The Local Nexus Network: Exploring the Future of Localised Food Systems and Associated Energy and Water Supply

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Abstract. The Local Nexus Network is addressing the intersection of two important emerging research areas, re-distributed manufacturing and the food-energy-water nexus. It is an on-going initiative which aims to develop an evidence-based comprehensive research agenda and foster an inclusive community of researchers and stakeholders for sustainable local food-energy-water nexuses. This paper presents the conceptual framing for understanding the challenges of local nexus, reports empirical findings around a particular case study, and makes initial reflections on the research and practical challenges and opportunities.

Keywords: re-distributed manufacturing; food-energy-water nexus; food system; energy consumption; water footprint

1 Introduction

Historically, human industrial and economic activities have been greatly shaped by the patterns of resource use in favour at the time. For thousands of years pre-1800, material and energy resources, mostly renewable, were extracted and used locally. The widening exploitation of energy-dense fossil fuels, in post-1800 industry has resulted in more centralised production. This is primarily based on geographically concentrated resources which are accompanied by large scale distribution infrastructures. Whilst the scale economies of these large and concentrated systems have served us well in certain respects, continued reliance on centralised resource extraction and production has contributed to the formation of a range of acute issues facing global society today, such as insecurity of essential resources, climate change, and social- and spatial-economic imbalance and injustice.

adfa, p. 1, 2011.

Driven by the desire to improve resource use and broader sustainability in response to the above issues, changes towards 're-distributed manufacturing' have been considered, to explore the future of localised production with indigenous sustainable resources to support the local economy and communities [1]. Among products and services that can potentially benefit from localised production, food represents one of the most essential commodities for every society. Furthermore, it has increasingly been recognised that close ties exist between food production and manufacture (i.e. processing) and energy and water, manifested by (i) the significant energy and water footprints in food production and processing and the mutual footprint between energy and water systems (e.g. [2], [3]), (ii) their intertwined connections with land and broader ecosystems, and (iii) the potential for more localised sources of energy and water supply alongside local food production. The inseparable challenges from these three sectors, and especially within the context of climate change, have been referred to as the "perfect storm" [4] which require an integrated and holistic approach as opposed to tackling them in separate silos. This understanding, conveyed via the "nexus" concept, has gained momentum in the last few years through several key reports from international organisations such as the World Economic Forum [5] and the UN ESCAP [6] and events such as the Bonn 2011 nexus conference (http://www.water-energy-food.org/).

Studies of food-energy-water nexus in combination with localised production are still relatively rare, although emerging [7]. The Local Nexus Network (LNN) (www.localnexus.org) is an on-going initiative which aims to develop an evidence-based comprehensive research agenda for sustainable local nexuses, by conducting preliminary research to establish an initial framework for understanding this area and to identify the significant research challenges. The project encompasses the important aspects of engineering technology and systems for food processing and energy/water supply, business models and supply chains, governance and whole-system integration. Two case studies, one on a new town (ongoing work, not reported in this paper) and another on an existing locale, have been used to support the conceptual investigation. A schematic outlining the approach is given in Figure 1.

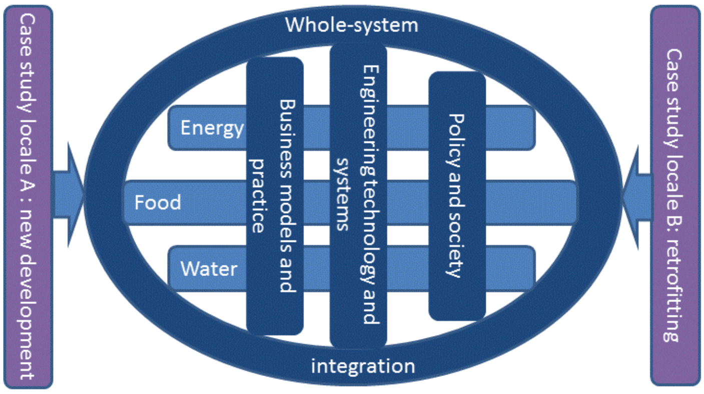

Fig. 1. The overall approach of the LNN.

