The Local Nexus Network Project Synthesis Report

Building sustainable local nexuses of food, energy and water

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Executive summary

Introduction

The LNN project was designed as a multi-institution, multidisciplinary project which was tasked with the goal of developing an evidence-based comprehensive research agenda. In so doing the project sought to foster an inclusive community of researchers and stakeholders for sustainable local nexuses organised around the environmental and social considerations linked to the redistributed manufacturing (RDM) of food. To achieve this, the LNN project undertook a complex multidisciplinary programme. This involved seven linked projects exploring a range of issues concerning the interplay between RDM and different aspects of the local nexus as well as of the policy and business implications of RDM. Issues covered included engineering technology and systems for food processing and energy/water supply, business models and supply chains, governance and whole-system integration.

To support effective integration of the data generated through these disciplinary studies and address questions regarding the practical "real world" value of RDM the studies focussed on two geographical case studies; Oxford and Northstowe and two exemplar products; bread and tomato paste. The selection of contrasting geographical areas allowed for comparison between the different challenges posed in affecting RDM of food in retrofitting RDM (Oxford) as opposed to incorporating RDM into a newly developed urban centre (Northstowe). The selection of two contrasting products allowed for an exploration of how RDM was likely to work in relation to products with significantly different supply chain characteristics. The report will then briefly discuss some of the main findings that the project reports yield, focussing on what they tell us about the feasibility of RDM and its capacity to address local nexus challenges.

RDM, the local nexus and the food sector.

Redistributed Manufacturing (RDM)

The term RDM is applied to a wide range of activities and processes through which manufacturing activity takes place in a more dispersed way than is currently the case, and involving new relationships in which the manufacturing process is more closely linked to the specific demands of diverse consumers. Thus RDM may encompass any technology, systems or strategies (or combination thereof) that enables such changes in the economics and organisation of manufacturing with specific reference to scale and location. It is important to note that while the focus in RDM is often placed on the manufacturing process itself. The emergence of such a model requires more widespread change than is suggested by a simple dispersal of manufacturing implies. As, if not more important, are innovations in the way in which producing firms communicate with their customers.

As the concept itself suggests, RDM in any specific sector is shaped by the nature of the product itself and highly fluid relationships between customers and producers. This makes it particularly difficult to make generalisations about RDM which apply across different sectors. In the case of the LNN project such issues featured in many of the final reports of the different feasibility studies. Rather than a single form RDM in the food sector is likely to assume a variety of guises depending on the nature of specific products, the different demands that production at different scales places on resources (including energy and food) and the level of local demand for redistributed products.

RDM in the UK food sector

The food manufacturing sector in the UK accounts for a total of 16% of all manufacturing in the UK (figure 2.1) and employing at least 400,000 people directly. Over the last two hundred years food production in the UK has gradually changed from being a small scale locally-based process, to a sector which is dominated by mechanised, quality-controlled, and large-scale manufacturing process. However, the depiction of the food manufacturing sector as an intensive centralised activity tells only a partial story. The social and cultural values related to food and its specific physical characteristics, add to the potential and also to the complexity of RDM in the food sector. For such reasons, food occupies something of an outlier position in relation to RDM. The food manufacturing sector is part of a complex food system through which diverse nutritional, social, economic and cultural needs can be met in multiple ways. Rather than a movement away from one form of manufacturing to another RDM in the food sector may be better understood as shifts in scale within the food system in which nutritional and other needs are met in different ways by firms servicing different markets. In this context, and as the reports reveal, changing demand plays a critical role in shaping the ways in which food is produced and on the potential for RDM in the food sector.

The "local nexus" vision and its relevance to re-distributed manufacturing

Rising demand for food poses challenges not only to the food system but also to the interconnected water, energy and food systems. There has been an increased recognition that there is an interrelationship between water, energy and food systems and that meeting the needs for one of these resources may have implications on the availability of others. The growing recognition of such interdependencies between the water, energy and food systems has increasingly led for calls to recognise the significance of the nexus that links water, energy and food resource systems. Doing so presents significant challenges, not least in overcoming disciplinary barriers and policy practice which have tended to deal with water, energy and food (WEF) as separate systems which need dedicated scrutiny and specific separate policies. The LNN project is thus particularly concerned with exploring the potential impacts both negative and positive that RDM has for the local WEF nexus in specific areas. The WEF Nexus is thus employed as the lens through which the feasibility of RDM in food is assessed.

Programme and methodology

Underlying the LNN project was a concern with the question of the capacity of RDM to offer the potential for sustainable manufacturing through the framing of the local nexus of food, energy and water impacts. The LNN project did so by investigating localised food manufacturing and the decentralised energy and water systems that interact with the food system along four research themes namely engineering, business, policy and society, and systems integration and three different sectors; food energy and water. The research was organised into a series of seven work packages. The outputs took the form of feasibility studies each of which focussed on one of the themes or sectors with an additional study which focussed on the delivery of a whole systems analysis;

Case Studies

The work undertaken through these feasibility projects focussed on two case study locales. One of these locations representing a situation of “retrofitting”, where an existing system is to be changed to benefit from the paradigm of local nexuses and another representing “new development”, where opportunities exist to introduce a new food, energy and water system. The first of the locations selected was Oxford, a small city in southern England with a population of 155,000 people. Compared with the average for Great Britain Oxford’s population is relatively affluent. Moreover, it has a high proportion of non-national residents. This combination provides a demand for a diverse and high value added food offer and a strong local food culture exists in Oxford. The second location is Northstowe, an area of new development 5 miles outside Cambridge. These case study locales provide a common background for the different research themes to interact and integrate and served purposes ranging from collection of empirical data to stakeholder engagement. In addition, two contrasting exemplar crops; bread and tomato paste were also examined in some depth.

Exemplar products

Questions of location and scale in food manufacturing are closely linked to the specific characteristics of different products. With this in mind the two exemplar products were used to explore questions of scale of manufacturing in detail. The idea being that these products would serve as means by which to test the likely implications of RDM for different food products. The two products chosen, namely bread and tomato paste, were selected because they are currently supplied via very different value chains affording researchers the opportunity to explore the divergent likely impacts of the RDM of different products.

Findings

Food Feasibility Report

The food report suggests that RDM in the food industry is likely to be a partial process which is suited to certain processes and products and which is heavily reliant on the changing shape of demand. This suggests that an optimum arrangement for any specific product will vary depending on the nature of that product and the shape that demand takes. The report further suggests that there are more significant indications of social and cultural benefit from redistributed food manufacturing, than of environmental benefit. There is also potential for economic benefit in reconsidering the location of manufacturing. The study cautioned against the danger of assuming that smaller-scale, more localised manufacturing is intrinsically environmentally and socially preferable. An in-depth approach is needed in order to evaluate the likely environmental costs and benefits associated with producing specific products at different scales and locations.

Understanding RDM in the food sector means understanding the key drivers of location and scale in food manufacturing businesses. A movement back towards smaller scale manufacturing will depend on different drivers such as changes in the combination of costs in the production process and demand drivers. A number of key characteristics can be discerned for products that have a high suitability for localised artisan manufacturing. These include freshness, culturally distinction or the 'authentic' nature of higher quality products. Yet such values are not in themselves sufficient to support RDM. Further work could explore in greater detail the full range of characteristics that make certain products more suitable for RDM. Such work would need to identify not only products for which the process of RDM is technically feasible but also the economic and social drivers that would support the move to RDM.

Energy Feasibility Report

An assessment of the likely energy impact of redistributing the manufacture of bread to the local level suggested that moves to more redistributed production would result in a significant increase in the energy required to produce the country's bread. In addition, there is likely to be a slight increase in emissions under this scenario unless local production was based on the technologies employed in highly energy efficient, larger scale bakeries. It may also be possible to reduce the energy requirements of locally based bakeries through, for example, mini hydro or solar installations, though this would be heavily dependent on sites possessing access to water resources or space for solar panels. Thus, from an energy point of view, RDM would only contribute to reduced demand if it involved the development of highly energy efficient local bakeries and home baking equipment. Whether such a situation could be economically feasible or structurally possible is open to question. This suggests that, from the point of view of energy efficiency and emissions reduction there is at best, a weak case to be made for RDM in the food sector from an energy perspective. Rather the report suggests that different scales produce better energy outcomes for different processes, the question of which scale works best depends on the characteristics of the specific process involved.

Water feasibility report

While the water study found that some elements of RDM could result in a marginal improvement in water supply these benefits would need to be offset against additional environmental and energy costs of securing water from local resources. When this is taken into account the extent of the benefit to be derived from RDM is limited. The most effective and economically efficient way of meeting the water requirements of small scale producers of bread would be through the provision of water from existing domestic supplies while the scope for tapping into alternative local supplies for these small scale producers is limited. By contrast somewhat larger scale producers might be better placed to exploit such alternative sources. Thus as is the case for energy, the water feasibility study found only limited evidence to support the idea that RDM in the production of bread would lead to greater efficiencies in the local WEF nexus. Rather the evidence presented in the report suggest that some changes in scale at which production takes place could yield some efficiencies, however from the WEF point of view the optimum scale for particular processes is varied and is related to the specific characteristics of the process itself and the capacities available at different scales.

Business Feasibility Report

The business report found that when considering available resources it is currently not feasible to re-localise the production of tomato paste confirming the findings from the Food feasibility report. In terms of bread, re-localising the entire bread supply chain may not be feasible, but there are opportunities to re-localise parts or all of the value chain. Again this result adds further emphasis to the need for re-localising in the food sector to proceed with reference to the specific characteristics of particular products and of stages in the production of these products. The report also draws attention to the need for moves toward RDM to explore the commercial, as well as technical case for RDM. What the report suggests is that rather than full RDM there is scope for partial RDM whereby certain steps in particular supply chains could be relocated. The suitability of RDM in the food sector is dependent on each specific product and will vary from one location to another and therefore requires individual evaluation taking into account economic, social and environmental benefits and costs. In each case there must be;

- Available resources in order for businesses to invest in RDM. These resources extend from environmental e.g. water, land; to labour, with the necessary skills to carry out a job within RDM,

- A market demand for the product whether this is the local market, national or international markets.

- Available and affordable technologies.

Policy and society feasibility report.

The report primarily focused on the question of public procurement finding that moves towards local procurement had been adopted by UK public procurers in the period leading up to 2008 as part of a drive to sustainability. The overriding trend since the financial crisis has been towards securing value for money. This has tended to restrict the extent to which public procurers can employ local sourcing as a criterion when making purchasing decisions. Nevertheless, while public procurement is a relatively small component of overall food consumption, public procurers are often among the largest purchasers of food within local economies and they do have considerable potential to support food RDM. However, while the potential of public procurers to positively contribute to the development of the local food sector through local sourcing has been asserted in the past, developments since the onset of the financial crisis mean there has been a reduction in the capacity of those charged with the direction of local procurement to source locally. Moreover, there is some evidence that suggests that the extent to which local public procurement contributes to making the food system more sustainable is limited. Further research and a renewed commitment to local procurement in public policy would be needed to support the sourcing of more food locally.

Systems feasibility report.

The study showed that designing and optimising a food supply system from the WEF nexus perspective is a particularly complex task if factors from the physical, socio-economic and policy layer are taken into account. This notwithstanding, exploring the feasibility of RDM from a whole system perspective identifies opportunities for RDM, however in the short term the RDM business model is unlikely be able to compete on a price basis with mass manufactured food products. Rather the study confirmed that RDM produced foods need to focus on the other benefits that RDM offers to consumers to make a business case and justify higher prices. These include better quality food (e.g. fresher and healthier). From the policy side, the evidence suggests that RDM of certain food products does provide benefits for a region as a whole (e.g. more employment, better environment, less pollution, better health, less spending on health care). Thus, the systems report points to the broader role that RDM can play in delivering public goods. There may be a strong case for public policies to support for RDM of certain foods through, for example, policy measures to tackle energy price differences for large and small energy consumers in order to create a level playing field.

Key Learning

The reports suggest a rather mixed outcome, while some of the reports pointed to potential benefits to be accrued from the redistributed manufacture of food many also pointed to the fact that RDM is likely to have detrimental as well as beneficial impacts on the local WEF nexus. Other key learning included

1. RDM in food cannot be understood in terms of a direct like-for-like replacement of mass produced products with local alternatives.

2. There are more significant indications of social and cultural benefit from redistributed food manufacturing, than of environmental benefit.

3. Smaller-scale, more localised manufacturing is not intrinsically environmentally and socially preferable.

4. An in-depth product specific approach is needed in order to evaluate the likely environmental costs and benefits associated with producing specific products at different scales and locations.

5. An optimum arrangement in terms of the scale at which production for any specific product will vary depending on the nature of that product and the shape that demand takes.

6. RDM in the food industry is likely to be a partial process which is suited to certain processes and products and which is heavily reliant on the changing shape of demand.

7. From a resource point of view (energy and water) there is little evidence that RDM per se would contribute to reduced demand.

8. RDM can offer some opportunities for small producers to manufacture products potentially leading to a re-shaping of some supply chains, and bringing the product closer to the consumer.

9. While the potential of public procurers to positively contribute to the development of the local food sector through local sourcing has been asserted in the past, there has been a reduction in the

capacity of those charged with the direction of local procurement to source locally since the onset of the financial crisis.

10. The business case for RDM in any particular product will depend on
    - Available resources in order for businesses to invest in RDM
    - A market demand for the product
    - Available affordable technologies.

11. RDM in foods generally leads to increased use of socio-economic resources. Any impact on the bio-physical sphere depends on the specific food product, process, local water footprint and crop yield.

12. Many of the potential benefits of RDM in the food sector take the form of public goods or benefits that accrue to localities as a whole rather than individual firms or consumers.

Gaps in evidence

The reports also identified a range of gaps in evidence these included:

Understanding of the complex dynamics that drive local food systems is limited and requires further exploration and clarification of key concepts.

There is a need for a comprehensive approach to the question of measuring the impacts of location and scale in food manufacturing taking into account not only the environmental considerations explored in the LNN but also the wider societal impacts of any move towards RDM.

There is a need to develop robust methodologies to assess the relative cost and value of different approaches to food purchasing and food processing which incorporates a comprehensive range of social, economic and environmental indicators.

The Business feasibility study in particular, pointed to certain opportunities for successful RDM, as well as to barriers that are likely to limit that potential. There is a need for further detailed work to explore such barriers and opportunities.

