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"For all kinds of reasons, it hasn't happened": A novel integrative perspective for analysing the barriers to biomass crops for bioenergy in the United Kingdom

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ABSTRACT

Upscaling perennial biomass crops (PBC) for bioenergy is a key element of decarbonisation plans in the UK. However uptake of PBC by farmers has been historically poor and the bioenergy industry nascent, reflecting international contexts. This has been problematised from a number of social, economic and policy perspectives and scales. Positioning this work in transition studies, we aim to examine barriers and enablers to upscaling *Miscanthus* and SRC willow feedstock for bioenergy and greenhouse gas removal in the UK. This study applies a conceptual framework that inserts farm level perspectives such as sociocultural motivations into an Innovation Systems (IS) functions approach. Qualitative data was collected in semi-structured interviews and participatory workshops with farmers (PBC growers and non-growers) and selected IS stakeholders (advisers, land agents, biomass industry intermediaries/supply chain, agriculture, environment, forestry, policy and NGO representatives). Analysis was structured around seven IS functions considered necessary for IS build-up, integrating macro and micro levels. This approach offers a deep integrated understanding of barriers and enablers to upscaling PBC. Results showed misalignment of the IS functions which are iteratively entangled with farm level actors' social processes and decisions, something which have hitherto been little understood or theorised in the bioenergy context. Identifying potential intervention points to improve system performance and understanding how farmers and other stakeholders negotiate demands for PBC are particularly relevant to policy makers' ambitions for large scale planting and GGR projections.

1. Introduction

The Intergovernmental Panel on Climate Change recognises a significant role for biomass crops[1] in greenhouse gas removal (GGR) [1]. This is reflected in EU decarbonisation targets and in UK national policy, where biomass crops have become a key element of future pathways and carbon budgets [2] as part of the requirement for a net 100 % reduction in greenhouse gas (GHG) emissions by 2050 compared with 1990 levels. High yielding perennial energy crops are expected to contribute to GGR by providing CO_2 'neutral' feedstock for energy production. When these crops are combined with carbon capture and storage (Bioenergy with Carbon Capture and Storage (BECCS)), the process is described as 'carbon negative', actively removing CO_2 from the atmosphere. To help meet the UK's ambition for negative emissions, an increasing amount of feedstock will need to be drawn from a range of domestic as well as imported sources [3].

Types of domestically grown agricultural crops which can be used for bioenergy include perennial biomass crops (PBC), namely Short Rotation Coppice (SRC) willow and *Miscanthus*. These crops are considered to be able to meet the growing demand for sustainable biomass feedstock [4,5]. It is envisaged expanding the growing of these PBC from 800 ha/year to around 23,000 ha/year to meet the 2050 net zero target. This

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[1] Biomass crops are one type of bioenergy crop although the terms are often used interchangeably. The former is used to distinguish second generation (non-food) perennial biomass crops from first generation energy crops (food crops). Biomass crops are used to supply feedstock to heat and power plants.

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would deliver 2 $MtCO_2e$ emissions savings in the land sector and an extra 11 $MtCO_2e$ with carbon capture and storage technologies by 2050, according to the Committee on Climate Change's (CCC) 'Further Ambition' scenario for agriculture and land use [2].

Whilst the rationale for growing these crops has shifted, they are not new to the UK agricultural landscape. Uptake of PBC has however been historically poor and the industry still nascent and since 2021 largely stagnated despite a number of industrial partnerships embedded in public–private funded projects [6]. Less than 0.2 % of arable land (about 10,000 ha) in the UK is dedicated to these crops at present [7]. This is not unique to the UK, low adoption has been widely reported across Europe and North America [8,9].

The reasons for this have been problematised from a number of social, economic and policy perspectives and scales and include: the lack of support from, and incoherence in, policy; instability in the market and the inherent uncertainties, both for potential growers and supply chain managers [10,11]; economic or technological constraints and limited knowledge flows [8,9,12]; fragmented supply chains [13]; and bioenergy actor capacity, plant breeding, market structure, long-term security of contracts [14,15]. Farm level determinants have also been identified as important and include: economic risk and loss aversion [16–18], as well as intrinsic socio-cultural motivations [14].