The purpose of this paper is to present initial results and thinking developed from the LNN so far, including (i) conceptual constructions proposed for understanding re-distributed food systems and the local nexus as a whole, (ii) empirical findings around a particular case study, and (iii) a preliminary discussion on the challenges and opportunities for research and practice.

2 Conceptual framing of the local nexus

Much of the complexity of the food-energy-water nexus stems from the interactions between these systems components. Multiple perspectives, held by different stakeholders and research contributors, add to this complexity, but are all important for understanding and improving the nexus interactions. Therefore, a *multi-layer structure* is adopted by the LNN, as summarised in Table 1. According to this structure, a nexus system can be intellectually approached at three different, yet inter-connected layers, namely 'physical', 'socio-economic', and 'policy and regulatory'. Each layer is characterised by the actors present, activities or processes that take place, flows that connect the actors and activities, and performance indicators that should be considered from the perspective of that layer. While the content of Table 1 is more illustrative than definitive, this basic structure has helped to frame the discussions at various events organised by the LNN.

While the above layered structure can be applied to the nexus at any spatial scale, a separate supply-chain conceptualisation, namely *food system configuration*, was proposed. This aimed to support the analysis of re-distributed food systems and the associated energy and water supply. More specifically, activities in a food system are considered to be distributed around and between two focal points, *farm gate* and *plate*. A food system configuration for a specific food product is characterised in the first place by the geographical location of the activities that take place before the farm gate (i.e. agriculture) and those between farm gate and plate which includes all the manufacturing and distribution processes. Waste processing activities are also included after plate to allow for the consideration of resource recycling and reuse. Relative to the location of plate (i.e. point of consumption), these food system activities may be termed local, regional, national or international. Another important characteristic of a food system configuration is the nature of the plate, i.e. the types of consumption, with distinctions made between household, institutional (e.g. schools, hospitals), and commercial catering. This distinction allows consideration of the differences in volume, variety, and mode of serving which may have an impact on the choice of processing/logistic options and locations.

Table 1. Layers for understanding the nexus.

Layer	Actor	Activity	Flow	Performance indicator
Physical	factory, equipment, vehicles, land/ecosystems	production, transport, storage	material, energy	process efficiency, flexibility, safety; product quality availability/accessibility; environmental impact
Socio-economic	business entities, social entities	business planning and management, trading, purchase	money, information	profitability, affordability, security of supply, social acceptability
Policy and regulatory	policy makers, executers, targets	policy making, execution, evaluation	information	degree of meeting policy goals, maintenance of public goods

3 A case study on bread

Guided by the above conceptual framing, a case study on bread, referring specifically to the city of Oxford, UK where data are available, has been initiated to contribute to the understanding the functions and the future directions of the local nexus.

3.1 Bread for Oxford: the current configuration and its shaping factors

Oxford is a university town in south central England, with a population of 158,000 people (June 2014). Because the food retail market and supply chains are relatively homogeneous and mature in the UK, it is fair to assume that the manner in which food is provided to Oxford is similar to that for the country as a whole: 90% of food retail outlets are ‘multiples’ (i.e. chain stores) with centralised supply and distribution systems [8]. The majority of the remaining independent retail outlets are also supplied by wholesalers using centralised distribution systems. Thus the extent to which Oxford is directly supplied with manufactured foods from local sources (for example, from within the county of Oxfordshire) is likely to be very small, estimated at around 1% by value. This is likely to be through a mixture of independent retailers, specialists such as bakers, co-operative stores, and local markets. That is not to say that Oxfordshire is not a producer and processor of foods – the county does have considerable arable agriculture and is home to a number of large food businesses – however, this food is not destined for consumption within the county.