There is a need to increase knowledge concerning both the technical requirements of such waste conversion and also concerning its real impact on energy demand and how it could lead to synergies among different local processes.

Further work needs to be undertaken concerning the quality of data available and also on the development of strategies for overcoming deficiencies in data available.

More work is required to understand the determinants of local food demand and how best these can be changed in ways which support the wider consumption of locally produced food.

Contents

1. Introduction

The Local Nexus Network (LNN) was one of six 24-month research networks on Redistributed Manufacturing (RDM) funded by the EPSRC and the ESRC which started in early 2015. Each of these research networks explored the concept of Redistributed Manufacturing (RDM) and in particular its potential implications for the future direction of travel in relation to the UK manufacturing scene. Collectively these research networks examine a broad range of manufacturing activities upon which the concept of RDM could have a bearing in an advanced economy such as that of the UK.

In broad terms the concept of re-distributed manufacturing is concerned with localised production with indigenous sustainable resources to support local economy and communities (EPSRC/ESRC 2013). The potential benefits of (re)localisation has been voiced by various groups, as reflected by economics schools of “eco-localism” (Curtis 2003)or “distributed economy” (Johansson, et al. 2005); grass-root social movements such as the Transition Towns Network (www.transitionnetwork.org);the emerging practices of community farming (Lyson 2004); and energy co-ops (Hargreaves et al. 2013). Among the products and services that can potentially benefit from localised production food, energy and water represent essential commodities for every society. Furthermore, it has increasingly been recognised that there exist close ties between these commodities, manifested by:

(1) The significant energy and water footprints in food production and the mutual footprint between energy and water production; and
(2) their intertwined connections with land and broader ecosystems.

This understanding, conveyed via the “nexus” concept, has gained momentum in the last few years through several key reports from e.g. World Economic Forum (WEF 2011) and the UN (UN ESCAP 2013) and events such as the Bonn 2011 nexus conference. Against this background the LNN project was proposed by an academic team with expertise in food systems, energy, water and systems engineering, business and supply chain strategies, as well as geography for local and regional development. The project focused on the development of local nexuses of food manufacturing and energy and water supply, which may provide opportunities for rationally customising resource utilisation, production, and consumption to meet the services required within a local context while contributing to the shared prosperity between business and community and between human society and natural ecosystems.

The LNN project was designed as a multi-institution multidisciplinary project which was tasked with goal of developing an evidence-based comprehensive research agenda. In so doing the project sought to foster an inclusive community of researchers and stakeholders for sustainable local nexuses organised around the environmental and social considerations linked to the redistributed manufacturing (RDM) of food. The project attempted to do so by:

1) Consolidating existing approaches to diverse aspects of local nexuses as it related to the manufacturing of food;
2) Articulating and prioritising research challenges and forming a corresponding portfolio of potentially useful methods and tools through which to assess the viability of RDM in food production in the context of the local nexus;
3) Producing an initial quantification of the socioeconomic and environmental potential of local nexuses, and assessing the key drivers and barriers for local nexus practice;
4) Establishing a preliminary knowledge base to support future research and development;
5) Building an inclusive community of researchers and stakeholders from all relevant sectors;
6) Identifying opportunities for reusing learnings generated from research on local nexuses in other RDM activities, in terms of local alignments of the components in a value chain and adaptation of energy and water services to the needs of RDM.

To achieve this objective, the LNN project was required to develop and undertake a complex multidisciplinary programme. This involved undertaking a range of disciplinary projects focussing on the interplay between RDM and different aspects of the local nexus as well as of the policy and business implications of RDM. These projects explored a range of issues including engineering technology and systems for food processing and energy/water supply, business models and supply chains, governance and whole-system integration. This was achieved via a linked series of feasibility projects which examined different aspects of RDM via the lens afforded by reference to the local food energy water nexus.

To support effective integration of the data generated through these disciplinary studies and address questions regarding the practical “real world” value of RDM. The studies collectively focussed on two geographical case studies and two exemplar products; bread and tomato paste. The selection of contrasting geographical areas; an established urban centre in Oxford and a new urban area currently being developed at Northstowe in Cambridgeshire, allowed comparison between the different challenges posed in affecting RDM of food in retrofitting RDM as opposed to incorporating RDM into a newly developed urban centre. The selection of two contrasting products allowed for an exploration of how RDM was likely to work in relation to products with significantly different supply chains characteristics. The idea behind this programme of work was to bring about an integrated cross disciplinary analysis of the challenges and opportunities RDM poses for the more sustainable management of food production and local nexus challenges. (Figure 1.1).

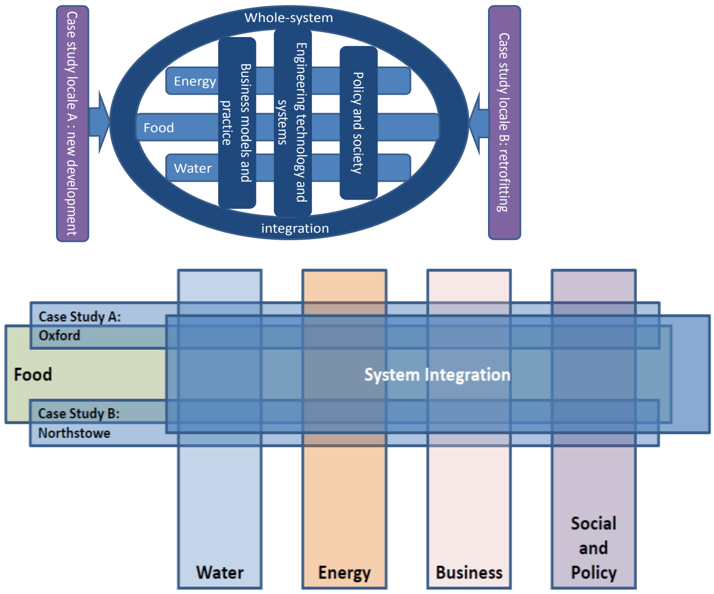

Figure 1.1 LNN project structure (Source: LNN presentation March 2016.)

These individual studies were concluded with the submission of the systems integration report which was finalised in July 2017. The purposes of this synthesis report is to give a brief overview of the findings of the seven feasibility reports outlining where possible what these reports suggest about the feasibility of RDM in the UK food sector and its implications for the management of local nexus challenges. In addition the report will briefly summarise the key gaps that these reports identify in current research regarding the RDM and nexus issues as they pertain to the food industry. In order to do so the report is presented as follows.

The next section of the report briefly summarises conceptualisations of RDM and the local nexus employed during the course of the project. Following from this the two geographical studies and two exemplar products that were employed in the study are briefly described. The report will then briefly discuss some of the main findings that the feasibility reports yield, wherever possible with reference to the case studies and exemplar products, focussing on what the reports tell us about the feasibility of RDM and its capacity to address local nexus challenges. The report concludes by briefly summarising some of the key gaps identified in relation to current knowledge and outlines key research priorities for the future identified during the report.

2. RDM, the local nexus and the food sector

2.1 Redistributed Manufacturing (RDM)

RDM is a relatively new concept that has to date received little scholarly attention, although recent interest from funding councils has engaged research in a number of diverse areas from medical devices, digital printing, sustainable cities and more recently the food, water and energy nexus. There is some variation in the use of the term RDM in the scientific, engineering and policy literatures. In general however, RDM has been defined as having two key attributes; that manufacturing is of smaller scale, and that it takes place closer to the consumer. Beyond these cardinal attributes, the term RDM is applied to a wide range of activities and processes through which manufacturing activity takes place in a more dispersed way than is currently the case, and involving new relationships in which the manufacturing process is more closely linked to the specific demands of diverse consumers. Thus understood RDM can encompass any technology, systems or strategies (or combination thereof) that enables change in relations to economics and organisation of manufacturing with specific reference to scale and location.

This new manufacturing model coincides with locally embedded small-scale manufacturing firms addressing significant and expanding market niches of uniquely customised or small batch demand. Crucially, however, these small scale operations do not directly compete with larger companies on the basis of price. Rather than scale economies such operations relay on other forms of firm efficiencies to ensure adaptability, responsiveness and innovation. In addition to changes in production scale RDM suggests changes in the nature of demand. The emergence of a niche or series of niches that can be occupied by firms engaged in RDM suggests that there are untapped markets for personalised, customised and innovative products. These products need to be produced in small batches or even as unique pieces. Such demands cannot be satisfied by the mass standardised products that low-cost economies have completely captured. Rather, such niche markets require customers to co-innovate or even co-produce with the manufacturer or the maker. Closer interaction between manufacturers and customers translates into more distributed consumption of distributed manufacturing, whereby customers source or commission the making of products locally.

The current interest in redistributed manufacturing (RDM) is thus linked to an analysis of evolving management trends and technical capabilities in the manufacturing sector as well as changing patterns of consumer demand. According to some commentators RDM represents a new manufacturing model which is capable of taking into account these implications. It is important to note that while the focus in RDM is often placed on the manufacturing process itself. The emergence of such a model requires more widespread change than is suggested by a simple dispersal of manufacturing implies. As Noble et al put it *“Re-distributed manufacturing epitomises an on-demand economy with local manufactories (however they may look) reshaping and redefining markets and supply chains, requiring new decentralised business models and having wide ranging challenges and implications. Redistributed manufacturing may be characterised by greater personalisation of products. Concurrently there are a wide range of engineering, materials, computing, infrastructure and chemical challenges”* (Pearson and Noble 2013). To which could also be added challenges in relation to the way in which manufacturers relate to their customers. Under RDM it is envisaged that relationships involve greater dialogue between producers and consumers. In this context, the relationship between RDM and new technologies extends beyond the simple availability of ways of making products. As, if not more important are innovations in the way in which producing firms communicate with their customers. Proximity to the consumer should not therefor be understood in purely spatial terms but rather in terms of the quality and nature of the communicative relations between producer and consumer.

The concept of RDM represents a significant shift away from the dynamics of scale economies which have dominated the organisation of manufacturing since the industrial revolution. These have seen industry being diverted to more centralised production primarily based on geographically concentrated resources, accompanied by large-scale distribution infrastructures. While these centrally organised and large scale systems have served well in certain respects. Supporters of RDM argue that continued reliance on centralised resource extraction and production has contributed to a range of acute global issues. These include concerns relating to the ongoing sustainability of current patterns of manufacturing in environmental, social and economic terms. In this context RDM offers a modern alternative in which some of these sustainability issues are resolved whilst simultaneously delivering products which are better tailored to the demands of specific consumers. In many ways, RDM has come to be associated with a situation whereby market forces can be harnessed to technology in the delivery of more sustainable forms of production through a closer alignment of production and consumption. The form of manufacturing firm envisaged is one which is small scale, flexible and responsive. Armed with new technologies, such firms are both capable of, and dependent on, making rapid adjustments to its product in response to changing consumer preferences.

The very nature of RDM creates challenges for those wishing to undertake research about, or implement RDM strategies. Since, as the concept itself suggests, RDM in any specific sector will be shaped to some extent by the nature of the product itself and highly fluid relationships between customers and producers. Thus, RDM does not appear as a discreet and clearly defined set of practices but as a range of somewhat related activities which result in the re-alignment of relationships between the producers, production process and consumers. This makes it particularly difficult to make generalisations about RDM which apply across different sectors. Technologies differ depending on the sector and the market being served as do the forms that interaction with consumers take. In the case of the LNN project such issues featured in many of the final reports of the different feasibility studies. In a number of cases the authors clearly indicated that the possible feasibility of redistribution of food production was very much linked to questions of scale and cost. Furthermore the reports place significance emphasis on the idea that no general case could be made for RDM in the food sector. The feasibility of RDM for different foods needs to be assessed on a case by case basis. This suggests that rather than a single form RDM in the food sector is likely to assume a variety of guises depending on the nature of specific products, the different demands that production at different scales places on resources (including energy and food) and the level of local demand for redistributed products.

2.2 RDM in the UK food sector

Currently the food manufacturing sector represents the single largest sector of the UK manufacturing economy accounting for a total of 16% of all manufacturing in the UK (figure 2.1) and employing at least 400,000 people directly. The UK food economy is highly integrated into the wider global trade in food. Besides the large proportion of the home market that the sector fills, UK food manufacturing is also involved in export activities. In 2016 UK food exports exceeded 20 billion pounds in value for the first time, an increase of over 10% over exports achieved in the previous year. The bulk of these exports (over 70 %) went to the European Union. Despite a strengthening performance, the UK is not food secure importing almost a quarter of all its food from overseas (www.foodsecurity.ac.uk/challenge/uk-threat/). This means that despite a growing food export business the UK is still a net importer of food. Changing relationships with the UK's most important trading partners pose important challenges for the UK food sector. A case where both the export and important of food may face added trade barriers alongside a more general desire to reduce the country's dependence on overseas food supplies may render the idea of RDM in the food sector an attractive mechanism through which to alter the terms of food trade and win local market share for UK food producers.

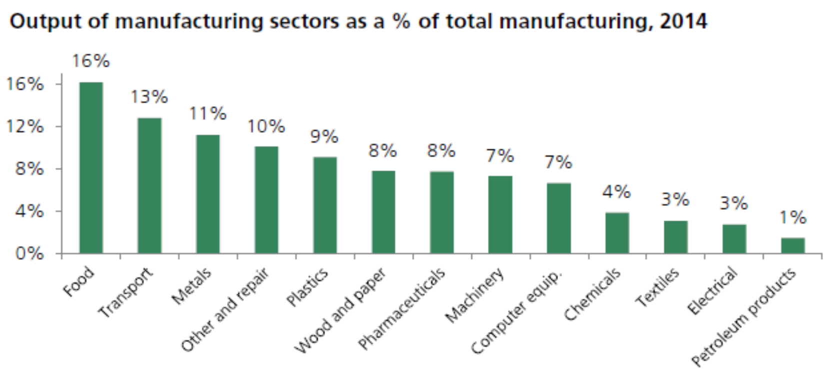

Figure 2.1 Manufacturing by sector in the UK

Along with other elements of the manufacturing sector; over the last two hundred years food production has gradually changed from being an artisan-led and locally-based process, to the mechanised, quality-controlled, and large-scale manufacturing process which dominates the sector today. These systems are bound by strict health and safety regulations. This is accompanied by an increasing mobilisation of technologies to track all stages in the production process from farm to fork. However, the depiction of the food manufacturing sector as an intensive centralised activity tells only a partial story. Food serves various functions in addition to nutrition (e.g. social) and shares different values (e.g. vegetarian, halal). For this reason, RDM of food products may be more constrained as compared with other products. Equally however, the various different forms of value vested in food provide unique opportunities (or niches) for local differentiation some of which are already occupied by dispersed producers. Furthermore, the specific physical characteristics of food, such as freshness, food shelf life and variations in taste add to the potential and also to the complexity of RDM in the food sector. While the nature of food products and demand may lend themselves to local differentiation the significant costs incurred through the need to ensure traceability and food safety present a significant challenge to smaller producers.

