is designed for this purpose.

Actual features

1. The library supports the storage of the following elements associated with each model (see the example in Table 5)
    a. a description of the model in domain terms;
    b. a mathematical model formulation and/or a formulation in pseudo-code
    c. model code or a link to this. The library offers the opportunity of downloading the model code
    d. a description of the model inputs and outputs in domain terms;

Table 5: Example of a model description

Name	Force model
Description in domain terms	Calculates the force required to accelerate a given mass
Mathematical formulation	F=ma
Model code	download from https://sourceforge.net/projects/anexampleproject
Input	Mass
	m, kilograms, float
Input	Acceleration
	a, metres per second squared, float
Output	force
	F, Newtons, float

2. The library is technique and implementation independent:
    a. models can be based on different mathematical techniques such as simulation and optimisation;
    b. models can be implemented in different software environments
3. The library offers a search function for searching models both based on domain terms and on mathematical / pseudo-code terms.

Future features

1. The library will be developed to support:
    a. the symbols, units and data types of the model inputs and outputs.
    b. a compatibility check of outputs and inputs of different models;
    c. the storage of datasets;

d. the description of datasets in domain terms;

e. a smart search function of models and datasets based on domain terms. For example, if a quality-decay model of lettuce is not available, a quality-decay model of endive could be suggested.

2. Moreover, the library will be developed to support the use of composed models, by:

   a. a demonstration of how each model is used in combination with other models, as part of a larger, composed model;

   b. a function for finding individual models within a larger composed model;

   c. providing suggestions for other models that are able to replace a particular model within a larger composed model.

3. Finally, the library will use explicitly defined terms from ontologies to describe the models, inputs and outputs

These features support the user in flexibly composing their model from the individual models contained in the library, using the datasets and models that are most appropriate. The compatibility check will occur on two levels, the syntactic level (do the inputs and outputs have the same data type and units?) and the semantic level (do the inputs and outputs refer to the same domain concepts?).

The use of ontologies avoids confusion due to synonyms (different words with the same meaning) and homonyms (the same word with different meanings). This is of particular importance given that models can come from several different disciplines. As an example, even the term 'food waste' may mean different things in different models. Linking the text to its definition in an ontology makes it clear what is meant. The use of ontologies also enables the smart search functionality, by defining the links between concepts, such as endive having a similar quality in decay to lettuce.

5.2.2 Outcomes of the search for comparable libraries

The following tables provide an evaluation of the comparable libraries identified in terms of the distinctive features of our library, both actual and planned. Note that a textual description of a model can contain whatever the user wants. However, we only regard the library as supporting a particular type of information if it explicitly suggests that the information be entered, or offers custom support for entering that information.

Table 6: Libraries for model developers

Library	NetLogo	GoldSim	Kepler	CoMSES Computational Model Library
Link	http://ccl.northwestern.edu/netlogo/index.shtml	http://www.goldsim.com/Library/Models/	https://kepler-project.org/	https://www.openabm.org/models
Description (taken from the library websites)	NetLogo is a programmable modelling environment for simulating natural and social phenomena. NetLogo is particularly well suited for modelling complex systems developing over time. The Modelling Commons is for sharing and discussing agent-based models written in NetLogo. If you download NetLogo, all of the models in the models library are included. You may also run the models in your browser.	The GoldSim Library is an online resource for the GoldSim user community. The purpose of the GoldSim Library is to provide modelling resources for GoldSim users.	Kepler is designed to help scientists, analysts, and computer programmers create, execute, and share models and analyses across a broad range of scientific and engineering disciplines. Kepler can operate on data stored in a variety of formats, locally and over the internet, and is an effective environment for integrating disparate software components. The Kepler software is developed and maintained by the cross-project Kepler collaboration, which is led by a team consisting of several of the key institutions that originated the project: UC Davis, UC Santa Barbara, and UC San Diego.	OpenABM is a node in the CoMSES Network, providing a growing collection of tutorials and FAQs on agent-based modelling, a model library intended to provide a locus for authors and modelers to share their models, and forums for modelling-related discussions and job postings.
Evaluation criteria				
Supports the storage of a description of the model in domain terms.	Yes	Yes	Yes	Yes
Supports the storage of a mathematical model formulation	No	No	No	No