Within this context, the LNN project has taken bread as an example of a manufactured product to explore in further depth the dimensions of scale and geography in food provisioning for Oxford. Assuming that Oxford's citizens consume bread at the national average rate, it is estimated that approximately 4990 tonnes of bread is sold every year through retail outlets for home use, 210 tonnes of bread is consumed out of the home in the form of sandwiches, and 40 tonnes is used in restaurants and catering outlets [9]. In total this equates to an annual consumption of 6.5 million standard 800g loaves of bread, or 41 loaves per person per year. 78% of the £1.6bn UK bread retail market is accounted for by sliced packaged bread from centralised plant manufacturing, sold through retail chains. Of this plant manufactured bread, 75-80% is produced by three large firms, each of which have around 10 bakeries spread across the UK, producing a variety of baked goods in addition to bread [10]. Thus the main thrust of the bread supply to Oxford can be considered to come from baking facilities that have a degree of regionalisation, but which cannot be considered 'local' to their place of consumption, if the 'local' scope is, as assumed in the case study, limited to the county of Oxfordshire.

In addition to sliced, packaged bread, another 17% of bread (in terms of both value and tonnage) comes via 'in-store bakeries'. These bakeries, often within supermarket outlets, are normally a combination of loaves baked 'from scratch' (i.e. fresh from raw ingredients) and 'bake-off', where a frozen, part-baked loaf from a centralised manufacturing facility is put into ovens locally for the final stages of baking. This 17% may therefore be considered to have a degree of localisation in manufacturing, although the exact split of scratch vs. bake-off is not known. The final 5% of bread by value is from artisanal bakeries where bread is produced on a smaller scale with a lower degree of mechanisation. Because these loaves are often sold for a higher price, artisan baking accounts for only 3% of the market by volume. Thus if it is assumed that scratch baking in store accounts for 10% of the market, then some 13% of bread in Oxford might be considered locally baked.

Besides baking, the other main manufacturing stage in the production of bread is the milling of grain into flour. Although 20% of wheat grain is imported from outside the country, the vast majority of actual milling activity occurs within the UK. Import of grains is considered a technical necessity by the baking industry as wheat grown overseas has a higher percentage of proteins that are critical in baking. Flours used commercially are often a mixture of UK and imported flours, blended to achieve the correct protein level for the customer. There are around 50 commercial-scale flour mills in the UK, producing for both national and regional customers, plus export markets. Although there are a number of commercial mills located in Oxfordshire, several of which sell their products locally, none of them sell to an exclusively local market, thus it is questionable whether they would be considered to be in and of themselves an example of 'local' food manufacture as described above. Nonetheless, craft bakers in and around the city of Oxford do purchase flour directly from these mills, thus constituting part of a local food supply chain. This is reinforced by the local procurement of grain by some of the mills, who have long-term relationships with nearby farmers.

The “local grain => local milling => local baking => local consumption” model is how Oxford would have been supplied with the bulk of its bread up to about 100 years ago. This model began to change with the dawn of the industrial era due to advances in transportation and technology, but also regulatory changes, affording more geographically expansive reach to more distant consumers and markets. The repeal of the Corn Laws (protective tariffs on imported grains) after 1846 meant that by the 1880s up to 45% of Britain’s grain was imported, mostly from North America. But it was not until the mid-20th century that there was a radical shift away from local bakeries towards centralised baking. This dominance was cemented by the widespread uptake of the Chorleywood Bread process after 1965, which allowed the cheap and rapid production of standardised long-life bread loaves using high-energy mixers and the addition of a variety of ‘dough-improving’ substances. Many local bakeries, unable to compete in the face of supermarket price wars, either became consolidated into larger regional bakeries, or closed down due to commercial pressure. A similar process of consolidation has occurred in milling, where four companies with 20-25 mills collectively now account for 65% of UK flour production [11]. Nonetheless, there still do remain local millers and bakers in the UK, although these account for only a very small part of the picture in terms of total tonnage. Seen overall, and compared to other products, the current configuration of milling and baking for Oxford’s bread supply can be thought of as a predominantly regional/national activity, accompanied by a less significant yet visible local portion.