For such reasons, it could be argued that food occupies something of an outlier position in relation to RDM with ideas around local specificity already well established. In addition, as the case study in relation to bread undertaken as part of this project illustrates, a small but significant artisanal food production base has long co-existed alongside the large-scale production of food. This base has survived for a variety of reasons amongst which cultural considerations, individual consumer preferences and local efficiencies (such as in the case of shortened supply chains reducing transport costs, enabling better management of volumes and ensuring freshness) can be counted. In most manufacturing sectors where RDM is most often mentioned it is in the context of new technologies which have made smaller production runs in geographically dispersed plants more feasible (see for example Moreno and Charnley 2016). However, in the case of food, traditional as well as new technologies have the potential to support the development of a more distributed manufacturing base. The technologies that need to be considered in relation to food RDM include traditional food processing technologies, existing manufacturing technologies that could be reconfigured to be used in smaller scale and also a number of new emerging food technologies that currently may have limited commercial applications, but could provide significant potential in the context of RDM.

As the case of Oxford, one of the geographical case studies undertaken as part of this work illustrates there are a multitude of ways through which RDM in the food sector can manifest itself. Furthermore ideas around RDM coincide with a range of other ideas relating to food localisation which while not specifically intended to achieve RDM may have similar outcomes. There is for example an existing network of small food production facilities within the Oxford which already serves a niche market and which counts amongst its producers companies which specifically base their value proposition on the use of traditional methods. This network includes traditional small food producers which have operated in the area for a considerable time serving existing local demand for locally produced food and new entrants taking advantage of both existing and new technologies to tap into local demand. Furthermore, within oxford there is a significant and active "local food movement" which articulates consumer demand for more local food. Indeed, in the context of the current study it may be worth exploring the extent to which this social movement impacts on the way in which food is produced within the city. This illustrates the complexity of understanding the potential role of RDM in the food sector and raises questions concerning the place of RDM when considering the dynamics of production within the food sector where a range of trends and practices influence the scale at which production takes place.

In summary food offers a case which is in many ways particularly suited to RDM, given the nature of the product itself and the specific characteristics of demand for food. Indeed, it is an industry in which there is already significant redistribution in the form, for example, of artisanal and in store bakeries whereby all or part of the production process is undertaken at local level. At the same time the very diverse range of products that collectively make up the food sector can be produced in a multitude of different ways meaning that the concept of RDM is particularly difficult to generalise in relation to food. This was articulated in the LNN food survey which identified at least four different avenues through which RDM in the food sector might take place;

At the most extreme level, there is the potential for a shift towards food manufacturing taking place in the home, using new technologies such as 3D printing. Home bread makers could be seen as an exemplar of this trend. Such home production could involve either the mechanisation of everyday home cooking activities, or the downscaling and ultimate displacement of mass manufacturing on production lines.

At a step-up in scale and a step away from the consumer in distance, artisanal food sector is also an example of RDM. This is typified by the small batch production of specific food products, often sold at a premium in local markets. Such products benefit from a growing demand among middle class consumers with relatively high disposable income for 'food with a story' – 'authentic' quality food produced locally with a high level of manual labour. The growth of farmers markets and box schemes can be interpreted as examples of the types of products and distribution systems that typify the artisanal paradigm, as well as phenomena such as the growth of the artisan brewing sector. Much has been written about 'alternative food networks', and it is of interest to this project to explore why the products of such networks are so highly valued by some consumers and what the future of this sector might look like. However, while the artisanal food sector has attracted considerable attention and indeed much debate about "alternative food networks" it is important to stress the relatively small place that this movement occupies as a proportion of total food production and manufacturing. Again referring to the work undertaken in the LNN project it is clear that while this sector is prominent in discussions it remains only a small element in the overall food system accounting for a relatively small percentage of overall food production.

Both the home production and artisanal food paradigms of RDM challenge the conventional definition of manufacturing, that is, ‘to make (something) on a large scale using machinery’ – the former because it is by definition small-scale and the latter because it is often relatively un-mechanised. RDM in food can be considered in two further ways that are more closely aligned with conventional definitions of manufacturing:

First is the idea that existing large manufacturing businesses might choose to split their operations into smaller units rather than following the current trend of centralisation. This might be driven by higher transport fuel prices for example.

Second, the food report identifies the process of on-shoring, whereby manufacturing currently performed overseas is either repatriated to the UK, in the case of products which were formerly produced locally or brought to the UK for the first time in the case of products which have not been produced in the UK before.

The multiple forms that RDM can take in the food system made added to the complexity of the task facing the LNN project. Given that different metrics could be applied to assess different forms of RDM in the food sector. To a certain extent different feasibility studies had to exercise a high degree of discretion concerning those activities that they intended to assess as embracing RDM in the food sector. This in turn poses challenges in the process of providing an overview of the conclusions reached by the individual studies.

In summary, the reports collectively raise question about what RDM comprises in the context of food production. The general conceptualisation of RDM as manufacturing at smaller scale, and occurring closer to the consumer, tends to suggest that current manufacturing is undertaken on a large scale and further from the consumer. The literature on RDM has generally focussed on how new technologies may enable firms working at smaller scales to achieve efficiencies through their capacity to adapt quickly to changes in demand which, the RDM canon tends to suggest, enable small firms to outperform larger companies. This view of RDM tends to suggest a dualism between conventional large scale manufacturing which dominates much of industry and modern dispersed manufacturing by smaller more responsive local firms. The LNN feasibility studies collectively raise questions as to whether this conceptualisation is appropriate to a food sector which is highly complex and hosts a range of firms producing a wide variety of products in diverse ways at different scales. This is particularly the case when the food manufacturing sector is understood as part of a complex food system through which diverse nutritional, social, economic and cultural needs can be met in multiple ways. In broad terms the reports identify four different scales at which food production takes place; internationally where foods are produced by large concerns which serve international or even global markets, nationally where a limited number of centres of production serve national markets, regional scale where different regional production centres produce food for regional markets and locally where small local firms serve local markets. However even these distinctions in terms of scale encompass highly variable manufacturing practices. For example, there are significant international food producers who employ artisanal styles of production and indeed it is possible for small scale producers of high quality food products to trade globally. Rather than a movement away from one form of manufacturing to another RDM in the food sector may be better understood as shifts in scale within the food system in which nutritional and other needs are met in different ways by firms servicing different markets. In this context, and as the reports reveal rather than meeting certain demands in different ways, changing demand plays a critical role in shaping the ways in which food is produced and on the potential for RDM in the food sector. For this reason while many of the final reports sought to explore the technical aspects of RDM in the food sector, a significant element of all the reports concern the need for changes in the demand side of the food system through, for example, measures to promote demand for locally produced food or the need for policies that incentivise the consumption of locally produced food.

2.3 The "local nexus" vision and its relevance to re-distributed manufacturing

Increasing demands resulting from agriculture and industrial processes, lifestyle changes and population growth are resulting in rising financial and environmental costs. Of growing concerns are the pressures on the key resources; energy, food and water. Water resources are under pressure from ever-increasing and competing uses including food and energy production. Equally more energy is being expended by, for example, consumers, manufacturers and service providers. As populations grow and become more affluent demand for food is also both rising and changing posing challenges not only to food system but also to the interconnected water, energy and food systems. There has been an increased recognition that there is an interrelationship between water, energy and food systems and that meeting the needs for one of these resources may have implications on the availability of others. Energy for example is required for a range of tasks associated with the management and utilisation of water. However, the energy inputs of securing water resources are often overlooked. Generic energy requirements in transporting water (i.e. energy in kWh required to deliver 1m^3 of clean water) have been summarised in the table below (table 2.1) from a study by the World Economic Forum (see WEF, 2011):

Table 2.1 Energy Requirements for transporting water by source

Lake or river	0.37 kWh/m^3
Groundwater	0.48 kWh/m^3
Wastewater treatment	0.62-0.87 kWh/m^3

Wastewater re-use	1-2.5 kWh/m^3
Seawater	2.58-8.5 kWh/m^3

The opposite is also true, the energy sector itself is a major water consumer with the 'largest withdrawal of water in the USA and most industrialised countries going for power plant cooling' (see WEF, 2011). In 2005, this amounted to half of all withdrawals (49%) in the USA (CSS, 2014). Other studies on energy and water focus specifically on biomass. Gerbens-Leenes *et al*., (2009) and Jordaan *et al., (*2013) point out that increasing the contribution of energy from biomass (an often cited example of interdependency in the WEF nexus) to meet energy security goals will mean larger consumption of fresh water and competition for water and land between energy and food crops. King *et al.,* (2013) suggests that water availability is the most important climatic change to consider in the design of future bioenergy systems. Despite the variations on bioenergy productivity in relation to water availability, biomass has an advantage over other energy sources in that it favours small scale decentralised systems where, unlike in huge power stations, water is not needed for cooling, or where water /steam used for cooling -if any- is re-circulated in a close circuit and can be then used for heating (through for example combined heat and power CHP plants). Equally, each step within the food supply chain involves water and energy. A Study by the Organisation for Economic Co-operation and Development indicates that agriculture is a major user of water, accounting for about 70% of the world's freshwater withdrawals and over 40% of OECD countries' total water withdrawals. This study also indicates 50% more food will need to be produced up to 2030, and production will need to be doubled by 2050 with less water available due to growing pressures from urbanisation, industrialisation and climate change (OECD, 2010). In relation to energy and food, the prices of food are linked to the global price of oil. Transporting food around the world makes food dependent on oil as the main energy source. Moreover, food processing is in many cases an energy intensive activity. In addition, policies that aim to diversify the sources of energy away from oil (e.g. the drive to turn corn into ethanol in the USA, softwood and sugarcane into biodiesel in Brazil and Mauritius) mean that food products are being transformed into fuel, and more and more arable land is being used for biofuel production in competition with growing food. Mohtar and Daher (2012) point out the controversy that biodiesels generate also in relation to water consumption and soil and water degradation associated with the excessive use of fertilizers.

The growing recognition of such interdependencies between the water energy and food systems has increasingly led for calls to recognise the significance of the nexus linking water, energy and food resource systems. Ringler *et al.,* (2013) recognise that the inter-connections between the Water, Energy and Food sectors has become more apparent as a result of pressures on natural resources and emphasise the need for nexus analyses to consider human well-being and environmental outcomes in addition to assessing benefits across the three sectors. Doing so presents significant challenges, not least in overcoming disciplinary barriers and policy practice which have tended to deal with water, energy and food as separate systems which need dedicated scrutiny and specific separate policies. A review of the integrated resource assessment and modelling literature by Bazilian *et al.*, (2011) confirmed that existing analytical and decision-making tools available tend to be designed and employed to understand a single resource/system. This notwithstanding the recent past has seen the development of better modelling and assessment tools to study interdependencies between the three sectors. The increased development of such tools can create the momentum to overcome barriers to understanding the interdependencies in the Water, Energy, Food (WEF) nexus (Leck *et al* 2015).

The concern with the Water, Energy Food nexus clearly has implications for RDM. Since food production and distribution at any scale involves the use and/or production of water and energy. Any change in the way that food is produced is likely to have impacts on the water energy food nexus. RDM involves changes in both the scale and location of production which are likely to have a particular impact on water and energy use within specific locality. Hence this study is particularly concerned with the local nexus impacts of changes in supply as for example in the case of bakeries drawing more water from local water resources or tomato production within specific localities requiring increased local energy use. The LNN project is thus particularly concerned to explore the potential impacts both adverse and positive that RDM has for the local WEF nexus in specific areas.

3. Programme and methodology

While on the one hand RDM has the potential to open up new possibilities (and implications) for both existing and new actors within the food supply chain (Gao et al., 2015; Ivanova et al., 2013; Kietzmann et al., 2014; Thiesse et al., 2015). The nature of the possible impact of RDM on the local water, energy and food system is poorly understood. The LNN reports collectively sought to explore the hypotheses that the development of an understanding of local nexuses of food manufacturing, energy and water supply will provide opportunities for rationally customising resource utilisation, production, and consumption to meet water, energy and food needs in a local context, contributing to the shared prosperity of business and community and between human society and natural ecosystems. In the case of the LNN, the WEF nexus provides a lens through which to explore the implications RDM in food may have for distributed regional growth and resilience. Thus, underlying the LNN project was a concern with the question of the capacity of RDM to offer the potential for sustainable manufacturing through the framing of the local nexus of food, energy and water impacts. The LNN did so by exploring;

(1) The implications of localised production of energy and water not only for local food systems due to the “nexus factors”, but also for supporting localised manufacturing of other products and services by fulfilling their infrastructural roles adapted to a re-distributed economy.

(2) Localised production of food as an established commodity as an example of making goods with locally available resources (particularly, biomass from local lands) to meet local needs. Thus generating important learnings with respect to the *rational alignment between local resources, production, and consumption*, to inform emerging manufacturing activities (e.g. biomass-based materials).

(3) Local nexuses as a model for exploring how RDM can contribute to the circular economy.

The LNN project explored these ideas by investigating localised food manufacturing and the decentralised energy and water systems that interact with the food system. The considered interactions that stem from the "nexus factors", i.e. energy and water requirements for the food system, competition with the food system over land use for supplying energy and water to the food chain as well as other users within the concerned localities and industries. From the food perspective the project considered activities along the entire 'food chain' such as producing (agriculture), processing and packaging, distributing, retailing and consuming. These "non-manufacturing" activities were investigated to the extent required for exploring technical, socio-economic and environmental synergies between all food system components and for addressing holistically the "nexus factors" with energy and water.