Furthermore, bioenergy crops have been described as a highly contested socio-technical solution to climate change with a range of socio-environmental issues [19]. The crops have been the subject of debates ranging from competition with alternative land use (notably, food), and the impacts on environment, biodiversity and landscape through (in) direct land use change, to concerns about the legitimacy of claims surrounding GGR and carbon removal and storage [20–22]. These debates have taken on a new inflection with the government ambitions for using biomass with BECCS, itself a highly contested technology [23,24]. Furthermore, upscaling biomass demand raises wider questions about how to reconcile the many current demands on land in the UK [25]. Clearly these biomass crops have a multi-sectoral dimension, bringing actors from many different regimes[2] (energy, food, environment, water) into the discussion. This has been demonstrated in studies taking a stakeholder participatory approach working with communities [26] and decision-makers [27].

Understanding the combination of these social, political, technical and economic dimensions of biomass crops, and their interactions requires a sociotechnical lens [28]. It also requires consideration of the role of farmers as crucial actors in the Innovation System as biomass feedstock producers.

Positioning this work in transition studies, this paper aims to examine the barriers and enablers to upscaling PBC production in the UK. It applies a conceptual framework that inserts farm level perspectives into an Innovation Systems (IS) approach [29,30]. Failure to consider farmers' capacity and willingness to grow biomass crops, what Warren et al. [31] call "their practical and socio-cultural realities", when setting government targets and strategies has characterised policy approaches in the past. There is a need to understand the farmers as well as assess the system in which they are embedded, notably the institutions, networks and relations with other actors. Combining analysis of actors at the micro-level (farm context), who enact or bring about change, with a macro-level analysis of system functions, can offer rich insights.

In doing this, the paper revisits the analysis of bioenergy crops in the context of net zero targets, new narratives surrounding GGR and BECCS, and delivering ecosystem services and diversifying farm incomes [4,32,33]. It also considers the UK backdrop of policy uncertainty in this post-Brexit period as the government implements a transition plan [34]. Our study re-examines farm level and industry perspectives in these contemporary contexts. In doing this it extends current research in two ways, it provides substantive empirical data, and contributes to and advances theory by developing a novel conceptual framework that integrates IS and farm level context perspectives. Although UK focused, both the data and theoretical developments are relevant to international contexts, as similar barriers to upscaling have been identified across Europe [6,18,35], and the USA [8].

2. Context

There is a history of varied policy support associated with bioenergy crops in the UK [11–13]. The Energy Crops Scheme (ECS) was available until 2013 (in 2 phases) together with other support measures [36]. Although production areas grew, overall the ECS was undersubscribed and markets remained small, collapse of bioenergy companies (e.g. the ARBRE plant) further undermined confidence in the industry [11,37].

Although PBC have been included in biomass potential assessments for many years, their cultivation has failed to become well established in the UK and this has been attributed in part to a disconnect between policy makers, notably energy and agriculture departments. The Department for Energy Security and Net Zero (DESNZ) (formerly BEIS) published the Biomass Strategy, issued in 2012, and updated in 2023 [7], with an interim biomass policy statement [38]. These documents stressed the key role that bioenergy has to play in decarbonisation, and referenced other benefits of energy crops including their low maintenance and input requirements, and their ability to grow on poorer land, prevent soil erosion, improve biodiversity and improve fuel security [6]. However, no targets or assistance for PBC have resulted. The planting scheme has not been reintroduced, although dedicated private bank loan schemes are now available to support PBC planting. Meanwhile the Department for Environment, Food and Rural Affairs (Defra) are implementing new Environment and Agriculture Acts (2021) as part of the post-Brexit transition period. The main farming subsidy the Basic Payment Scheme is being withdrawn from land managers (farmers, landowners) in England[3] and new agri-environmental schemes (ELMS), specifically the Sustainable Farming Incentive (SFI) and Countryside Stewardship (CS), are being rolled out with 55,000 agri-environment agreements recorded in April 2024. These pay farmers for 'public goods' and reflect UK's national and international commitments to halt and reverse biodiversity loss, to support nature recovery, restore soil health and water quality in agricultural landscapes. Land managers have also encountered market volatility and high input prices following the outbreak of the war in Ukraine. The new UK government elected in July 2024 will continue with SFI and CS, however, apart from a commitment to an ambitious renewable energy programme, the role envisaged for biomass in decarbonisation is as yet unknown.