3.2 Possible re-distributed futures

The current geographical configuration of Oxford’s bread system is not the only one imaginable. As described above, bread supply in the past would have looked very different; and in other parts of Europe it still does because of historical and institutional legacies and different food cultures [12]. In France, for example, local craft bakeries have 55% market share, compared to 5% in the UK. In Italy they have 85% market share [13]. In France, although large millers dominate flour production, there are also a larger number of small to medium mills, partly due to historical production quotas restricting expansion. If Oxford’s bread provision looked more like that in one of these countries, what would be the implications? First of all, the city would need many more bakeries, and many more bakers. Given the implied shift from a centralised, highly mechanised process to a more labour intensive style of baking, there would initially be a lack of skilled labour in the city. The high cost of renting appropriate floor-space for bakery units would also be challenging. Both labour and rental costs would be passed on to customers in the form of more expensive bread, so a cultural change is also implied in that consumers would have to be prepared to spend more. In return, consumers would benefit from fresher bread, potentially with fewer of the additives normally used to lengthen shelf life, and potential for a greater degree of social interaction with the source of their food and other consumers. The recent growth in value of the artisan bread sector by 10.8% between 2009-2014, despite the fall in volume in the bread market overall, shows that many consumers are not motivated solely by price [14].

But a French or Italian model, with large numbers of independent artisan bakeries, is not the only way of reconfiguring bread manufacturing. Supermarkets could bake a higher proportion of bread in their stores, either from scratch or using part-baked bread. There could be a single highly automated factory on the outskirts of the city producing bread to be sold through multiple retail distribution channels, bringing localisation but preserving some of the economies of scale found within the current model. At the extreme end of the spectrum, a scenario could be imagined in which a large percentage of the Oxford population used bread makers to produce their daily bread in their own houses. When considering these kinds of scenarios it is questionable whether the word 'manufacturing' truly applies, since it is normally used to refer to large-scale and highly mechanised operations with processed inputs. Nonetheless, a change such as the mainstreaming of home breadmakers would most certainly have a significant impact on the bread manufacturing sector, and there are other examples of more localised production displacing centralised production. Craft brewing, for example, where beer is produced on a small scale with often labour-intensive processes, is now significant enough that larger beer manufacturers feel threatened by this emergent market sector.

The implications of the localisation of food manufacturing activities will differ depending on the precise details of the configuration that is envisaged. For instance, a scenario in which there are more, smaller bakeries than in the current configuration, but where they remain owned by a small number of large companies, will result in very different socio-economic considerations than a scenario in which ownership as well as physical manufacturing facilities are distributed. The key challenge to the viability of redistributed manufacturing of bread remains the ability to compete on price with the economies of scale from large manufacturing plants. For more local manufacturing to compete on price, the costs of distribution (e.g. transport fuel or road taxes) would need to rise to outweigh the economies of scale. Alternatively, a reduction in labour costs relative to the cost of energy needed to run machinery could shift the balance towards more labour-intensive production where fewer economies of scale are possible. In the case of microbreweries, it was a change in the taxation regime giving preferential treatment to smaller brewers that helped to kickstart the growth of a redistributed manufacturing sector, so policy levers could also be employed. Also, it should be mentioned that the competitiveness of price is linked to the wider issue of whether consumers will be prepared to pay more when the economic, social and environmental costs of the current model of provisioning are made more visible.

3.3 Energy consumption and greenhouse gas emissions

Several studies exist on the energy consumption for part or the whole of the life cycle of the production of standard bread in the UK. In a work published in 1980, Beech [15] estimated the primary energy consumption for growing bread wheat to be ca. 4 MJ/kg bread (out of the total consumption of ca. 15 MJ/kg bread for wheat production, milling, baking and keeping in shops), which is significantly higher than 2.5 MJ/kg wheat, an estimate for standard bread wheat growth from a more recent study by Williams *et al.* [16]. The latter work also presented an estimate of 1.7 MJ/kg for organic wheat, which despite the lower yields, higher inputs into fieldwork, and up to 200% more land needed still requires less energy input than standard wheat because of the avoided use of synthetic nitrogen fertilizers.