Library	NetLogo	GoldSim	Kepler	CoMSES Computational Model Library
and/or a formulation in pseudo-code.				
Supports the storage of model code or a link to this. The library offers the opportunity of downloading the model code	Yes	Yes	Yes	Yes
Supports the storage of a description of the model inputs and outputs in domain terms.	No	No	Yes	No
Models can be based on different mathematical techniques such as simulation and optimization;	Only simulation models can be stored.	Only simulation models can be stored.	Yes	Only agent-based models can be stored
Models can be implemented in different software environments	Only models written in NetLogo can be stored.	Only models written in GoldSim can be stored.	Yes, but this is limited to a set of environments supported by Kepler, and must be done from within a Kepler component	Yes
Offers a search function for searching models both based on domain terms and on mathematical / pseudo-code terms.	No search function exists.	You can search the library using keywords or phrases (domain terms). The easiest way to navigate the Library is by using the navigation panel on the left side of the page. This will allow you to "drill down" within specific sections of the Library.	Yes	Yes

Library	NetLogo	GoldSim	Kepler	CoMSES Computational Model Library
Supports the storage of the symbols, units and data types of the model inputs and outputs.	No	No	Data types only	No
Supports a compatibility check of outputs and inputs of different models.	No	No	Syntactic compatibility is checked, but the feedback over the error is a java stack trace, which is difficult to understand.	No
Supports the storage of datasets.	No	No	Yes	No
Supports the storage of a description of datasets in domain terms.	No	No	Yes	No
Supports a *smart* search function in domain terms.	No	No	No	No
Supports a demonstration of how each model is used in combination with other models, as part of a larger, composed model.	No	No	Yes	No
Offers a function for finding individual models within a larger composed model.	No	No	Yes, models can be included in composite models and are clearly visible in the model	No
Supports providing suggestions for alternative models	No	No	No	No
Domain terms can be explicitly defined	No	No	Yes, links to concepts in an ontology can be included in the description	No

Table 7: Libraries for specific domains

Library	MEECE	Models Library (PPS)
Link	http://www.meece.eu/library.aspx	http://models.pps.wur.nl/
Description (taken from the library websites)	The Marine Ecosystem Models considered within MEECE are built on a *diversity of approaches and programming languages* to answer specific scientific questions covering the major trophic components of the marine ecosystem. The MEECE Model Library provides in a **'stand alone' state with all necessary documentation,** technical guides and metadata so that any competent programmer unfamiliar with model, can perform integrated end-2-end numerical experiments.	This model library site is an initiative of the group Plant Production Systems of the Wageningen University. Modelling in the agricultural and environmental fields (e.g. model for specific crop, routine for soil water and/or nitrogen fluxes, etc.).
Evaluation criteria		
Supports the storage of a description of the model in domain terms.	Yes	Yes
Supports the storage of a mathematical model formulation and/or a formulation in pseudo-code.	No	No
Supports the storage of model code or a link to this. The library offers the opportunity of downloading the model code	No	No
Supports the storage of a description of the model inputs and outputs in domain terms.	No	No