This project articulated, and developed concepts and methodologies to address a number of engineering and social science challenges that need to be resolved if the local nexus is to be advanced. These included:

(1) Optimal trade-off between efficiency, flexibility, reliability, and cost-effectiveness of smaller-scale technology and systems suitable for local production;

(2) Rational alignment of resource, production, and consumption to maximise the benefits enabled by geographical proximity, including rationalisation of the geographical range for localisation (i.e. how "local" is "optimally" local in a specific setting);

(3) New business models and strategies for companies of various sizes to realise the "physical" potential of the local nexuses in the real economy and seize commercial opportunities rendered by (re-) localisation;

(4) Innovation in policies and governance to catalyse socioeconomic developments around local nexuses. These challenges, all closely stemming from the special requirements and potential benefits of *localised production*, mark the most essential differences from, and offer complementarity to, other on-going initiatives such as the Nexus Network (ESRC) and the Centre for Sustainable Energy Use in Food Chains (EPSRC).

As already discussed the LNN project explored the local nexuses along four research themes (Figure 1.1) namely engineering, business, policy and society, and systems integration and three different sectors; food energy and water. The research was organised into a series of work packages (P1 – P 7) and the outputs took the form of feasibility studies each of which focussed on one of the themes or sectors with an additional study which focussed on the delivery of a whole systems analysis;

P1 delivered a study exploring the feasibility of RDM from a food perspective. In doing so the study built on the local implications of the “food system” concept as developed in ECI (Ingram 2011) to assess re-engineering food system *activities* (producing; processing and packaging; transporting and storing; retailing; and consuming) at county- and city-levels, Furthermore, it explored how these *activities* affect food system *outcomes* in terms of (a) the major components of food security (b) energy and water use across all food system activities (c) The sustainability of the multiple food system enterprises

P2 delivered a study exploring the feasibility of RDM from an energy perspective by; (1) assessing the requirements for energy supply to localised food systems (2) assessing the potential for energy recovery (3) developing local energy system scenarios consistent with local resource availability and recovery potential and that satisfy demands and (4) evaluating options of scale-flexible energy generation and storage technologies suitable for implementing the above systems with respect to efficiency, cost effectiveness, safety, and environmental impact.

P3 delivered a study exploring the feasibility of RDM from a water perspective involving such activities as (1) An assessment of the changing landscape of water demands in the context of localised production and related community initiatives, (2) The development of application scenarios that address these demands to inform technology portfolio analysis for water processing (3) An investigation of graded water reuse and recycling opportunities among processes involved in the food production chain energy generation and other domestic and industrial activities within the same locality, and (4) an exploration of possible synergies among localised/small-scale water and energy technologies and systems for improved resource recovery.

P4 explored the feasibility of the business case for by investigating the business opportunities and challenges of localised food production and energy and water supply.

P5 on policy and society explored the feasibility of RDM from the policy perspective. In addition to a general literature review of relevant concepts, cases, and issues, the report in particular focussed on drivers and strategies of public procurement by local authorities due to its critical role in enabling and supporting local production systems and building in circular economy concepts to promote and embed sustainability locally.

P6 on systems integration and generalisation focussed on the implications of RDM from whole systems.

P7 Focused in particular on the engineering and technological feasibility of RDM in the food sector.

4. Case Studies

4.1 Introduction

The work undertaken through these feasibility projects focussed on two case study locales. One of these locations representing a situation of "retrofitting", where an existing system is to be changed to benefit from the paradigm of local nexuses and another representing "new development", where opportunities exist to introduce a new food, energy and water system. These case study locales provide a common background for the different research themes to interact and integrate and served purposes ranging from collection of empirical data to stakeholder engagement. In addition, two contrasting exemplar crops; bread and tomato paste were also examined in some depth.

4.2. Oxford City

Oxford is a small city in southern England. It has a population of 155,000 people, of which around 30,000 are students at either Oxford University or Oxford Brookes University. Since students are not present for the whole year, from the point of view of food consumption the effective size of the population is likely to be smaller than the official population figure. There is only a small body of locally specific research on where these people get their food from, but since the UK's food system is relatively homogeneous, it can be assumed that patterns of food consumption and procurement in Oxford are similar to the rest of the country. According to Defra's Family Food survey, on average each person in Oxford will purchase 593kg of food every year, from supermarkets, grocers and other shops, mostly for home consumption (although 20% of this food will be thrown away in the home before being consumed). 70-80% of the food that is purchased is processed or manufactured in some way 466kg - a total of 72,000 tonnes for the whole city. So if Oxford is representative of the national picture, 25,000 tonnes of the city's food is manufactured overseas. Of the remaining 65%, the majority is manufactured on a regional or national level. Only a very small percentage (less than 1%) of processed food consumed in Oxford is manufactured locally. Most food reaches the city through supermarket outlets, operating from a supply chain network of regional distribution centres (RDCs).

Compared with the average for Great Britain Oxford's population is more likely to be in employment, be better qualified and earn more (Table 4.1). The City of Oxford has a high number of students and university staff relative to its population. Moreover, it has a high proportion of both international students and relatively wealthy students. This combination provides a demand for a diverse and high value added food offer. A strong local food culture has emerged across Oxford evidenced by the range of independent restaurants and the success of local Farmers Markets. There exists a wide range of food-related activities and initiatives in Oxford, such as the pioneering study “Food Printing Oxford” commissioned by Oxford City Council, the local food festival with over 10,000 participants hosted by the Earth Trust, and the internationally famous annual Oxford Farming Conference. Good Food Oxford (which promotes local and sustainable production, preparation and consumption across the county), continues to build its base of over 130 supportive organisations. The overall scale of public sector food procurement in Oxfordshire relative to overall food demand in the county is believed to be slightly higher than the average for the country as a whole, largely as a result of Oxford University Colleges providing catering for students.

Table 4.1: Selected socio-economic indicators potentially relevant to ‘local’ food demand Comparison of Oxfordshire and Great Britain

	Oxfordshire	Great Britain
Total population estimate 2015 (persons)	677,800	63,258,400
Economically active in employment	79.5%	73.7%
Gross weekly pay Full time workers	£ 578.4	£ 529.6
Average hourly pay	£ 14.8	£ 13.3
Managers, Professionals, Associate Professionals	56.4%	44.6
NVQ level 4 and above	51.7%	37.1%

Source: Nomis October 2016 https://www.nomisweb.co.uk/

4.3 Northstowe

Northstowe is an area of new development which has been in planning and construction for around 15 years and will create up to 10,000 new homes. The areas is located on the site of RAF Oakington and green field sites where developers optioned much of the land in Longstanton parish and to a lesser extent land in the parish of Oakington and Westwick (LDHS, 2016). The area is located five miles northwest of the city of Cambridge between the villages of Oakington and Longstanton. In 2012 outline consent was given to Gallagher to progress with the first phase of 1500 homes, a primary school, road improvements and a local centre. The primary school started on site in 2015 and the first homes are expected in 2016/17 (Northstowe, 2016a). In the 2015 United Kingdom budget on 18 March 2015, George Osborne confirmed the Government's intent to create a joint venture with a private sector partner to lead development on the Government-owned part of the town location. Three-quarters of the homes started by 2020 will be constructed under a direct contract with the public sector (HM Treasury, 2015). 2015 saw outline consent agreed in principle to build a further 3,500 homes, a town centre, 3 more schools including a secondary school education campus and a link road to the A14, plus a road linking the town to a Guided Busway. The homes in phase two cannot be occupied until a major A14 upgrade is completed which starts in 2016 and finishes in 2020 (Northstowe, 2016a). In April 2016, Bloor Homes was named as the first housebuilder for the site with 92 new homes planned in a range of types and sizes up to five bedrooms (Cambridge news, 2016).

As a new area there is little evidence concerning local demographics and food consumption, however considering the areas location, the nature of the houses planned and its proximity to Cambridge the population is likely to be relatively affluent. Planners of the project suggest that the development will lead to the creation of 11,000 jobs in the local community and the wider Greater Cambridge area, encompassing education, healthcare and retail (Northstowe, 2016a). There is no mention about manufacturing jobs or food manufacturing jobs other than there will also be office, research and development and light industrial employment opportunities. The town centre has been designed to include a mix of retail, food and drink (restaurants, pubs food outlets), health and community related opportunities. The Northstowe planners also claim that an extra 12,000 construction jobs and 6,500 in the regional supply chain will be created through the development. They also state that these will result in employment gains through commercial development in the region of £700 million to the UK economy (Northstowe, 2016a). The project also includes the Cambridge Compass Enterprise Zone which boasts reduced business rates but doesn't detail what these are and what types of businesses will benefit as a result. In terms of small firm start-up and entrepreneurial activity there is little mention other than the enterprise zone. Manufacturing is also excluded from receiving much attention.

With respect to sustainability, Northstowe will include open spaces and buildings designed to enhance biodiversity it also shows in the planning details that green corridors will be created to link Northstowe to the wider landscape. Much of the Northstowe development will be on land that is currently being used for agriculture and horticulture (LDHS, 2016), and its conversion to other uses under the proposals for the areas development may have an effect on the local food supply chain and lead to the reduction of food production in the area. Very little is mentioned in terms of space for food production other than a few allotments, nor do they mention how much productive farmland will be consumed by the development which raises the potential issues of flooding and loss of the environmental landscape, the planners do detail a sustainable drainage system to manage surface water runoff (Northstowe, 2016b). Whilst detailing the aims for a low carbon community there is little attention paid to how it will create low carbon businesses.

As a case study Northstowe is an area of new development rather than retrofitting of existing systems as in the case in Oxford. A rich set of information is available in the public domain covering building types, water, energy, demographics, transport, and waste management. In theory this data allows a sensible estimation of food demand by the local population and the energy and water demands corresponding to a conceived local food system. This supports research on opportunities and challenges of introducing fit-for-purpose energy and water systems for a new development where domestic and other demands need to be considered along with localised (food) production

5. Exemplar products

5.1 Introduction

As is alluded to above the concept of RDM in the food sector is of necessity quite broadly defined. Questions of location and scale in food manufacturing are closely linked to the specific characteristics of different products. With this in mind the two exemplar products were used to explore questions of scale of manufacturing in detail. The idea being that these products would serve as means by which to test the likely implications of RDM for different food products. The two products chosen, namely Bread and tomato paste, were selected because they are currently supplied via very different value chains affording researchers the opportunity to explore the divergent likely impacts of the RDM of different products.

5.2 Bread

Bread is a staple carbohydrate in the UK, commonly made of wheat flour, water, yeast, salt and a range of additives. As wheat and bread became more central to the British agricultural system and diet, new legislation (e.g. the imposition and removal of the Corn Laws in the 19th Century) and technologies (roller mills, fine sieves, baking tins) became increasingly important to its historical trajectory.

By the early-mid 20th Century, bread production was becoming increasingly industrialised, with growing distribution of pre-sliced square shaped loaves produced in large factories. According to Cauvain & Young 2015, “The evolution of breadmaking techniques has changed more since the mid-1940s than in all the preceding centuries.” (Cauvain & Young, 2015) The traditional small bakeries that had previously served individual neighbourhoods with fresh bread began to die out by the 1950s, but it was the widespread uptake of the Chorleywood Bread Process (CBP) after 1965 that cemented the dominance of the industrial baker. This technological innovation shortened the time taken to make bread by replacing the original fermentation process with an intense period of high-energy mixing which allowed added enzymes and other agents to simulate the effect of fermentation.

Currently the UK population every year purchases some 2.1 million tonnes of bread, or 2.7bn standard 800g loaves.[1] According to the Federation of Bakers the average UK household purchases 80 loaves of bread a year,[2] while the UK's National Diet and Nutrition Survey estimates average consumption by adults at 2.5 medium slices per day. (Bates, Lennox, Bates C et al. 2011). The level of consumption is however declining inexorably over time. In 1996, bread consumption was half the level recorded in 1942, and consumption continues to drop (DEFRA 2000). Most of this fall is accounted for by the reduction in white bread consumption, while consumption of brown and speciality breads has seen a general trend of slow increase since the 1970s (figure 5.1).

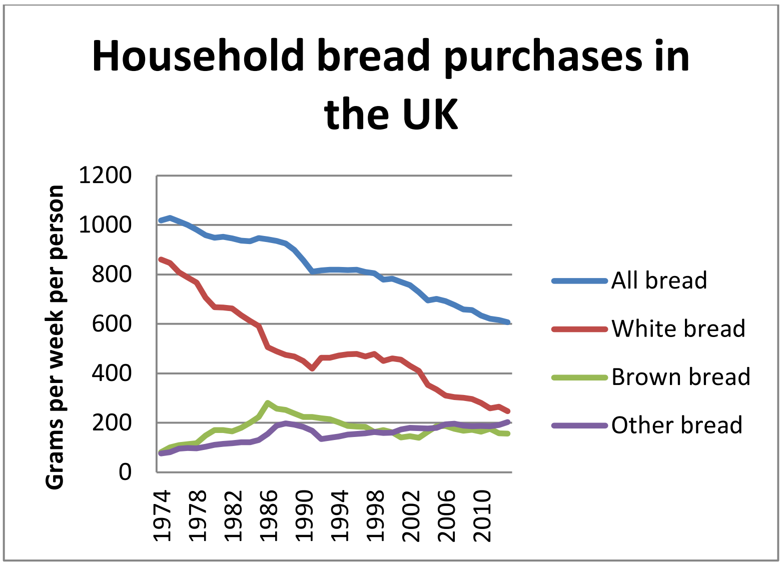

Figure 5.1: *Household bread purchases in the UK*

Although per capita bread consumption has been steadily declining over the past half century, bread is still a key source of energy (11% of total), carbohydrate (20%) and protein (9%) in the diet of UK adults (Bates, Bates, Prentice A et al. 2011). Bread is also an important source of micronutrients including thiamine, niacin, folate, zinc, calcium and manganese (O'Connor 2012). The health consequences of bread consumption vary depending on the type of bread eaten - white processed bread has less nutritional value than high fibre wholemeal bread. The majority of bread is purchased for preparation or consumption in the household, with around 5% of the total being purchased out of the home in the form of pre-prepared sandwiches, or consumed with or as part of meals in restaurants, cafes or canteens.[3] Bread is eaten primarily at breakfast

[1] Calculated from Defra Family Food
[2] IBIS World Industry Reports
http://clients1.ibisworld.co.uk/reports/uk/industry/productsandmarkets.aspx?entid=580
[3] Calculated from Defra Family Food Survey

and lunchtime rather than at dinner (Gibson and Gunn 2011). Women eat far less bread than men (76g / day average compared to 133g).