Among the manufacturing steps, the baking process appears to be most energy-intensive. Beech [15] estimated the primary energy consumption of standard industrial making to be ca. 7 MJ/kg bread. In comparison, the Carbon Trust study [17] analysed actual annual energy data for 13 bakeries, and the following energy intensities were calculated based on the amount of delivered energy a site uses each year and its annual production, with estimates of 551 kWh of fossil fuels (predominately gas) and 218 kWh of electricity, per tonne of product. Assuming a 35% conversion rate from primary energy to electricity, this is approximately 4MJ/kg bread of primary energy, which is very close to the estimate from a European study by Le-bail *et al.* in 2010 [18].

It appears that the more recent studies have shown a greater energy efficiency across the life cycle of bread production, which may be attributed to improvement in technology and practice. More interestingly for re-distributed manufacturing and in relative terms, Beech [15] concluded that compared to industrial baking, energy consumption of home baking could be lower if sufficient oven loading (e.g. 2-3 loafs of 670g each per batch) is adopted and gas is used as the fuel; the efficiency can however drop significantly with lower loading levels and, regardless of the loading level, with the use of electric ovens. Le-bail *et al.* [18], on the other hand, compared the energy demand in conventional bread baking with that in the processing of frozen part-baked breads – the option of the bake-off operations as mentioned in Section 3.1 – and concluded that the part-baked process demands about 2.2 times as much energy as the conventional bread making process.

Closely related to energy consumption is greenhouse gas (GHG) emission. According to Williams *et al.* [16], 0.80 t CO_2 equivalent is produced per tonne of wheat, 80% of which arises from the use of fertilisers. For the bakery operations, the Carbon Trust study [17] showed 0.23 t CO2 equivalent per tonne of baked product (primarily breads) when averaged across 89 industrial bakery sites in the UK. This amounts to 0.57 million tonnes of CO_2 equivalent per year for the sector and equates to approximately 0.45% of the UK's industrial emissions. The overall maximum carbon saving potential for the sector through good practice and future innovation is estimated to be 26.5%. In a separate study by WRAP [16], bread baking (at plant, in-store or at home) is reported to be responsible for 20% of the GHG emissions of bread, while user behaviour (bread freezing and toasting) and appliance use contribute 25% of the total GHG emissions, and fertiliser use in wheat growing accounts for 25% of the total GHG emissions. While a detailed study is needed to draw definite conclusions, one can imagine that if changes occur to the locations and scales of different activities in the bread system, the picture of GHG emissions is most likely to change, part of which may be accompanied by changes in user behaviour.

3.4 Water footprint

Water is required in all the bread manufacturing steps including agriculture (i.e. wheat growing), the milling process and bread making. Water used in agriculture is required for growing wheat, accounting for over 95% of lifecycle water use of bread in the UK [19]. During the milling process, water is added to soften the wheat, making it easier to process. Based on the information collected from 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 and accounts for the second most important ingredient by weight (i.e. around 36%) after flour as the main ingredient. While water is the second most important ingredient of bread making process, the total water used in baking bread is insignificant compared to the amount used for growing wheat. However, the water used during all stages of manufacturing (i.e. milling and baking processes) needs to be as high quality as drinking water. Both milling and baking companies interviewed in the Oxford area reported they use mains water to supply the necessary water for their processes. This is because mains water is easily accessible and drinking water quality is regularly tested and rigorously checked by the UK water companies and Drinking Water Inspectorate to ensure drinking water standards are met [20].

The global average water footprint for wheat bread is 1608 m^3 per tonne [21]. Water footprint is categorised into blue, green and grey water. Blue water footprint and green water footprint refer to the volume of (i) surface and groundwater and that of (ii) rainwater consumed, respectively. Grey water footprint is defined as "the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards" [21]. The global share of these categories in wheat bread production is estimated to be 70% green water, 19% blue water and 11% grey water. Due to the climate in Oxfordshire, wheat is not irrigated (i.e. uses no blue water) and is a rain-fed crop over the length of growing period [21]. The global average water footprint per tonne is similar in either irrigated or rain-fed agriculture [22]. However, as the UK wheat yield is amongst the highest in the world (i.e. an average of 6.2 tonne/ha compared to the global average of 2.2 tonne/ha over the period of past 50 years [23]), the water footprint for producing wheat bread in Oxfordshire substantially reduces to a total of 524 m^3 water per tonne of bread, based on the data between 1996 and 2005 [21]. This is made up of 385 m^3 (74%) green water and 139 m^3 (26%) for grey water.