Miscanthus[4] and SRC willow are perennial and relatively unfamiliar crops to UK farmers. They can grow on low-grade land that arguably would otherwise not be economic or suitable for cultivating food crops; they require very few inputs after establishment and therefore have low emissions [39]. However there are some trade-offs with the risk of

[2] Regimes are the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems [57].

[3] These arrangements are devolved in Wales, Scotland and Northern Ireland.

[4] The literature assessing the economics of Miscanthus cultivation nearly exclusively deals with *Miscanthus* × *giganteus*.

encroaching on areas containing high-biodiversity or high-carbon stocks, such as semi-natural grasslands [15]. The most common reasons for growers to grow PBC are not related to financial returns, but to the low requirement for field operations and maintenance costs, and regeneration capacity. This provides a practical solution for fields that are non-productive, difficult to access, close to housing, as well as allowing use of fields for gamebird cover, providing a secondary income [36,40]. However the crops are described as marginal value, high volume, consequently financial returns to growers and the profitability of these bioenergy systems require high yields to be realised over time [41]. Poor establishment in particular can lead to lower than expected yields [40].

Several authors have highlighted the scope for PBC to enhance ecosystem services [33,42–44] through habitat provision and nutrient cycling, improved, water and soil quality [45]. With respect to carbon, biomass from *Miscanthus* is considered a carbon-neutral resource whether or not the soil carbon stocks increase [46], however PBCs are sometimes controversial because their production and use can be a carbon source or sink depending on climate, production conditions and practices, and especially the fate of fixed carbon in their use [47]. The quality of evidence varies and is dependent on the plant species and location [42], with limited research available across the whole life cycle of these long-lived perennial crops [6]. This is a particular point of contention with regard to the role of BECCS [23,24]. There is a growing body of work about management practices for optimising overall carbon balance of PBC [48]. Trade-offs in relation to sustainability and the SDGs have also been the subject of analysis [45].

3. Conceptual framework

Innovation systems (IS) comprise a combination of technological, organisational and institutional novelties and the involvement of a multitude of actors at different scales [49]. They are conceptualised as emerging systems where actors, institutions, networks and technologies interact. The quality of these interactions influences the development and diffusion of technologies [29]. The IS approach is suited to the multi-sectoral dimension of bioenergy which is characterised by multiple actors and interactions, different institutional settings and socio-temporal dynamics [14]. IS studies recognise the importance of the social environment, social networks, expectations and learning processes [13], and emphasise the processes of learning-by-doing; learning-by-using and learning by-interacting [12,49].

Using an IS approach, transitions associated with bioenergy can be studied in terms of system performance and failure, and barriers [12] or blocking mechanisms [50]. 'Functions of innovation systems' are the key processes that are important in building an IS, they are the dynamic processes between the structural components of the system: actors, networks and institutions [51]. Actors are individuals and organisations,

Table 1
Innovation systems functions.

F1 Entrepreneurial activities: Entrepreneurs in innovation systems are important. They turn the potential of new knowledge development, networks and markets into concrete action to generate and take advantage of business opportunities. Entrepreneurs have many definitions, for example "….individuals who manage a business with the intention of expanding that business and with the leadership and managerial capabilities for achieving their goals" [71].
F2 Knowledge development: This refers to learning activities related to the emerging technology, but also related to markets, networks, users etc. Learning activities include learning-through R&D and learning-by-doing. The Agricultural IS literature emphasises the importance of platforms and networks where such interactive learning occurs.
F3 Networks and Knowledge diffusion: Networks are central to IS. They facilitate the exchange of knowledge between all the actors involved. The processes of learning-by-doing, learning-by-using and learning-by-interacting are important. The diffusion of information through networks, for example, for changing norms and values, can lead to a change in R&D agendas.
F4 Guidance of the Search (i.e. influence the direction in which actors deploy their resources): Activities within the IS that shape the needs, requirements and expectations of actors with respect to their support of the emerging technology. These activities can positively affect the visibility and clarity of specific needs among technology users, for example, government targets for renewable energy. This gives legitimacy and stimulates allocation of resources, it also refers to signals, expectations, promises, policy – expressed by various actors – and the convergence of these in a particular direction of technology development that may work out positively or negatively for the technology concerned.
F5 Market Formation: Emerging technologies usually cannot compete with incumbent technologies. Therefore, the creation of artificial (niche) markets is needed, e.g. by financially supporting the use of the emerging technology. There is a key link with other functions such as resource mobilisation to obtain capital.
F8 Resource Mobilisation: The allocation of sufficient financial, material and human capital to make the emerging technology viable. Specifically, for biomass technologies, the availability of the biomass resource itself is an underlying factor that determines all IS functions.
F7 Lobbies, support from advocacy coalitions: The rise of an emerging technology often meets with resistance in the incumbent regime. In order for an IS to develop, an advocacy coalition should be strong enough to effectively influence policy making and act as catalyst to create legitimacy/counteract resistance of change.