The manufacturing of bread occurs in two stages. First the milling stage, during which grain is transformed into flour; and second, the baking stage, which includes the addition of water, yeast, salt and other ingredients.

In milling, individual wheat grains are broken down into progressively finer pieces, retaining more or less of the bran (the outer coating of the seed) and germ (the vitamin-rich reproductive embryo of the seed) depending on whether white, brown or wholemeal flour is required. The process is as follows:

- **Grading:** according to multiple criteria the most important of which is protein content.
- **Cleaning:** wheat is cleaned to remove stones, dust, grit, metal and other impurities. A variety of the following may be employed:
- **Conditioning (tempering):** water is added to soften the wheat, making it easier to process
- **Blending**: Wheat of different grades and moistures is blended together to obtain a batch with the required characteristics (the grist)
- **Breaking:** the wheat passes through rollers, breaking or cracking open the grain
    - The material passes from the roller through metal sieves separating it into three categories
        - Middlings, or farina: the finest material
        - Semolina: larger pieces
        - Interior still attached to bran
- **Middlings purifier:** sieves separate the grain into endosperm, bran and germ.
- **Middlings grinding**: middlings are ground into flour by large smooth metal rollers. Each time flour is ground it is sieved to separate it into flours of different fineness, which can be combined as desired to produce a final product.
- **Processing**: small amounts of oxidizing agents etc. added along with vitamins and minerals as required by law. Flour is normally matured for 1 – 2 months.
- **Packing:** into bags for industrial, commercial or household use.

The basic operation of the baking stage involves mixing flour with water to create a network of gluten strands that can trap and hold gas bubbles created by the fermentation of sugars in the dough by yeasts. Time is required for both the development of the long gluten strands and the formation of gas bubbles. When the risen bread is baked the starch in the dough gelatinises, making the bubbles that have been formed into a permanent feature of the loaf, called the crumb. There are four stages common to all baking processes.

1. Mixing
2. Proving / fermenting
3. Baking
4. Cooling

There are two main variants used in commercial bread production in the UK, the Chorleywood Bread Process (CBP) which was invented in the 1960s and accounts for most bagged sliced industrial bread on sale, and the more traditional Bulk Fermentation Process (BFP), which is used by some smaller commercial bakers and craft bakers. The essential difference between BFP and CBP is found at the fermentation stage. While traditional bulk fermentation requires around 3 hours of fermentation time, the innovation of the CBP was that by introducing a significant level of mechanical energy, changing the formulation of the dough with extra water and hard fats, and adding a mixture of dough improving chemicals, the fermentation time requirement was virtually eliminated. In the CBP the dough develops the ability to stretch and retain gas within the first five minutes of the process. As well as radically reducing the time needed to bake bread, the CBP also allowed the use of lower protein British wheat where previously British bakers had been heavily dependent on imported high protein wheat.

5.3 Tomato Paste

Tomato paste is a concentrated long shelf-life product used globally as an ingredient in preparing meals and food products[4]. It can be used by consumers or it can be used by other food manufacturing organisations, catering services, restaurants, pubs and so on. An example of the ingredients found in tomato paste include rehydrated Sun-dried Tomatoes (53%), Sunflower Seed Oil, Wine Vinegar, Sea Salt, Natural Flavourings, Garlic, Sugar, Cracked Black Pepper, Acidity Regulator: Citric Acid (Sacla, 2016). Another example is an organic 'free from' paste which contains - Water, Vegetable Oil, Sun Dried Tomatoes (28%), Red Wine Vinegar, Salt, Herbs.

Tomato paste is produced by removing the seeds, skin and pulp of tomatoes to create a tomato juice, which is then thickened by evaporation. Modern tomato cultivars contain up to 94% water by weight (Bastin 1997) – reducing the water content drastically whilst still preserving the fruit's flavour and utility in

[4] What might technically be classed as double concentrate tomato paste (the kind you would find for sale in a tube in the supermarket) is normally called tomato puree in the UK, while in the US tomato puree would refer to a product with a much more liquid consistency.

cooking means that it can be transported more cheaply. A second important feature of tomato paste is that it transforms a product that in its ripe form has a short shelf life and is extremely hard to transport without damage, into a durable long-life form. These factors have been central to the growth of the tomato industry as they allow the tomato to be sold over a wide geographical region and outside of the relatively short summer harvest period.

Tomato paste as a global commodity ingredient is a relatively modern phenomenon. Industrial tomato processing and preservation took off in North America, where in the latter half of the 19th century the process was scaled up with automated canning, and later on, with mechanised harvesting. It was California that transformed the tomato from a local, seasonal crop to a global commodity product for mass consumption, and California is still the world's preeminent tomato processing region. The EU accounts for one third of world output of processing tomatoes. Major production regions outside of Europe and California include; Turkey, China and Thailand (Pritchard and Burch, 2003). California is historically the most important competitive threat for the European supply chain (Bunte and Roza, 2007: 25) although China and Turkey have been identified as emergent threats. The European tomato processing industry processed more than 11,000,000 tonnes of raw tomatoes in 2004. Italy has a 53% share of European production followed by Spain (22%) and Portugal and Greece (10% each). The production of processing tomatoes is still growing fast, notably in Spain and Italy. Processing tomatoes are produced on relatively large farms specialised in extensive production of arable crops and vegetables (Bunte and Roza, 2007: 9). The EU subsidise the tomato processing industry through a quota system provided the industry paid minimum prices to growers (Bunte and Roza, 2007).

Modern tomato processing is carried out in large factories handling very high volumes of tomatoes. They typically operate 24 hours a day during the tomato season.

Harvest: Generally, the whole field is mechanically harvested in one go, when the fruit are at optimum ripeness. The harvester automatically separates out stems, leaves and green tomatoes.

Delivery: Tomatoes are delivered to the processing facility as soon as possible, often within hours of harvest. Tomatoes are graded for suitability and to determine payments – tested for colour, taste, mould level, disease etc.

Sorting and cleaning: Tomatoes are washed and any remaining roots, stems and leaves are removed manually alongside tomatoes of substandard quality.

Pulp production: Tomatoes are crushed and heated to form a course pulp.

Hot break / cold break: The pulp is heated to one of two temperatures. Hot break takes place at 98-100°c, denaturing enzymes that break down peptide chains and resulting in a more viscous paste, but at some cost to flavour. Cold break processes happen at around 60°c leaving the enzymes functioning to break down peptide chains, meaning a less viscous paste, but with slightly better flavour.

Finishing: The pulp is put through screens that remove skin, seeds and pulp.

Evaporation: The juice is thickened, generally using a vacuum evaporator.

Packaging: The paste is sterilised and rapidly cooled, and packaged depending on final destination.

Facilities will often produce other tomato products in addition to paste, for example canned whole tomatoes, chopped tomatoes, tomato sauce or tomato juice.

In order to produce tomato paste a specific tomato variety is normally used namely Roma, this variety can be grown and ripened outside and is dependent on the climate of the country where it is grown, for this reason it is not suited to the UK climate as the temperature and sunlight would not be sufficient. These are also not a variety of tomatoes that could be grown in greenhouse conditions. This poses particular challenges concerning the production of tomato paste in the UK.

Each of the seven feasibility studies which made up the LNN project employed a combination of the two case studies and two exemplar products in order to develop assessments of the feasibility of RDM in food production in the UK. However the way in which they did so varied between feasibility studies. For example the policy and society feasibility studied looked at the possible impact that support from public procurement might have on RDM in Oxford while the energy feasibility studies primarily focussed on the likely impact of the RDM on bread production. Some of the reports focussed in more depth on technical questions, this was particularly the case of the study examining engineering technology and systems which focussed on the likely impact of different technologies for the feasibility of RDM in the food sector. The varying ways in which the different projects employed the case studies makes the drawing of direct comparisons between the studies challenging. In order to do so in the next section of the report attempts to summarise some of the principle findings of the different projects as they relate to these exemplar case studies and projects.

6. Main findings

6.1 LNN Food Feasibility Report

From a basic review of the literature the food feasibility report found that little work has focused on what RDM means for the food sector. This report therefore both highlighted the existence of this gap and sought to address it by providing an initial scoping of RDM for food, the extent of concentration within food manufacturing, the potential drivers of RDM, and the outcomes that it might bring.

The study identified the complexity associated with defining RDM in relation to food. Making the point that in the current food manufacturing landscape, RDM could, and indeed is very likely to be, be interpreted in multiple ways. The report also highlighted the complex role played by demand on the question of RDM in the food system. The artisan food sector for example is very much dependent on middle class consumers with relatively high disposable income. Such consumers are partly responsible for the growth in such phenomena as veg boxes and farmers' markets. This shows the extent to which consumers have driven certain forms of redistribution of production within food systems. However, whether this redistribution falls within the RDM paradigm is open to debate. What is clear is that RDM in food cannot be understood in terms of a direct like-to-like replacement of mass produced products with local alternatives. RDM in food also depends on shifting tastes which create the demand for different products which can be sourced and produced locally. Again a food systems approach offers the possibility of taking a broader overview of how varying needs (nutritional, economic, social and cultural) are currently met through the production and consumption of a varying assortment of food products and of the dynamics through which change in this system occurs.

The study also revealed the extent of the challenge posed to efforts to achieve RDM in the food sector. Focussing in particular on the city of Oxford with its relatively high proportion of affluent, educated and middle class people and vibrant local food culture as an example, the study confirms that the bulk of oxford's food is not produced locally (perhaps 1% is locally processed). The study of exemplar products reinforces this view and highlights some of the ambiguity surrounding the concept of RDM in the food sector. The manufacturing of bread, for instance, is dominated nationally by three key firms that between them control 80% of the volume of production and produce bread in a series of regional plants. At the same time bread is also a product for which home and artisanal production have long been practiced alongside large scale production. There are already home bread-making machines on the market and local artisanal bakeries are gaining in market share, however it is notable that the fastest growing element of bread production are in-store bakeries which are normally found in supermarkets and where production involves the finishing of part prepared products which may be produced in larger regional or national production and distribution centres. Furthermore, it is unlikely that the first part of the bread making process, flour milling, could be performed at smaller scales to any great extent as it is a low-margin bulk product, unlike bread, which has potential to be a premium product with higher margins making up for lost economies of scale.

The food feasibility study suggests that there are more significant indications of social and cultural benefit from redistributed food manufacturing, than of environmental benefit. There is also potential for economic benefit in reconsidering the location of manufacturing so that for example it provides employment domestically rather than abroad, and reduces import dependency. This may be especially beneficial in the global South, rather than in developed economies such as the UK. The study cautioned against the danger of assuming that smaller-scale, more localised manufacturing is intrinsically environmentally and socially preferable. In many cases, larger scale is associated with greater environmental efficiency in manufacturing. Again, the study makes the case that questions concerning RDM in the food sector are very complex. An in-depth approach is needed in order to evaluate the likely environmental costs and benefits associated with producing specific products at different scales and locations.

The discussion of Oxford and bread included in the food report raises important questions concerning the extent to which demand for RDM in the food sector is likely to reverse current trends in food production. What the food report reveals is that RDM in the food industry is likely to be a partial process which is suited to certain processes and products and which is heavily reliant on the changing shape of demand. This suggests that an optimum arrangement for any specific product will vary depending on the nature of that product and the shape that demand takes. Understanding RDM in the food sector means understanding the key drivers of location and scale in food manufacturing businesses. The shift towards larger, more centralised manufacturing across the 20th century has been driven by economies of scale and the growth which support the clustering of facilities around geographical locations with competitive advantage in the agricultural production of primary ingredients. Policies may also operate against smaller actors, by for example creating subsidy regimes that benefit major businesses.

A movement back towards smaller scale manufacturing will depend on different drivers such as changes in the combination of costs in the production process. For example, increasing transport costs may force companies to consider more localised production. Technological and social innovation could intervene to change the economic logic of particular scales – for example new internet technologies may make it possible to “cut out the middleman” between small producers and customers, reducing the cost of local products and making them more competitive with mass production. Regulation and policy could play a similar role, for example by supporting smaller businesses with tax breaks. However as, if not more important are the characteristics of the specific product itself, the nature of the industrial process which is required to produce it and the forms of value vested in the product. A number of key characteristics can be discerned for products that have a high suitability for localised artisan manufacturing. These include freshness, culturally distinction or the ‘authentic’ nature of higher quality products. Yet such values are not in themselves sufficient to support RDM. Authenticity for example, is a quality that is often associated with globally traded products. Further work could explore in greater detail the full range of characteristics that make certain products more suited to RDM as well as attempt to more accurately measure the rate of growth in this local manufacturing sector. Such work would need to identify not only products for which the process of RDM is technically feasible but also the economic and social drivers that would support the move to RDM.

6.2 Energy feasibility report

The work undertaken within the Energy Feasibility Study explored the feasibility of RDM in terms of energy, and existing literature and data were reviewed on the Nexus and the linkages between Energy and Water, Energy and Food etc. A review of existing academic and grey literature and data on energy use for the production of two chosen food products: tomato paste and bread, was undertaken. A detailed study of selected energy system scenarios linked to bread manufacturing processes was also undertaken illustrating the current situation versus a possible future where redistributed manufacturing (RDM) would be more widespread.

The detailed analysis presented in the report focussed on the energy efficiency and emissions profile of bread manufacturing. A study of 13 bread producing sites was undertaken which indicated that if only natural gas technologies were used instead of the current mix of electricity, natural gas and other, overall emissions for the sector could go down by as much as 35% from 570,000 to 371,420 tonnes of CO_2-e per year. If only electricity-based technologies were used, overall emissions for the sector would increase by 87% from 570,000 to 1,071,420 tonnes of CO_2-e per year. This is because technology-wise, although electric ovens are generally more energy efficient than gas-fired ovens, the combustion of gas directly in the plant would produce fewer emissions than electricity generated using any form of fossil fuels, which is more carbon-intensive than direct use of gas. These figures are coarse estimates, and the hypothetical scenarios used in this study were intended to highlight the differences in emissions between using one technology over another. An important conclusion of the research was that the most efficient of the plants studied in both electricity and fossil fuel usage was not a large-scale operation. In this case, efficiency seemed to be linked to optimum technology and practices, not to scale of production. Other findings include the possibility of energy savings if technology for the optimisation of flue gas was widely used in the UK's bakery sector. Energy savings of up to 4.7% could be achieved simply by improving ventilation in ovens, which in the UK's bakery sector could mean a reduction from 1,440 GWh gas energy down to 1,372 GWh used by the sector. Furthermore, the analysis concluded that energy savings of up to 528 GWh per year in the UK could be achieved by avoiding bread wastage, which represents approximately 1/4 of the current total energy used in the sector (2,000 GWh as per the Carbon Trust (2010)). Also, some energy estimated to be up to 198 GWh could be generated using anaerobic digestion from 660,000 tonnes of bread wasted in the UK every year. This represents approximately 10% of the current total energy used in the sector, and in addition fertilizer could also be produced out of the digestate.