Library	MEECE	Models Library (PPS)
Models can be based on different mathematical techniques such as simulation and optimization;	Yes	Yes
Models can be implemented in different software environments	No code available	No code available
Offers a search function for searching models both based on domain terms and on mathematical / pseudo-code terms.	Users can search for a modelling tool addressing specific descriptors in a geographic region of interest, or browse the technical content of the library.	Users can search on (terms within) model name and/or terms from the research descriptions; Alphabetical overview of all models in the library.
Supports the storage of the symbols, units and data types of the model inputs and outputs.	No	No
Supports a compatibility check of outputs and inputs of different models.	No	No
Supports the storage of datasets.	Datasets are stored as well.	The Data section, contains data that can be used for modelling or research.
Supports the storage of a description of datasets in domain terms.	Unknown – datasets are password protected	Yes
Supports a *smart* search function in domain terms.	No	No
Supports a demonstration of how each model is used in combination with other models, as part of a larger, composed model.	No	No
Offers a function for finding individual models within a larger composed model.	No	No

Library	MEECE	Models Library (PPS)
Supports providing suggestions for alternative models	No	No
Domain terms can be explicitly defined	No	No

Table 8: Generic libraries for research

Library	myExperiment	Taverna	HubZero[15]
Link	http://www.myexperiment.org/	http://www.taverna.org.uk/	https://hubzero.org/
Description (taken from the library websites)	myExperiment is a collaborative environment where scientists can safely publish their workflows and in silico experiments, share them with groups and find those of others. myExperiment is brought to you by a joint team from the universities of Southampton, Manchester and Oxford in the UK, led by David De Roure and Carole Goble. myExperiment is currently supported by three European Commission 7th Framework Programme (FP7) projects: BioVeL (Grant No 283359), SCAPE (Grant No 270137), and the Wf4Ever Project (Grant No 270192) as well as the e-Research South and myGrid EPSRC Platform grants.	Taverna is an open source and domain-independent Workflow Management System – a suite of tools used to design and execute scientific workflows and aid in silico experimentation. Taverna was created by the myGrid team and is now an Apache Incubator project. ***Note: Taverna stores workflows in myExperiment***	HUBzero® is an open source software platform for building powerful Web sites that support scientific discovery, learning, and collaboration. Originally created by researchers at Purdue University in conjunction with the NSF-sponsored Network for Computational Nanotechnology to support nanoHUB.org, the HUBzero platform now supports dozens of hubs across a variety of disciplines, including cancer research, pharmaceuticals, biofuels, microelectromechanical systems, climate modelling, water quality, volcanology, and more.
Evaluation criteria			
Supports the storage of a description of the model in domain terms.	Yes	Yes	Yes, and this can be customised by adding extra fields
Supports the storage of a mathematical model formulation and/or a	No	No	No

[15] Note that as DataVerse and HubZero are open source projects, there may be versions that possess more functionality. It is not possible to investigate every variant.

Library	myExperiment	Taverna	HubZero[15]
formulation in pseudo-code.			
Supports the storage of model code or a link to this. The library offers the opportunity of downloading the model code	Yes	Yes	Yes
Supports the storage of a description of the model inputs and outputs in domain terms.	Yes	Yes	No (could be added with custom fields)
Models can be based on different mathematical techniques such as simulation and optimization;	Yes	Yes	Yes
Models can be implemented in different software environments	Yes	Yes, but they must be wrapped in a web service	Yes
Offers a search function for searching models both based on domain terms and on mathematical / pseudo-code terms.	Yes	Yes	Yes
Supports the storage of the symbols, units and data types of the model inputs and outputs.	No	Can indicate if an input has a singular value or multiple values	No (could be added with custom fields)
Supports a compatibility check of outputs and inputs of different models.	No	Syntactic compatibility can be determined for components that have a SCAPE profile defined	No

Library	myExperiment	Taverna	HubZero[15]
Supports the storage of datasets.	Yes, as generic files	Yes, as generic files	Yes, as a resource or a subcategory of a resource
Supports the storage of a description of datasets in domain terms.	Yes	Yes	Yes
Supports a *smart* search function in domain terms.	No	No	No
Supports a demonstration of how each model is used in combination with other models, as part of a larger, composed model.	Yes, via attributions	Yes, via attributions	No
Offers a function for finding individual models within a larger composed model.	Yes, can describe 'processors' and 'beanshells' within the model, and link to individual models via attributions	Yes, can describe 'processors' and 'beanshells' within the model, and link to individual models via attributions	No
Supports providing suggestions for alternative models	No	No	No
Domain terms can be explicitly defined	No	No	No, with the exception of an extension for the biomedical domain