Adapted from Negro and Hekkert [54] and Breukers et al. [29].

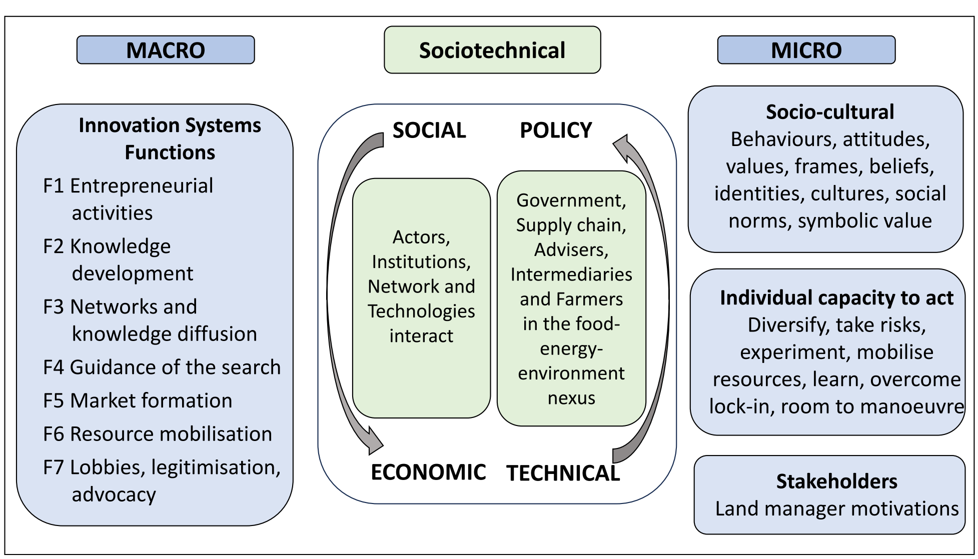

Fig. 1. Conceptual framework combining micro farm level perspectives with macro IS functions.

in IS they are delineated based on their role in economic activity [48] and can typically encompass private firms or firm sub-units, governmental and non-governmental agencies, universities, research facilities, venture capitalists and associations [52]. Institutions[5] are regarded as the rules of the game, comprising laws and regulations, sociocultural as well as technical norms, use patterns, shared expectations. Networks include the many interactions and dynamic relationships among individuals or groups of actors and organisations [53]. According to Markand and Truffer [52] the key metaphor here is that actors are embedded in an institutional context.

The analysis of the dynamics between the actors, institutions and networks centres around seven key processes or system functions that are considered necessary for IS build-up [30]. Weak or absent IS functions, arise from limitations in the structural components. According to Hekkert et al. [30] different 'virtuous cycles' of mutually reinforcing functions may exist in well-functioning IS, as a result of different sequences and combinations of functions.

The seven functions described in Table 1 provide a heuristic framework to analyse the emergence of an innovation and for identifying barriers and enablers.

The IS framework is critiqued for the fact that its explanatory power lies mainly in the part of institutions (macro-level), and less on the actions of the individuals and entrepreneurs (micro-level). This is despite the central idea behind the concept of IS being that innovation is both an individual and a collective act [55] with the individual perspective, especially that of the entrepreneur(s) being critical [52]. According to Kemp [55] "Transitions are best viewed as macro-outcomes of micro-decisions (cf. Schelling) in a changing landscape that cannot be reduced to specific events and decisions. They result from the interplay of individual and collective decisions under collective structures (rule systems) in a heterogeneous sociotechnical landscape". Scholars have called for more attention to the specific role individuals play at the micro-level [52,56] and have criticised global models for insufficiently addressing agency [57]. Furthermore, IS studies have focused more on technological innovations, not the complexities or social relations of innovations in the context of land use and crop production. As a consequence, in analysis specifically of biomass, IS "fares less well in grasping the controversial nature of biomass" as Breukers et al. observe [29].