Based on the findings above, a series of scenarios were modelled to analyse energy consumption and emissions for the bread manufacturing at different scales in the UK. A benchmarking scenario was first modelled that represents the current situation in the sector with an estimated 98% of all bread consumed in the UK being produced in the industrial sector, and 2% of bread assumed to be produced at local level in medium to small scale plants and artisan bakeries (1.5%) and at home (0.5%) using current technologies. These were referred to as RDM -medium / artisan scale, and RDM -home scale scenarios respectively. The current situation scenario was then compared against a scenario where 20% of the UK's bread would be produced at local level by either RDM at the medium / artisan scale, or RDM at the home scale, or by RDM using the best available technology available as reported for site 4 above.

The detailed analysis shows that if 20% of the UK's bread was produced at medium / artisanal and home level, the energy used and associated emissions produced annually would increase significantly compared to the current situation where only approximately 2% of bread is baked at local scale. This increase in energy use would be the result of using less efficient technologies at local bakeries, and especially in homes to produce up to 20% of national bread production. Emissions would also increase significantly, although industrial baking would still be responsible for the majority of energy usage and emissions produced in the sector. However, improvements in energy usage appear possible if bread production was localised, but only if optimum technologies were used.

When considering the average power or demand (in GW), as in the rate of energy used in a period of time (a year) for the different scales, the analysis in this study shows that if 20% of the UK's bread production was decentralised at the local level by using RDM -medium /artisan bakeries and RDM –home baking, the average energy demand and associated emissions for the bakery sector would increase. However, significant reductions in overall energy demand of up to 0.123 GW could be achieve for the sector if using RDM -optimum technologies similar to that already employed in a highly efficient middle size bakery plant in the country.

Finally, based on limited data collected during site investigations, some estimates were calculated to illustrate the potential for renewable energies at local level. This exercise suggests that one of the local mills visited around Oxford can generate up to 17% of their energy needs using a local hydro power generator on one of their sites. Similarly, the newly installed solar panels on a small combined bakery facility and shop near Oxford produced approximately 11% of their energy needs. It was noted through site visits and interviews, that proximity to rivers and limitations in river flows for hydroelectricity generation, as well as limitations in roof-space for solar energy could make these options more attractive for the small localised manufacturing scale than for the large centralised scale.

In summary the scenarios employed in the energy report to assess the likely energy impact of redistributing the manufacture of bread to the local level suggest that a change from the current situation in which 98% of bread is produced in larger bakeries and only 2% is produced in local bakeries or at home. To a new situation where 80% of bread is produced in larger bakeries and 20% of production is produced in local bakeries or at home employing current technologies would result in a significant increase in the energy required to produce the country's bread. In addition there is likely to be a slight increase in emissions under this scenario. However if local production was based on the technologies employed in an energy efficient medium sized bakery (analogous to the best performing bakery in the national study) then there would be a significant reduction in energy demand. It may also be possible to reduce the energy requirements of locally based bakeries through for example mini hydro or solar installations, though this would be heavily dependent on these sites possessing access to water resources or pace for solar panels. Thus from an energy point of view RDM would only contribute to reduced demand if it involved the development of highly energy efficient local bakeries and home baking equipment. However whether such a situation could be economically feasible is open to question. In addition such a situation would require an enormous co-ordination of multiple actors involved in baking bread in the home and in small scale artisanal baking. This suggests that, from the point of view of energy efficiency and emissions reduction there is an at best weak case to be made for RDM in the food sector. Rather the report suggests that different scales produce better energy outcomes for different processes, the question of which scale works best depends on the characteristics of the specific process involved.

6.3 Water feasibility report

The water report undertook a detailed examination of the water feasibility of RDM in the food sector. The purpose being to identify the potentials, bottlenecks and constraints of the water sector for local food production at regional and city level. The different steps in food production and manufacturing for bread and tomato paste were particularly analysed and water demand and availability were investigated in the context of local food production in the UK and specifically for two case studies of the project (i.e. Oxford and Northstowe in Cambridgeshire).

The study itself included a number of elements. A literature review was undertaken related to food-energy-water with a particular focus on water. The features of the case studies, Oxford and Northstowe were then outlined and used to identify the potential of water resources in each area and the likely demands that the development of local food production and manufacturing would pose to water resources in both locations.

Water availability and land use required for cultivation and processing were also evaluated in both case studies.

The third main element of the water feasibility study focussed on the local production demand and required water quality for the manufacturing/processing of the two exemplar products bread and tomato paste along with potentials for water saving and improving efficiency.

The analyses of the water footprint and demand at different steps of tomato cultivation and processing showed that 99% of water is used for primary production. Nevertheless the results indicate that the water footprint is considerably smaller in the local production case as compared with imported tomato paste. This could have potentially positive impacts on the water-energy nexus in tomato paste production. The analysis thus suggests that there is some potential for water conservation and energy efficiency measures for tomato paste. These could in turn result in economic benefits from reduced energy costs and significant environmental benefits from the preservation of groundwater resources and reduced wastewater discharge. However, the energy and carbon footprints of tomato cultivation are would be quite large in local heated greenhouses, although this is partially offset by the energy savings resulting from reduced transportation. This exemplar reveals the benefits of considering simultaneously the impacts of water, energy and carbon footprints on the sustainability assessment of local food production. Highlighting how gains in respect of one dimension of the WEF Nexus

The analysis of the water footprint of wheat based bread production was also explored at different scales in the UK and compared with values in the world. Water is a primary ingredient for all steps of bread production although water used in agriculture for wheat cultivation accounts for over 95% of lifecycle water use in bread production in the UK. The water footprint for wheat bread in the UK is 522 m^3/tonne which is around 3 times smaller than global average (1608 m^3/tonne) due to the high wheat yield in the UK. Oxfordshire's wheat bread water footprint is close to the national average (524 m^3/tonne) whereas Cambridgeshire has a slightly lower value (505 m^3/tonne) of the UK average. During the milling process, water is added to soften the wheat, making it easier to process. Based on the information collected from the two mills in Oxfordshire, the amount of water used within the process is approximately 1% of total wheat by weight. For baking bread, water is combined with flour to form a dough, accounting for the second most important ingredient by weight (i.e. around 36%) after flour. While water is the second most important ingredient of bread making process, the total water used in baking bread is insignificant. Due to the relatively low cost of water in Oxfordshire (around £2.5/m^3) and Cambridgeshire (around £3.5/m^3) as well as the acceptable quality of water, domestic (mains) supplies are the main source of water used by bakeries and mills and preferred to other alternative water sources. Regardless of small water bills reducing water use may offer a number of benefits especially for local factories. Water savings for of around 30%

could be achieved. There are is some potential for reducing water use in the bread making processes (e.g. warewashers). The main benefits of reducing water use in bakeries would be 1) reduction of water use and thus water bill; 2) reduction of sewage discharge and hence sewer charges because most water companies calculate those charges as a percentage of the metered water use; 3) reduced energy use and consequent energy bills. Providing raw water from alternative water sources (e.g. rainwater harvesting and groundwater abstraction) for replacing some water uses has some advantages (e.g. financially), but also have some implications for energy and environmental impact. For example, acquiring supplies of clean, locally sourced water (as distinct to mains drinking-quality water), would require pumping, collection and treatment before use. These steps are energy demanding when compared with mains water and associated energy impacts.

In summary while the water study found that from a water perspective RDM of some elements of RDM could result in a marginal improvement in water supply these benefits would need to be offset against additional environmental and energy costs of securing water from local resources (particularly the embedded energy in the use of locally supplied water). When this is taken into account the extent of the benefit to be derived from RDM may be limited. The most effective and economically efficient way of meeting the water requirements of small scale producers of bread would be through the provision of water from existing domestic supplies while the scope for tapping into alternative local supplies for these small scale producers is limited. By contrast somewhat larger scale producers might be better placed to exploit such alternative sources. Thus as is the case for energy the water feasibility study found only limited evidence to support the idea that RDM in the production of bread would lead to greater efficiencies in the local WEF nexus. Rather the evidence presented in the report suggest that some changes in scale at which production takes place could yield some efficiencies, however from the WEF point of view the optimum scale for particular processes is varied and is related to the specific characteristics of the process itself.

6.4 Business feasibility report

The business feasibility study developed a research agenda around the RDM for the food value chain, focusing on how RDM could affect local production, resources available and support for the local economy and communities through the potential to contribute to the idea of 'shared prosperity' between business and community and between human society and natural ecosystems.   The main research aim of the study was to identify the business opportunities for, and constraints of, relocalising food processing. Using tomato paste and bread as exemplars through which to explore the opportunities for, but also the bottlenecks of, shortening the value chains of processed food products.

The literature review examined the development of national and local food chains in the UK and the multiple dimensions that affect the sustainable provision of foodstuffs. Taking into account a range of concerns including: economics, social, human health, and environmental and ethical sourcing. The literature review echoed the findings of the water and energy feasibility studies. When adopting a value chain approach, relocalising food manufacturing is desirable and possible but only for certain components of the value chain. While redistributed manufacturing (RDM) has the potential to open up new possibilities for both existing and new players within the food supply chain, its full potential and implications are not yet well understood in any area of manufacturing.

A number of challenges present themselves to RDM in food including maintaining supply for mass markets, ensuring the optimal use of resources and the need for high-end value products. A key driving factor of whether business will engage in RDM will be: the cost of investment and the expected returns. Businesses evaluate whether RDM offers benefits and creates value whether this is economic, social, or environmental. A detailed consideration of existing food supply chain actors in Oxford seems to suggest that the food processing sector is quite localised already. Among businesses there is a widespread recognition of the merits of locally sourcing products. Local suppliers are viewed as more reliable, better quality and quicker to respond to demand. Firms are also aware of the benefits of trading locally. However, despite the benefits, firms seem more interested in expanding their local network of customers than of suppliers, albeit that in both cases this is the view of a minority of firms. In short while the re-localisation of food processing seems to be on the table for businesses it is not seen as a priority.

A consideration of two exemplar products, bread and tomato paste demonstrates how RDM creates specific opportunities and challenges in the case of specific products. In the case of tomato paste RDM would require localising a European / Global product. This poses even greater challenges than relocalising a nationally produced product. Key challenges include the lack of suitability of the crop to the UK climate, which would require all tomatoes to be sourced from the global market with implications for the cost of transport and the resulting environmental and energy costs, and lack of infrastructure for manufacturing. A localised tomato paste business would also require training a workforce as well as developing standards, supply chain arrangements and so on. As a result the report concluded that the RDM model is unsustainable for tomato paste and presents a good example of how products need to be carefully selected before presenting any business case for RDM.

There are viable opportunities for RDM in the bread sector, whereby RDM could co-exist with the current centralized mode of production for milling, dough manufacture and baking. However, there are a number of key challenges:

- Wheat processing, essentially milling (and associated quality control aspects) has become centralised.
- Bakeries also highly centralised.
- Re-localisation of bread making would also require re-localising wheat production in some regions. This would have implications on land use in these areas.
- Upscaling and replication of small scale millers and bakers to deliver more output to the local area.

In relation to the bread supply chain, the process of bread offers the greatest promise from both the RDM and WEF nexus perspectives. Currently, bakeries are highly centralised and are able to produce industrialised bread at low cost due to economies of scale. Small local start-ups are unlikely to be able to compete on the basis of cost; however other aspects of the product such as freshness, customised portions (i.e. less waste) and personalised ingredients (e.g. linked to health issues) might require smaller production runs and command a higher price. RDM can thus offer some opportunities for small producers to manufacture products potentially leading to a re-shaping of the bread supply chain, bringing the product closer to the consumer. These local supply chains would co-exist with, rather than replace, the current value chain. This would also require business to recognise the environmental and social components of the value proposition, i.e. a triple proposition. In many respects and as was illustrated in the food feasibility study this model is already in place, small bakeries do co-exist alongside larger bakeries producing smaller batches of products which appeal to specific consumers and sell at a premium. Whether this model can form a template for wider RDM is not explored in the report. However such developments would be driven changing local demand and the capacity for such small operations to develop a sustainable business employing this model.

The business report thus highlighted the important role that demand plays in RDM in the food sector and pointed to some of the trends that may lead to changes in the shape of demand in the bread sector. It is, for example, becoming feasible for customers to order specialised breads to their own particular dietary requirements or to suit their taste preferences. Innovations in the development of life stage nutrition and the need to develop nutritional based products are also influencing the shape of demand. RDM could assist in future developments in this area enabling bread producers to customise their products to the nutritional needs of individual customers. Further work needs to be conducted as to the business case for such enterprises and how they would co-exist with the current niche products available. Further work focusing on consumer behaviour would also need to be undertaken to explore the production cost of these customised breads and whether consumers would be willing to pay for these products.