Based on regulations set out by the Environment Agency (EA), water abstraction for more than 20 m^3/day from either a surface or an underground source needs an abstraction licence (although some cases such as trickle irrigation are exempt) [24]. The availability of water resources for abstraction is assessed by the EA through the Catchment Abstraction Management Strategy (CAMS) approach. The EA uses CAMS based on 16 different mapped groundwater catchment areas in the UK for water abstraction licencing. Most areas in Oxfordshire are grouped in three catchments of the West Thames map area [25], which are all predominately rural and semi-rural, grassland and the remainder woodland and small urban areas. These lands are used extensively for agriculture such as arable farming and grazing. For most of the areas in this case study, the EA will grant an abstraction licence only during periods of high flow. Consumptive groundwater licences, which do not have a direct and immediate impact on river flow, may be permitted all year, providing the level of resource use allows it, but may have restrictions such as prescribed groundwater level.

Based on interviews with local milling and bakery businesses in Oxford, the water they use in manufacturing is supplied via mains water at present, and consequently it has energy embedded in it as a result of this water being abstracted, transported, stored, treated and distributed to their premises by the water company (Thames Water). As their water demand is less than the threshold of 20 m^3/day, an abstraction licence would not be required if these businesses decided to opt for direct abstraction from a local surface or groundwater source. However, locally sourced water (as distinct to mains drinking-quality water) would need to be pumped, stored and treated before being used in milling and baking. These steps are energy demanding and need further analysis in relation to water and energy nexus issues.

4 Opportunities and challenges of local nexus: initial reflections

Through the bread case study presented above, another case study on tomato paste currently undertaken and several stake-holder workshops, an understanding of the opportunities and challenges of local nexus is forming.

4.1 Opportunities: arising from broader values and functions of the food system

The potential of a localised form of the food system needs to be articulated with a broader understanding of the different elements of ‘value’ associated with food and hence desired functions of the food system. In the physical layer (Table 1), food is valued as the means to provide a secure and balanced supply of nutrition, without compromising the ecosystem and the environment. In the socio-economic layer, the food industry is a major sector expected to bring economic value to businesses as well as the workforce. In both aspects, it is widely accepted by the stakeholders that balancing *equality* - between different sections of society, between humans and nature, between businesses, and between businesses and consumers – and *efficiency* is highly desirable. Furthermore, food plays distinct social and cultural roles in human society and helps to enhance the healthy connections between human and nature, and within local and urban communities.

The positioning of these values and functions, has allowed a range of potential benefits and opportunities for a more localised food system to be considered. In the physical layer, food may be a higher quality through improved freshness, personalisation and customisation. Safety risks and waste may be reduced due to the shortened supply chain. Furthermore, locally abundant resources, such as water or renewable energy, may gain utilisation in certain cases, and resource recycling and reuse (e.g. of nutrients) may be better promoted contributing to improved resource efficiencies. Socio-economically, it may lead to reduction of costs due to resource savings, promote the growth of small businesses and hence local employment. It may also offer an opportunity to allow people to rebalance between “cheap” food (as a consequence of the current large-scale centralised production) and stronger communities (possibly boosted via improved local employment and sense of community).