We argue that inserting a micro-level approach into IS function analysis can help to understand why, despite historic farm and market level incentives, alongside policy ambitions for bioenergy, energy crops have failed to meet expectations [36]. Capturing the individual perspectives of farmers, entrepreneurs, and their relations with stakeholders is key to understanding how decisions about biomass production at the farm level interact with the IS. We know from a large body of research that farmer decision making processes are the outcome of a complex interaction of economic, social and environmental objectives. Studies of environmental and transition behaviours have shown that although economic issues are important, farmers are rarely rational decision makers or profit maximisers [58–60]. Structural issues of farm capacity (tenure, labour, infrastructure, debt, contracts, succession), and the influence of social norms, cultural beliefs, socio-psychological factors, aesthetic judgements and personal values concerning nature, family and community have all been found to be important.

These complexities have been played out with farmer decisions about bioenergy crops which are affected by practical on-farm and economic barriers [61], unfamiliar agronomy [9] and negative perceptions of the impact on the farm environment. The long-term nature of the crop has heightened these concerns in relation to individual capacity to diversify, take risks, experiment and mobilise resources [16,17,40]. These are linked to credibility of information [14] and access to markets [62,63].

[5] In this way institutions are distinct from organisations.

Farmers' intrinsic socio-cultural motivations, attitudes, identity, farming culture and the symbolic value attached to food production also shape farmer behaviours towards bioenergy crops [14,31]. Scholars have drawn on the notion of what constitutes 'good farming' among farming peers in relation to non-food crops [31,64] to explain a reluctance to grow bioenergy crops. This is extended to marginal land and its symbolic and practical value [65] and the misconceptions and policy assumptions that are made about how it is used and valued [63,66]. Furthermore, farmers are embedded in a number of influential peer to peer and stakeholder (adviser, supply chain etc) networks and are influenced by intermediaries in bioenergy crop production [67].

Here we link this rich body of rural studies, often inspired by micro-sociological theories, to IS functions. We propose a conceptual framework that combines these micro farm level perspectives with macro IS functions (Fig. 1). Past studies of biomass have drawn either on socio-technical systems [13,28] to understand upscaling potential or focused on the farmer's sociocultural perspective [31]. Our integrative approach aims to position farmers and stakeholders operating at the farm level as individual actors embedded in and shaping the IS functions, responding to institutions, and interacting in networks. We use contemporary qualitative analysis to contribute to theoretical development.

4. Methodology

The conceptual framework (Fig. 1) guided the data collection and analysis. This was centred around seven key processes or system functions which provide a structure for identifying barriers and enablers to the development of IS (Table 1) incorporating farmer motivations, strategies and capacity to act, referred to here as 'farm context analysis'. We also include stakeholders who enact PBC as well as interact with and influence farm level decisions, spanning macro- and micro-levels. These operate as individuals or in actor groups who share common activities and are active in networks which can be formal, for example, biomass feedstock supply chains, or informal, for example, conservation adviser partnerships [52]. Some stakeholders have intermediary roles, defined by Helliwell et al. as "active participants in the system, capable of creating (and sometimes preventing) change above, below and across other actors" [67]. Stakeholders represent different institutions including industry, policy and practice (energy, agriculture and environment).

4.1. Data collection and analysis

Based on this framework, analysis was undertaken of qualitative data collected in semi-structured interviews (online and face to face) and participatory workshops with existing biomass growers (we use the term growers) and non-growers (we use the term farmers) and selected stakeholders. Participants were identified through a stakeholder mapping exercise of the main actors and organisations in the PBC IS. This was conducted using recent policy and research documents (e.g. the Biomass Strategy responses to the call for evidence; the Supergen Bioenergy Hub which has been working with academia, industry, government and societal stakeholders), and validated by experts and industry intermediaries within the project, followed by a snowballing approach. Phase 1 focused on existing growers and industry stakeholders across England and involved 9–10 interviews and one workshop for *Miscanthus* and SRC willow respectively. Phase 2 aimed to capture wider non-grower (farmer) and stakeholder views in four regions across England and Wales: North-East, mid-Wales, Yorks and Humber and Midlands. These were selected to represent different biophysical regions, farming systems and market opportunities, with 16–18 interviews in each region. In total there were 86 interviews (39 farmers/growers, 47 stakeholders) and 62 workshop participants. See Supplementary Tables S1–S3 in Supplementary material for details.