The report identified other possibilities for RDM in the wider food sector. These include micro food manufacturing, producing customised orders on the streets, at venues (e.g. (food) festivals, farmers markets, service stations etc.). This could potentially in the distant future involve 3D printing if there is consumer acceptance of the technology for food and the cost of production is viable. Other less technology based alternatives using RDM could involve using fresh ingredients, whereby customers use an app to place an order for hot dinner to arrive at a certain time at their house, this is made on-demand in local RDM food factory and delivered straight to the customer, this system could allow customers to pick ingredients etc. and could be beneficial to those with food intolerances. Fruit and vegetable box schemes could also offer another alternative for delivering locally manufactured produce. Again such possibilities reflect current trends in the food sector and the growth of on-line food ordering services which could serve as a blueprint for such

In summary the report found that while local food is a well-researched topic fewer studies explore local food in terms of food manufacturing and, in relation to the concept of RDM, little research has specifically focussed on the production of food. This is an area which requires further research. The business report found that when considering available resources it is currently not feasible to re-localise the production of tomato paste confirming the findings from the Food feasibility report. In terms of bread, re-localising the entire bread supply chain may not be feasible, but there are opportunities to re-localise parts or all of the value chain depending on the product (e.g. artisan hand-made bread, local bakery with baking on-site), or having local farmers produce wheat, milled locally and then baked locally. Again this result adds further emphasis to the need for re-localising in the food sector to proceed with reference to the specific characteristics of particular products and of stages in the production of these products. The report also draws attention to the need for moves toward RDM to explore the commercial, as well as technical case for RDM. For example, while RDM could provide opportunities for more advanced milling and baking procedures using technologies which are economically viable for small production runs the business case for such innovations has yet to be made. Thus again it is the case that the business feasibility report found that RDM of food requires careful consideration, as there will be economic, social and environmental trade-offs. What the report suggests is that rather than full RDM there is scope for partial RDM whereby certain steps in particular supply chains could be relocated. In doing so it is necessary to consider not only the impact of such re-localisation on the local system but also on wider global systems. The suitability of RDM in the food sector is dependent on each specific product and will vary from one location to another and therefore requires individual evaluation taking into account economic, social and environmental benefits and costs in each case there must be;

- Available resources in order for businesses to invest in RDM. These resources extend from environmental e.g. water, land; labour with the necessary skills to carry out a job within RDM,

- A market demand for the product whether this is the local market, national or international markets.

- Available and affordable technologies.

6.5 Policy and society feasibility report.

The aims of this report were to identify the barriers and potentials for the localisation of public procurement for sustainable local development. This consisted of a literature review of both the barriers and potentials of public procurement localisation that supports local production systems and supply chains, together with a more in-depth and focused approach to the issues by focusing upon the county of Oxfordshire undertaking selected interviews with key actors and experts in the field.

Public sector food and catering purchases accounted for around £2.4bn (around 5.5%) of the food service sector in 2012 (DEFRA, 2014) or under 2% of overall purchasing of food in the UK. This purchasing is highly fragmented. In 2006, Deloitte (2006) estimated there to be over 30,000 public sector organisations in England and Wales that place orders for food on a daily basis. Despite this fragmentation, in many local contexts public procurers remain among the largest purchasers of food in the local area. Between 2002 and 2008, policy support for sustainable and local food procurement grew, including the development of the Public Sector Food Procurement Initiative (PSFPI) which followed the World Summit on Sustainable Development in 2002. This impetus was reflected in a number of important Government policy agendas, most notably on efficiency, public health and nutrition, and sustainability, together addressing the public sector's wider and longer term impact on the environment and economy.

Since 2008 and following the global financial crisis the climate in public procurement has swung away from local procurement. Food procurement managers have been faced with staffing cuts and changing roles and responsibilities, mounting budgetary pressures and a growing array of performance targets in relation to nutritional standards, animal welfare and food safety. Procurement managers, particularly within England now need to be highly motivated and bold to introduce any additional non-statutory contract criteria (e.g. local and sustainable meal content). At the same time key staff, who may have been drivers of local procurement have been lost further denting movements towards local procurement.,

Furthermore over recent years a number of studies have questioned the assumption that re-localization is critical in achieving more sustainable food systems. From an environmental perspective, food re-localization potentially reduces food miles but it may place unsustainable pressures on local water and energy resources (see for example Sonnino and McWilliam 2011). This question also surfaces in the energy and water feasibility studies undertaken as part of this study which raise doubts as to the extent of the WEEF nexus impacts of food RDM. Even whether re-localisation would result in significant reduction in food miles is open to question. The scale of weekly demand for meals coming from large public sector sites such as acute hospitals and prisons afford chilled food manufacturers the opportunity to load several thousand meals on a delivery to a single site resulting in tiny fractions of food miles per meal associated with meal delivery. There has been a shift in academic discourse away from the benefits of short food supply chains and localised food networks towards emphasis on improving food quality and access to ‘good’ food.

This creates a challenging context for those responsible for public procurement in which the desire to source locally must be balanced against other constraints. Furthermore the majority of the public sector has remained unaware of which standards to buy to and consequently, different standards and approaches are used. This scattergun approach fails to use to use the purchasing power the public sector has, and fails to give a clear and consistent signal to the market of what it’s looking for (Defra, 2014). Nevertheless the public sector through national governments and agencies and organisations at a local or regional level have the potential directly to encourage, enlighten and enforce more sustainable procurement through their publicly funded power of purchase and by encouraging their suppliers to procure more sustainably. This could in turn be expected to influence the behaviour of some of their clients (pupils and parents in the case of school meals, patients in the case of hospitals, etc.). It is important to note therefor that public local procurement could be one small part of an integrated strategy to develop sustainable local food markets.

A handful of catering service providers and ready meals producers dominate the provision of manufactured food to the public sector in the UK. Public procurers could potentially place higher demands on these suppliers in terms of their local manufacture of food or their sourcing of local food produce and products. This strategy could be encouraged in the public food procurement market.

In summary the report suggests that while public procurement is a relatively small component of overall food consumption. Public procurers are often among the largest purchasers of food within local economies. While the potential of public procurers to positively contribute to the development of the local food sector through local sourcing has been asserted in the past, since the onset of the financial crisis there has been a reduction in the capacity of those charged with the direction of local procurement to source locally. Moreover there is some evidence that suggests that the extent to which local public procurement contributes to making the food system more sustainable is limited. Further research and a renewed commitment to local procurement in public policy would be needed to support the sourcing of more food locally.

6.6 Systems feasibility report.

The systems study built on earlier work done within the project which evaluated food, energy, water, business and policy aspects separately adding a new layer of research from a system perspective. The systems report employed a range of metrics related to the WEF in order to evaluate the costs and benefits that accrue from RDM in food. In particular, the study employed life cycle analysis (LCA) and material flow analysis to provide insights into the amount of resource use in the complete supply chain. These insights were used to consider whether localised food supply chains offered advantages in terms of resource efficiency.

Taking the case of bread as an example the study found that localising food production creates challenges and opportunities. While the use of bio-physical resources such as land, water and energy consumption decreases under RDM, the socio-economic resources labour and production costs increase. Considering the more general relevance of these findings to RDM in relation to food more generally, the increased use of socio-economic resources holds in general; however, the decrease in the bio-physical sphere strongly depends on the specific food product, local water footprint and crop yield. Since food products are very diverse, each product would need careful consideration to evaluate the feasibility of producing the product locally.

In summary therefore the study further illustrates that assessing the pros and cons of an alternative food supply system is complicated and time-consuming. Designing and optimising a food supply system from the WEF nexus perspective is a particularly complex task if factors from the physical, socio-economic and policy layer are taken into account. This notwithstanding, exploring the feasibility of RDM from a whole system perspective identifies opportunities for RDM, however in the short term the RDM business model is unlikely be able to compete on a price basis with mass manufactured food products. Rather the study confirmed that RDM produced foods need to focus on the other benefits that RDM offers to consumers to make a business case and justify higher prices. These include better quality food (e.g. fresher and healthier) In the long term, technological innovations such as smart robotics could change the economics of local food manufacturing, helping to reduce the cost barrier however the extent to which such technologies impact on the features that differentiate local foods from other mass produced products needs to be considered. From the policy side, the evidence suggests that RDM of certain food products does provide benefits for a region as a whole (e.g. more employment, better environment, less pollution, better health, less spending on health care). Thus, seen from the perspective of the whole system, certain significant benefits can be ascribed to RDM in the food sector. However, many of these benefits accrue to society as a whole rather than to the individual consumer. The systems report thus points to the broader role that RDM can play in delivering public goods. This suggests that there may be a strong case for public policies to support for RDM of certain foods through, for example, policy measures to tackle energy price differences for large and small energy consumers in order to create a level playing field.

6.7 Key learning

As the findings outlined above demonstrate, the various studies that formed part of the LNN drew very different conclusions concerning different aspects of RDM in relation to the food sector. In general however, all of the studies illustrated the complexity entailed in seeking to evaluate the likely costs and benefits of RDM in a diffuse and complex field such as that of food production. The reports suggest a rather mixed outcome, while some of the reports pointed to potential benefits to be accrued from the redistributed manufacture of food many also pointed to the fact that RDM is likely to have detrimental as well as beneficial impacts on the local WEF nexus. Furthermore gains in any one of the dimensions of food energy and water security, may in many cases have adverse impacts on others. Collectively, the reports caution against any over simplistic assumptions about the contribution of RDM in the food sector and sustainability. RDM of any particular food product is likely to have its own consequences in terms of water and energy usage which may have different impacts at different scales. Careful consideration needs to be given to the likely impact of RDM on a case by case basis. Considered in this light it may be the case that RDM may have favourable impacts in the case of certain foods and detrimental effects on others. While somewhat beyond the scope of the study RDM may benefit localities in socio-economic terms through for example the creation of employment locally or the retention of wealth generated within local economic circuits. It is notable too that some of the gains take the form of public goods. It may be the case that appropriate state interventions would be needed if RDM is to be effected, and these benefits secured. Among the key learning that comes out of the project is:

1. RDM in food cannot be understood in terms of a direct like-to-like replacement of mass produced products with local alternatives. This points for the need for significant changes in demand if RDM is to be successful in food manufacturing.

2. There are more significant indications of social and cultural benefit from redistributed food manufacturing, than of environmental benefit.

3. The reports warn against the danger of assuming that smaller-scale, more localised manufacturing is intrinsically environmentally and socially preferable.

4. An in-depth approach is needed in order to evaluate the likely environmental costs and benefits associated with producing specific products at different scales and locations.

5. RDM in relation to food is complex and is very likely to be, be interpreted in multiple ways. An optimum arrangement in terms of the scale at which production for any specific product will vary depending on the nature of that product and the shape that demand takes.

6. RDM in the food industry is likely to be a partial process which is suited to certain processes and products and which is heavily reliant on the changing shape of demand. Work is needed to identify not only products for which the process of RDM is technically feasible but also where economic and social drivers would support the move to RDM.

7. From a resource point of view (energy and water) there is little evidence that RDM per se would contribute to reduced demand. Moreover there is evidence to suggest that RDM could increase local demand for resources unless additional measures are taken to ensure improved resource use efficiency. However whether such a situation could be economically feasible is open to question.

8. RDM can offer some opportunities for small producers to manufacture products potentially leading to a re-shaping of some supply chains, and bringing the product closer to the consumer. These local supply chains would co-exist with, rather than replace, the current value chain.

9. While the potential of public procurers to positively contribute to the development of the local food sector through local sourcing has been asserted in the past, since the onset of the financial crisis there has been a reduction in the capacity of those charged with the direction of local procurement to source locally.

10. The business case for RDM in any particular product will depend on

11. Available resources in order for businesses to invest in RDM.
12. A market demand for the product.
13. Available affordable technologies.

14. In whole system terms RDM in foods generally leads to increased use of socio-economic resources. Any impact on the bio-physical sphere strongly depends on the specific food product, process, local water footprint and crop yield. Since food products are very diverse, each product would need careful consideration to evaluate the feasibility of producing the product in a redistributed way.
15. Many of the potential benefits of RDM in the food sector take the form of public goods or benefits that accrue to localities as a whole rather than individual firms or consumers. Where such public

goods justify the development of RDM it may be the case that supportive policies are both needed and justified to ensure the delivery of these wider societal benefits through food RDM.

Overall, the reports present a rather mixed picture of the potential role of RDM and of its impact on the Local WEF food nexus while on the one hand they identify some potential for RDM to reduce the demands for water and energy resources these are often based on local food producers adopting technologies and practices which may currently be cost prohibitive or which in some cases can be adopted much more easily by producers working at larger scales. The reports do however identify certain opportunities where RDM could be adopted in the food sector. In many cases these niches represent developments of existing trends within the food sector with at best limited impacts on the Water Energy Food Sector. Furthermore some of the reports strongly point to the areas where studies do strongly emphasise is that RDM in the food sector is offers different potential outcomes in relation to the WEF nexus depending on the particular characteristics of specific products and processes. Rather than RDM the project illustrates that food production at different scales can have different impacts on the WEF, and that taking such impacts into account could play a useful role in assessing the relative costs and benefits of production at different scales for different food products.

7. Gaps in evidence

7.1 Understanding the dynamics of local food

To date what is meant by local food and sustainable food remain at best fuzzy concepts. In the absence of workable definitions to define either local or sustainable then academics and policy makers are faced with a considerable field of ambiguity in relation to local food. This uncertainty is further increased in talking about RDM in the food sector since what constitutes manufacturing in the food sector is itself a concept upon which there is little agreement. The fuzziness that surrounds concepts of local food feeds uncertainty and makes it difficult to accurately assess the costs and benefits that accrue from initiatives and policies to promote locally sourced food. This in turn may pose problems in relation to efforts to implement policies to promote local food. In the case of public procurement for example anecdotal evidence suggests that in some cases procurers have been able to exploit their asymmetric knowledge of both potential food suppliers and public sector meal consumers' demands to deliver essentially token changes to their purchasing arrangements in order to achieve poorly defined quotas or targets. Moreover, and as the LNN project illustrates different definitions of local food create significant challenges to researchers in attempting to "measure" local food production and consumption.

There is a need for fundamental work to develop an understanding of what is meant by such terms as local, redistributed and artisanal food and of the relationships between these concepts. It is suggested that such an understanding needs to locate various styles of food production within the broader food systems of which they form part. Such work needs to not simply define local food as an objects but illustrate the role it plays in the dynamic processes through which food needs (nutritional, social, cultural and economic) are met on an ongoing basis. Such work needs to understand local food processes as a continually changing dimension of food systems and devise means for conceptualisations how changes in these dynamics impacts on the Water Energy Food Nexus at different levels.