4.2 Challenges: functioning of a localised food system within constraints

In parallel to the broad expectations on the positive contribution of a localised food system to the broader values and functions, a number of challenges have been identified. These relate to the various constraints within which the system could deliver its functions. Physically, increased local food production and processing means extra local demands for land, energy and water. Therefore, a rationally re-distributed food system should consider the location of its various activities (agriculture and processing) in conformation with resource availability, and avoid worsening any local “nexus” stresses. In the design of a specific system, possibilities of reusing energy and water within the food system and between different local economic sectors should be considered to ease any tension. When treated carefully, the nexus challenges may be turned into opportunities. Another category of physical constraints relates to the suitability of technology for smaller-scale operations and any additional handling introduced by re-distribution (e.g. processing of frozen part-baked doughs), where innovation is desired to enable such operations to be realised with an acceptable efficiency. There are other more practical constraints, such as dated manufacturing facilities and limited floor-space availability in urban areas, which need to be overcome to allow existing local food operations to expand and/or for brownfield sites to be reused and repurposed.

There are also socio-economic and regulatory challenges, which may emerge together with some of the opportunities presented earlier. For example, although localised operations may promote efficient resource utilisation, the potential loss of economy of scale may negate economic gains derived from resource savings. Also, while a localised food system has the potential to contribute to the building of stronger communities, equally there is a risk of creating a two-tier society in which local food businesses primarily serve an economically privileged sub-population with premium products, leaving the deprived rest to “standard” food supply. Similarly, the potential for increased local employment may be offset by the shortage of qualified workforce. On food safety, the challenge of establishing a proper regulatory framework to deal with a large number of small manufacturers may counter-balance the benefits of shorter supply chains. Such challenges need to be addressed to allow localised food systems to achieve their full potential.

4.3 Unknowns around transition pathways

How can a move from the current system to a future where a re-distributed food system successfully delivers its desired values and functions? In addition to addressing the challenges identified above, further research and practical challenges pertain to the transition pathways. We are still in the early stages of identifying and understanding such challenges, yet several sets of key questions have already emerged from discussions with stakeholders.

- *The role of the state, policy and regulation:* How can policy provide the conditions and frameworks to promote locally sustainable food? Is greater certainty and predictability needed for the actors involved? Can we change the way we think about regulation from something that is obstructive and adds costs in tackling the 'bads' generated by the food system to something that is developmental and promotes the kinds of 'goods' we want the food system to generate (i.e. local production, employment, better dietary and health outcomes)?
- *Leadership and vision:* Who can articulate and provide the vision for the local nexus? Where are the sources of leadership? The state? The market? The public? How can top-down, elite and/or technocratic sources of public/private views be reconciled/complemented by bottom-up, popular and civic/public perspectives?
- *Ownership and control:* What forms of ownership and control are appropriate for more sustainable and re-distributed local nexuses? Are private and shareholder based forms appropriate and able to change and deliver? Can new and innovative forms of more distributed, decentralised and civic/public ownership and control be developed?
- *The nature of change towards a more sustainable local nexus:* While the pressures and arguments in favour of transition towards a more sustainable local nexus become more evident, how will change unfold? Are deeper and more serious shocks, disruptions and crises likely to punctuate and encourage change? Are more incremental, slower burn forms of change likely to prevail? How can strategic and planned actions shape the nature of change? Does the nature of the current, centralised model itself present barriers, through path dependence and lock-in? Who can/should lead and shape such processes?

5 Concluding remarks

To facilitate the understanding of re-distributed food systems and the associated energy and water supply and use we have proposed a multi-layer framework and the notion of food system configuration. The empirical analysis of the bread production for Oxford city has revealed a mixed (national-regional-local) configuration of the current system, its historical shaping factors, and has begun to outline the potentials and techno-socio-economic implications of future, more localised configurations. The analysis of the associated energy and water use shows further resource and environmental implications of the current system and of the more distributed options. The initial learning from the empirical studies and from the collected opinions of stakeholders has crystalized into a number of potential opportunities and challenges of the local nexus, including several key questions about the transition from where we are today to a desirable future. As the work of the LNN project continues, this learning will be broadened and deepened, with further insights to be gained on critical issues such as unification/integration of multiple values conceived for the food system, clarification of the semantics of the characteristic geographical scales (e.g. local, regional, etc.), and conceptualisation of multi-scale or mixed economies within which the role of more localised operations could be better articulated. The LNN will continue to develop a sound conceptual basis and an evidence-based research agenda for the future development of this area.

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