Growers and non-grower participants covered a range of arable and livestock types from lowland and upland farms, representing different

Table 2
The analytical process including an example of Function 1 Entrepreneurial function.

Phase 1 Semi-structured interviews �	Preliminary interview analysis �	Phase 1 Workshop validating interviews & mapping barriers & enablers �	Phase 2 Interviews & workshop in case studies validating & extending phase 1 �	Finalising integrative analysis of IS function with micro-level �	Finalising function linkages �
Interview schedule structured around IS functions & micro level (farm level actor motivations, socio cultural factors)	Preliminary analysis Deductive & inductive coding	Refining analysis Deductive & inductive coding	Refining analysis Deductive & inductive coding	Finalising coding to describe IS function with micro-level perspectives	Links to other functions & role in IS performance overall
Example F1 Entrepreneurial activities — individuals turn the potential of new knowledge development, networks & markets into concrete action to generate & take advantage of business opportunities	Deductive — business activities & motivations of industry stakeholders, intermediaries Inductive — farmers show a range of entrepreneurial activities (risk averse, innovative, derisking)	Deductive — confirm supply chain intermediary actions Inductive — potential for creative revenue streams & opportunities for growers with PBC		Small entrepreneurial supply chain sector, limited competition & fragmented networks. Farmers can be entrepreneurial but many do not see PBC as a business opportunity	Inconsistent government signals (F4) & absence of a market (F5), reduces entrepreneurs' (F1) confidence with consequences for other functions

sizes and tenures. All farmers were male and from a wide age range. Stakeholders (a balance between male and female) included representatives from i) agri-environment sector (catchment partnership, Wildlife NGOs, large land owning charities, conservation agencies), ii) biomass industry (power plants, supply chain intermediaries who arrange contracts between growers and power plants, (bio)renewables researchers, managers and consultants, agricultural banks who offer credit to farmers), iii) farmer representatives (farmer unions, advisers, land agents, agricultural colleges), iv) forestry (land use advisers, forestry officers, researchers), and v) policy makers (national (Defra, DESNZ, Welsh Government) and local authorities).

The interview schedules were designed to cover the main components of the conceptual framework, structured around the macro-level IS functions (and the structural components: actors, institutions, networks that contribute to realising each function), and micro-farm level motivations, strategies and capacities, and the intermediary and network interactions. In each phase, the workshops followed the interviews and were designed to validate and extend the interview analysis. For example, informed by interview analysis which clustered industry, policy and farm level factors, Phase 1 workshop stakeholders undertook participatory mapping, further identifying and unpacking barriers and enablers to PBC upscaling (see Supplementary Fig. S1 in Supplementary material).

The interviews and workshops were recorded and transcribed then coded in NVivo v. 12. The analysis was developed iteratively by the researchers as the data collection phases progressed. First, interview data was analysed deductively using initial coding structured around the seven functions (as elaborated in Table 1) and the micro-level dimensions (intrinsic/extrinsic motivations, socio-cultural identity, norms). Additional themes were added inductively and mapped onto the seven IS functions offering new insights to IS analysis. Recurring themes were also coded to identify systemic problems by exploring across interviewee sectors and organisation types to represent the actors, networks and institutions of the IS. Table 2 maps out this iterative analytical process providing an example for the F1 Entrepreneurial function.