Table 9: Generic libraries for research

Library	DataVerse[16]	FigShare
Link	http://dataverse.org/	https://figshare.com/
Description (taken from the library websites)	Dataverse is an open source web application to share, preserve, cite, explore, and analyze research data. It facilitates making data available to others, and allows you to replicate others' work more easily. Researchers, data authors, publishers, data distributors, and affiliated institutions all receive academic credit and web visibility. Dataverse software is being developed at Harvard's Institute for Quantitative Social Science (IQSS), along with many collaborators and contributors worldwide.	Simplifying your research workflow. Easily manage all your research outputs and make them available in a citable, shareable and discoverable manner
Evaluation criteria		
Supports the storage of a description of the model in domain terms.	Yes	Yes
Supports the storage of a mathematical model formulation and/or a formulation in pseudo-code.	No	No
Supports the storage of model code or a link to this. The library offers the opportunity of downloading the model code	Yes	Yes
Supports the storage of a description of the model inputs and outputs in domain terms.	No	No

[16] Note that as DataVerse and HubZero are open source projects, there may be versions that possess more functionality. It is not possible to investigate every variant.

Library	DataVerse[16]	FigShare
Models can be based on different mathematical techniques such as simulation and optimization;	Yes	Yes
Models can be implemented in different software environments	Yes	Yes
Offers a search function for searching models both based on domain terms and on mathematical / pseudo-code terms.	Yes	Yes
Supports the storage of the symbols, units and data types of the model inputs and outputs.	No	No
Supports a compatibility check of outputs and inputs of different models.	No	No
Supports the storage of datasets.	Yes	Yes
Supports the storage of a description of datasets in domain terms.	Yes	Yes
Supports a *smart* search function in domain terms.	No	No
Supports a demonstration of how each model is used in combination with other models, as part of a larger, composed model.	No	No
Offers a function for finding individual models within a larger composed model.	No	No
Supports providing suggestions for alternative models	No	No
Domain terms can be explicitly defined	Supports a limited number of metadata schemas	No, with the exception of the external FigMeta community project that allows users to mark up their FigShare records

6 Conclusions

6.1 The combined role of DSMs, DSTs and DSLs

DSTs and DSMs can play a crucial role in assisting those involved in the food supply chain to reduce food waste and its associated impacts. By using robust models and existing data the assessment of the potential impact of actions can be made significantly more efficient than requiring stakeholders to undertake their own evaluation. Use of well-built DSTs and DSMs also helps ensure that good practice within options is promoted (e.g. via recommendations provided in modelled outputs) and that there is consistency in the outputs received by target users. In order to ensure that the DSTs and DSMs are readily accessible and appropriately used a well-structured DSL is vital. By making it easier for the target audiences to search for appropriate DSMs and DSTs and ensuring clear descriptions are provided the DSL can help enable the provision of advice to decision-makers in government and industry to help them to reduce food waste

6.2 Current REFRESH DSL, DSM and DST provision

Based on the evaluation of the current REFRESH DSL it was concluded that it has the following distinctive features, actual and planned:

Actual features:

- the content represented by food-supply-chain-waste models;
- the combination of software-independence and detailed, structured model description;
- an explicit encouragement to users to describe models mathematically and/or in pseudocode;
- grouping different software implementations under the same model description;

Planned features:

- explicit definition of the semantic meaning of models and inputs/outputs/parameters (by linking to ontology concepts);
- smart-search function;
- description of the symbols, units and data types of model inputs/outputs;
- semantic and syntactic compatibility check;
- proposing alternative models;

There is variety and scope in the REFRESH tools available for the target audiences to use. The benefit of the REFRESH DSTs and DSMs is that they share the same

characteristics as other tools available, confirming their appeal. However, the same benefit is also a considerable challenge as there will be a need to highlight and articulate the additional benefits and value of using the REFRESH outputs over other resources available.