7.2 Developing criteria for assessing the societal costs and benefits of RDM in food production

This report demonstrates that it is impossible to say a priori whether smaller scale manufacturing would improve food safety or nutrition without comparing very specific cases. As already mentioned above the analysis of RDM and its impacts on the WEF nexus undertaken in the course of the LNN project indicates that the likely impact of RDM on resource use is neither wholly good nor wholly bad. Different resources are impacted in different ways by moves towards RDM. However while the analysis presented in the LNN may not support a significant shift towards smaller scale food manufacturing under current conditions, there may be a case to be made that such a shift would provide societal or environmental benefits and thus should benefit from policy support. There is a need for a comprehensive approach to the question of measuring the impacts of location and scale in food manufacturing taking into account not only the environmental considerations explored in the LNN but also the wider societal impacts of any move towards RDM. Such a study would need to develop a comprehensive set of indicators through which the likely costs and benefits of RDM are to be assessed. As a starting point for future research, 7 factors are listed below that this early stage research suggests might warrant particular attention going forward:

1. Regional economic development

2. Food security

3. Food miles

4. Energy use

5. The human economy

6. Nutrition

7. Development impact

Further work is required to better define these key areas of societal impact affected by scale and location in food manufacturing. However, an initial review leads to the conclusion that impacts do not unambiguously point in the direction of either larger- or smaller-scale manufacturing offering net benefits to society. Instead, a picture of trade-offs emerges where the appropriate scale of manufacturing depends on what outcomes are desirable within any given context. If the generation of social capital and cultural value take prime position, it may be that smaller-scale manufacturing is most appropriate; whereas if energy efficiency is a key concern perhaps a larger better-capitalised factory is best placed to deliver it. If reducing food miles is the aim then smaller and more local may be better. However this is not necessarily the case, efforts to assess such assertions are required and these will in some cases challenge long held ideas about the relative merits of local food as opposed to that produced in larger scale operations.

These judgements cannot be made in the abstract furthermore, and as is clearly illustrated in the LNN projects, such ideas cannot be made in generalizable terms for all food and drink products. Different products have very different characteristics, leading to different outcomes. There will be benefits from the localisation of bread manufacturing that will not occur in the localisation of tomato paste manufacturing. This point is supported by the findings of GLAMUR, with one of the project's seven key concluding messages as follows:

> *… Scale matters for some sustainability attributes, not for others. In some cases scale improves performance, in others it is the contrary. A generalized, abstract, comparative assessment of 'local' and 'global' food chains as abstract entities cannot be done.* [5]

How society should decide where the balance of scale best lies is a complex problem that veers into political and ethical territory. In this context further research on the development of suitable indicators for assessing the costs and benefits of changes in the location and scale of food production is particularly valuable.

7.3 Evidence of the benefits of local public procurement

In the main and as the results of the Society and Policy feasibility study show evidence demonstrating that local public procurement regenerates communities remains anecdotal at best(Thatcher and Sharp, 2008). While a range of studies have considered the various environmental, social and economic benefits that can arise from purchasing local and sustainable food. Typically such studies have focussed on a limited range of impacts of a relatively small scale sustainable food procurement initiative that have been spatially and organisationally restricted. Studies to compare the relative impact of procuring more food locally and sustainably have tended to have a narrow focus such as reducing food miles or carbon footprints. There is a need to develop robust methodologies to assess the relative cost and value of different approaches to food

[5] GLAMUR's Main Messages. http://glamur.eu/wp-content/uploads/2016/01/glamur-leaflet.pdf

purchasing and food processing which incorporates a comprehensive range of social economic and environmental indicators. In the absence of such tools and the transparency and measurable criteria they would provide, public sector organisations can expect to achieve only modest steps towards more local or more sustainable food procurement.

7.4 Business models for RDM

The Business feasibility in particular pointed to certain opportunities for successful RDM as well as to barriers that are likely to limit that potential. There is a need for further detailed work to explore such barriers and opportunities. Based on the insights generated from the study a range of such barriers and opportunities were identified that may merit further exploration these include;

Industrial symbiosis

Industrial symbiosis in the context of RDM and the WEF nexus may offer opportunities to relocate and integrate various process flows of companies located in the vicinity of each other. Research questions worth investigating further could include:

- Which organisations are best suited to initiate such FEW system optimisations?
- How does such multi-stakeholder project start and evolve?
- How to align the aim of increased resource efficiency with the interests of private companies?
- How could supply chains be reorganised to support industrial symbioses?
- What would be the optimal configuration?

Engineering design tools

Dedicated design tools for the WEF requires still quite some research in order to develop more effective tools. To support changes in industry Practices related questions include.

- How to choose the suitable system boundaries to optimise a particular food system?
- How to deal with the limited data availability? This could be related to the complete lack of appropriate data, different scales at which the data is available (e.g. national vs. local), outdated information and the different resolution (both in spatial and temporal).

Food processing equipment

Due to the large range of production scales already present in food. The food sector is typified a large range of available equipment for different production scales. This ranges from machinery for large scale production to equipment designed for the household level (e.g. bread baking machines, pasta making appliances, blenders, ovens, microwaves, etc.). The lack of equipment for smaller scale production can be seen as an opportunity for RDM in food. Research could usefully address questions concerning access to and the affordability of food processing equipment suitable for different scales of production addressing issues such as:

- Which equipment is required for the processing of food at non-conventional scales?
- How can equipment be supplied?
- Related to possible digital innovation, what are the key design differences for the required equipment compared with traditional equipment?

Technological innovations

Related to the previous question are issues concerning the potential role of technology in food RDM. While new technologies may support efficient production questions concerns their affordability for smaller producers. Moreover, in ways which are highly significant in the food sector there may be a need to address tensions between the possible efficiency gains linked to the introduction of new technologies and the intrinsic value of traditional processes in an industry where artisanal local production often relies on traditional methods. Some of the questions that could be addressed include.

- Which food processing steps could be eliminated by using new technologies so that the supply chain shortens and the possible production location could become closer to the consumer?
- To what extent would such innovations be acceptable to producers and consumers?
- What new skills would be required to successfully adopt such innovations?
- Could new innovations support the integration of food production processes?

Shared services

One of the key limitations facing RDM is the challenge that small firms face in controlling costs as opposed to larger scale firms which can benefit from economies of scale. There is a possibility that RDM of food products could be leveraged by using shared facilities so that small scale companies are still able to enjoy these benefits associated with economies of scale. New businesses could evolve around this theme, offering shared services to local food companies. This could be related to (cold) storage of food ingredients/products, maintenance of equipment, supply of ingredients, legal service office supporting local companies complying with (food safety) regulations or shared insurances to minimise (the cost of) risks. In this context some questions worth exploring include;

- The identification of shared services which could become the basis of a viable business model?

7.5 Food waste and the circular economy

A recurrent theme in many of the reports was reference to food waste and the possibilities that RDM offers to address the challenge of dealing with and/or reducing waste. One example of this from the energy feasibility study concerned the issue of waste bread and spoke of the savings that could be achieved through reducing levels of waste. Smaller bakeries locally located might have a greater capacity to match production to local demand avoiding some of the waste associated with supplying bread through long supply chains,. The same report also made mention of the possibility of converting waste bred into energy which could then be used to reduce external energy demands. Ways to reduce food waste and turning waste into resources offer potential to increase resource efficiency. One of the main barriers is the lack of knowledge concerning the detailed processes involved in converting waste into energy. Increasing knowledge concerning both the technical requirements of such waste conversion and also concerning its real impact on energy demand and how it could lead to synergies among different local processes.

7.6 Data availability for more accurate models

From the feasibility studies it becomes apparent that data availability creates constraints to the actual extent to which various configurations of food supply systems can be quantified. The lack of data is a limiting factor to assess whether local food production systems offer clear benefits. Questions also arise concerning the scale at which data is available and also concerning the geographical areas for which data is made available. It is clearly the case, given the complexity of the questions surrounding the challenges of RDM in the food sector that further work needs to be undertaken concerning the quality of data available and also on the development of strategies for overcoming deficiencies in the data available.

7.7 Demand Side Issues

Taken as a whole, the feasibility studies highlight the central role of demand in shaping the future of RDM in the food sector. This is particularly the case given that RDM in the food sector rarely represents a like for like substitute of one product for another. Consumer behaviour is difficult to understand in relation to the selection of foods where basic nutritional needs are accompanied by cultural and social needs and wants. Yet it is this complex set of needs which drive consumer demand which will in turn play an important role in determining the likely success of RDM in respect of specific food products in particular locations. The evidence of existing artisanal and localised food ventures demonstrated that in certain cases at least sufficient demand exists to render the RDM of food a success, even in cases where a product costs significantly more than a similar product produced by current large scale manufacturers. However a certain air of realism needs to be attached to this observation. Existing artisanal and localised foods make up a relatively small proportion of total foods consumed in the UK. Oxford, a city with a vibrant food culture possibly derives as little as 1% of its food from local production. Significant moves towards greater RDM in the food sector require significant shifts in demand. Achieving such shifts will of course involve marketing. There are opportunities to market RDM of food as "the future of food", "locally sourced and manufactured food", or "local, healthy and fresh, good for the environment, good for the local economy and good for you". However it may be the case that the forces shaping food demand need to be shaped in more fundamental ways. More work is required to understand the determinants of local food demand and how best these can be changed in ways which support the wider consumption of locally produced food.

8. Key Questions for future research

The respective feasibility Studies each produced several questions for future research the key questions are summarised below.

8.1 Food Feasibility Study

Key questions identified through the food feasibility study include the following;

- How has the distribution of food manufacturing changed over time in the UK, both in terms of ownership and geography?
- How will different future scenarios affect the distribution of food manufacturing – for example in a world with much higher transport fuel prices, or different international trade rules?
- How well do the four preliminary categories of RDM proposed in this paper fulfil analytical needs? Can they be strengthened or improved upon?
- What indicators are best used to measure the outcomes of different scales and locations in food manufacturing, and how can they be effectively measured?
- How do drivers and outcomes of change differ across the four RDM types?

8.2 Energy Feasibility Study

Key future research issues identified in the energy feasibility report included;

- Data collection and further exploration of the potential for symbiotic processes to re-use/optimise energy, water and waste/ waste by-products, such as using wasted energy from other industries in milling and baking processes

- Studying the geographical implications of relocating manufacturing facilities (e.g. potential for relocating greenhouses near industries with excess energy losses such as bakery plants).
- Data collection and further exploration of the potential for ground-source heat pumps (especially ground-sourced heat coils under green-houses), CHPs/biomass, energy from waste, solar, wind and hydro in the milling and bread manufacturing sectors.
- Data collection and investigation of the operational emissions and potential for emissions reduction if more solar and hydro were used instead of gas or grid-electricity at local level.
- Investigate energy decentralisation and the role of policy in promoting localised renewable energy sources (e.g. biomass /CHPs, solar, energy from waste, wind, hydro, biogas for villages as exchange for free/cheap electricity)
- Data collection and investigation of the links between potential for decentralised water treatment plants and links to biogas.
- Investigate if efficiencies are possible when using hydrogen for cooking at local scale in UK.
- Further research the implications for energy up and down the full food supply chain (not only focussing in the manufacturing processes, including energy from waste in the studied or other food supply chains).
- Investigate potential for water re-use, and water and energy nexuses for suitable foods and their full supply chain (e.g. upstream water and energy footprints in agriculture, rainwater harvesting from green-houses, grey water/ effluent recycling and heat storage for processing).
- Data collection and calculation of energy savings linked to rainwater harvesting and grey water recycling (e.g. for tomatoes -if possible completing information collected from interviews and fieldwork- and other food supply chains).
- Data collection and study energy savings in relation to economic savings (i.e. savings in emissions and energy bills over a horizon of 20 years if alternative energy sources were used).
- Data collection and study of energy use for bread manufacturing depending on whether flour is milled using domestic and/or small scale local mills (relevant in relation to RDM of bread in the UK if data are available) versus industrial centralised mills.

8.3 Water Feasibility Study

Some key research questions Identified through the water feasibility study include:

- What is the optimum level of water supply from different water sources (e.g. groundwater, rainwater, stormwater, grey water, black water, yellow water) for local food production considering economic, social and environmental factors?

- What innovative technologies are needed to improve efficiency in providing alternative sources of supply?
- What is the best match for water quality between demands and supplies?
- What type of water treatment is required and at what cost?

8.4 Business Feasibility Study

Among the main future research questions identified by the business feasibility study were:

1. How do we create dynamic Business models to take account of: incremental changes that could take place over 5 years; medium term changes 5-10 years; and, long term changes over ten years?
2. What are the trade-offs of re-distributing food manufacturing for the entire supply chain of specific products in terms of economics, social, environmental, and cultural factors?
3. Could re-distributed food manufacturing alter the flow of power across food supply chains and provide opportunity for local and regional economic development?
4. How can re-distributed food manufacturing address the triple bottom line in any business model (firm, industry, or value chain)?
5. Re-localising food manufacturing may enable the re-localisation of other actors within the value chain, what are the knock-on resource effects of this process?
6. What are the effects of changes in the political dimensions of the UK which could affect business decisions in relation to re-distributed manufacturing?
7. How should, or indeed can, RDM be implemented in a low margin sector (not artisanal or specialist products) there would need to be a clear business case in terms of costs and returns on investment particularly for smaller enterprises. How can this be addressed for smaller firms, and what business model is needed?

8.5 Policy Feasibility Study

Key questions for future investigation include?

- What impact can a shift to re-localised meal manufacture have upon
    - Client satisfaction with quality, freshness and taste?
    - Overall levels of food waste?
    - Nutritional content?
    - Flexibility in meal content – allergen content, halaal, calorie count, etc.?
    - Food safety?

    - Food security?
- What is the relative cost and value of different approaches to food purchasing and food manufacture (for the purchasing institution, the manufacturing area, the purchasing area, for the end consumer…) and what tools and measurable criteria should be used?
- What unintended consequences could occur as a food procurement strategies that favoured the procurement of locally manufactured food? (pattern of job loss and gain in food manufacture; changes to less sustainable forms of land use – arable to meat; arable to manufacturing)
- To what extent could support for re-distributed manufacturing of food help to facilitate the success of the healthy eating agendas of public sector institutions?
- To what extent is it possible to assess the value of food as contributor to successful outcomes (such as the impact on attendance and educational attainment in the case of schools; successful treatment outcomes in the case of hospitals) and in turn gauge the contribution of the on-site manufacture of fresh meals to such outcome

8.6 Systems Feasibility Report

Industrial symbiosis in the context of RDM and the FEW nexus offer opportunities to relocate and integrate various process flows of companies located in the vicinity of each other. Although industrial symbiosis is not new and initiatives have often led to limited success, a number of research questions which could be worth investigating further include:

- Given the interactions among multiple stakeholders, which organisations are best suited to initiate WEF system optimisations?
- How does such multi-stakeholder project start and evolve?
- How to align the aim of increased resource efficiency with the interests of the companies involved?
- Could supply chains be reorganised such that industrial symbioses can happen more easily?
- What would be the optimal configuration?

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