5. Results

5.1. Entrepreneurial activities (F1)

5.1.1. Supply chain entrepreneurship

The entrepreneurs are actors (individuals or companies) predominantly engaged in the biomass supply chain for energy, although there are alternative markets emerging. They include supply chain intermediaries, nursery suppliers, willow pelletizers, briquette makers, small scale biomass boiler suppliers, as well as planting, harvesting and haulage contractors and banks. What defines them is that they are creating novel businesses in relation to biomass. Supplementary Table S1 illustrates the range of activities they engage in. One opinion expressed by an industry stakeholder was that this is an active area:

> "*Private enterprise is better than government, and that there are no shortage of innovators, entrepreneurs, nor people to make and take risks*".
> MISH1

Supply chain intermediaries are small in number, for *Miscanthus* it is dominated by one company, while for willow, it was described as fragmented and small. They promote, arrange and manage contracts between growers and power stations in a relatively short supply chain, acquiring, organising transport and processing biomass. In this respect they act as key intermediaries. They work to expand and strengthen the practical and/or commercial environment, by engaging in research projects, developing new knowledge about techniques, networks and new markets for new varieties. They promote to and recruit growers of PBC. From the grower perspective they were variously described as 'helpful' (G6), 'pro-active' (WG3), 'optimistic' (WG4), and 'good at pushing things' (WG3). Their business models vary, some offering long-term contracts with guaranteed indexed prices related to biomass quality, with some including financial support mechanisms. Their shared confidence in the crops as a business opportunity for farmers and for themselves, is illustrated in this industry stakeholder quote:

> "*Some large land owners are looking at Miscanthus, and scratching their heads saying 'Where's the catch?'. There is no catch. You've got a crappy field. Stick some Miscanthus in it, leave it there for, it's going to do good for the climate it's going to affect your overall carbon output for the farm. Get possibly some loans for the upfront costs, and in 12 years time, you're going be repaid on capital interest, and making a big fat margin off the back of it for very little" input*".
> MISH1

5.1.2. Farm level entrepreneurship

A range of characteristics were shown by growers, some consistent with entrepreneurs, that is, individual business people exhibiting concrete action to take advantage of business opportunities. Growers demonstrate a range of strategies and motivations, and stakeholders found it hard to describe a typical grower although they tended to characterise them as inherently innovative, with a "*good business head on them*", for example:

> "*Yes, it's less about what they're growing or their age but more or whether they're the innovators [...] there's quite a range. I've spoken to a dairy farmer who put all of his farm down to Miscanthus, and then treated it as a pension. He said, 'You know, that's it, I don't have to worry about it. They come in, they harvest it, they bail it.' And then I've spoken to large arable farmers who are taking out less productive parts of their land. But it's always the ones that are on the cutting edge that you're getting first, isn't it? The ones that are keen to try something first, and then you've got the others just having a look to see how it goes? So, whether they're a dairy farmer in retirement or a larger arable farm, that at the moment, they're the forward-thinking ones*?"
>
> MISH2

Growers have also developed alternative markets, for example, animal bedding from *Miscanthus*, or growing for local biomass power supply. Some are new to farming, have a range of commercial ventures and skills, and do not rely on the farm for their primary income. Regarding these growers, one stakeholder remarked "*Farmers [growers] are great risk takers and entrepreneurs, individual business people, they see an opportunity, they'll take it*" (MISH1). Large estates in particular have "*a completely business mind about income*" according to a workshop participant. Another workshop participant (livestock farmer in Wales) observed: "*I reckon we would double, if not treble our income by going to Miscanthus compared to running sheep for rent and the hay crop that we take*".

However, many growers' strategies do not conform to this type as they were motivated by the low maintenance and low inputs of PBC and saw the opportunity to wind down the business with regular payments, supported by the ECP that reduced the risk.

With respect to non-growers, some farm advisers and industry stakeholders regard them as risk averse and not entrepreneurial, described variously as: "*blinkered, they like to do what they've always done*", and "*sceptical*".

However, the risks involved in the business decision to grow PBC are recognised with the cost of establishment (with no ECP now available), cash flow issues and long-term commitment being key, as this industry stakeholder explains:

> "*So, I would say establishment costs and the fact that it's fixed in you know, you're writing off that crop out of your rotation for a long period of time, are the two biggest barriers to the crop*".
>
> MISH2

A number of participants described PBC as a capital-intensive system and beyond the means of many farmers. As these growers explained:

> "*We're probably looking at an investment of £30,000. You tell me what farmers has that, I mean I know I'm looking at that and thinking this better produce some money*".
>
> WF8 (just starting to grow *Miscanthus*)

> "*I'm worried my capital investment won't be returned within the 12-year period that we allowed for the land to be utilised. I may be better off putting spuds in there*".
>
> WF5

> "*The trouble is if you plant it, you don't get any income for three years. It doesn't matter however good your spreadsheet looks ... it is horrible looking at a negative for three years*".
>
> MG4

This has heightened implications in the current context of farmers losing their BPS and "*living by the seat of their pants*" making such upfront costs unfeasible. Wrapped up in this, is the change in mindset required for stepping away from the habit or pattern of annual cropping, accounting and selling. As one NGO stakeholder observed: "*Farmers don't look at 20 years in the future, they want a financial yield that's going to provide something next year*" (HSH5). These *Miscanthus* growers observed that it required a "*change in your way of thinking...[a] massive adjustment*" (MG4), and that "*you have to be able to take a very, very long-term view in terms of returns and land use*" (YF7).