6.3 DSLs, DSTs and DSMs from other providers and future considerations for REFRESH

DSLs

No DSLs for food waste models were found during the search described in section 4.2. The generic libraries (e.g. FigShare, HubZero) were software independent, but lacked structure in the model description, which is essential to a clear understanding of the model and its inputs/outputs. The specialised libraries (e.g. Kepler) provided much more structure, but limited the type of software implementation. HubZero, FigShare, DataVerse and Taverna offered some very limited support for defining the semantic meanings of parameters. Kepler and, in certain cases, Taverna, determine syntactic compatibility. All libraries examined lacked support for advanced functions such as smart search, suggesting alternative models, and semantic compatibility.

We believe that these advanced functions provide valuable assistance to scientists when they are searching for and combining models from different disciplines. We also believe that clear, structured descriptions of models, supported with clearly defined semantic meanings, are essential to a good understanding of the models, which is a prerequisite for using them properly. This need becomes greater as scientists work across disciplines, with unfamiliar terminology and technology.

We therefore conclude that the DSL is a valuable addition to the existing libraries, for the purposes of building multi-disciplinary models, in particular for food waste.

The evaluated libraries had several functions that are neither implemented nor planned in the Decision Support library. The most important are:

- user management and user access;
- community support (forum, wiki etc.);
- version management;
- professional and appealing user interface;
- running models (beyond our scope);

While these functions are not necessary to realise the core goals of the library, they can have a considerable influence on the willingness of users to work with the library. We need to consider how we could incorporate these functions into the DSL. An option would be to combine the DSL with one of the existing libraries, for example HubZero or DataVerse. These are both open source, and therefore open to extension. Whether this work can be conducted within REFRESH or not, will depend on the needs of the food waste pilots in which the DSL is to be validated.

DSMs and DSTs

In general there is a focus is on DSMs whose target audience is academia and consultants, whereas a large opportunity lies with food businesses that will utilise DSTs. Consultation with food businesses is recommended to identify their requirements, and to further understand the type of DSTs which would benefit their operations. Current user feedback is that they desire tools to cover a broad scope, and that they would prefer indicative tools which can be used to drive insight in the right direction – rather than fewer more detailed tools and models.

In terms of gaps in provision there are two calculations that current tool offerings cannot undertake which the REFRESH outputs could address in future:

- Estimate the carbon impacts of, and carbon offsets achieved, through food redistribution and how this differs within and between product categories;
- Wider costs of food waste reduction for a business i.e. procurement, labour, water, energy.

In addition, warehouse/chill house and logistics are the gaps in the food supply chain that are currently not covered by DSTs or DSMs. Animal proteins (i.e. poultry, beef, lamb and fish) are a potential food type to extend into to increase market uptake.

There are no 'functionality' requirements which are not met by DSTs and DSMs. Clean modern interfaces for ease of use, smart search function enabling easy and quick sourcing of data and insights and simple and clear taxonomy for users to understand linkages of data are already included with the DST and DSM REFRESH work plans. Additional recommendations, such as housing the tools in an online platform etc. can be made to increase the uptake and use of the resources however these go considerably beyond the scope and scale of the REFRESH project.

The on-going updating of the DSTs and DSMs pose a significant challenge which as yet, no other provider has managed to solve. Therefore, it is suggested that the longevity of the tools is carefully considered and a plan put in place to ensure that the resources created and shared will be updated and future proofed.

7 References

De Roure, D., Goble, C. and Stevens, R. 2009. " The Design and Realisation of the myExperiment Virtual Research Environment for Social Sharing of Workflows." In *Future Generation Computer Systems 25*, 561-567. Elsevier. doi:10.1016/j.future.2008.06.010