In reality farmers often have few options to be entrepreneurial as they have little room for manoeuvre, as they are already embedded in agricultural policy and market institutions, with tenancy or supply chain contracts, underpinned by local farming cultures. This was illustrated in the mid-Wales are where the workshop was held, where dairy farming and advisory institutions aim to optimise all land for dairy enterprises, with no notion of 'spare land' for biomass crops. This inability to change trajectory or absorb risk is also evident for tenant farmers who either have short and often insecure tenancies and are apprehensive about the landlord's response, as a forestry stakeholder explained:

> "*I mean, tenancy agreements seem to be getting shorter and shorter. So it means that any, any tenants got to see a quick return. And speaking with the Tenant Farmers Association, any actions that reopen a tenancy agreement between landlord and tenant is definitely shied away*".
>
> HSH3

Furthermore, for some, following an alternative revenue streams such as SFI is arguably a more sensible entrepreneurial decision. However some farmers and advisers are beginning to see possible future entrepreneurial business opportunities with PBC and some expressed interest in any future payment for ecosystem services offered for PBC. Land agents and catchment initiative advisers identified creative scenarios which could help farmers optimise and diversify their revenue streams with possible future stacking, for example, combining PBC feedstock income with ecosystem service payments like carbon credits (although there was hesitancy about voluntary carbon markets with little trust in governance integrity), water quality and flood mitigation. Non-growers were also able to envisage planting PBC as a derisking strategy, a means to diversify, increase farm resilience, and reduce costly inputs of fertiliser and labour, allowing "*stability in the income stream*". Flood tolerant PBC in particular represented an opportunity for those farmers who had experienced repeated flooding and loss of crops.

Ultimately the decision is economic. While carbon storage was of interest, overall the crop has to make financial sense, as one industry stakeholder remarked:

> "*...Versus other crops, it's [Miscanthus] carbon positive. That has to be a good thing. [...] But first and foremost, of course, it's got to stack up as economically as a crop in its own right. For the carbon benefit, there will be I imagine very few farmers who would go into Miscanthus, purely for its climate related benefits unless there was something else on the farm that require them to be net zero*".
>
> MISH1

5.2. Knowledge development (F2)

R&D is supported by government funding, there are active partnerships and projects involving universities and supply chain actors but these tend to be within the bioenergy rather than the agricultural regime. Research is conducted in PBC agronomy, establishment techniques, plant breeding, yield enhancement and alternative markets, supplemented with analysis of PBC benefits to/impacts on environment (biodiversity, GGR, soil carbon, water quality and quantity). The need to overcome separation between disciplines, sectors and regimes to facilitate learning, knowledge development was highlighted by many participants. Specifically, the disconnect between agriculture and bioenergy sectors (with biomass crops falling between the two in both cases), and between forestry (parallels are drawn with PBC) and agriculture are longstanding issues and manifest at all points in the agricultural knowledge system (agricultural colleges, advisory services, etc.).

Growers described intermediaries in the supply chain as the only source of PBC knowledge, often through a single person. Most growers valued their support "…*they're very hands on, right, they helped you right through the whole crop*" (MG4). However, whilst it was acknowledged that there are knowledgeable technical experts in the industry, they were described as existing in pockets and not within reach of all farmers around the country. Growers remarked that they had to rely on estimates of future revenue from a small number of experts, making the decision to plant an uncomfortable '*leap of faith*' because, as one grower explained, "*we had to believe the salesman*" (WG5). The lack of independent, best practice advice for growers was flagged up by a number of participants.

There is little opportunity for growers to build their own experiential learning about growing PBC, as many operations are undertaken by contractors. Overall there is limited knowledge about PBC among farmers and advisers who tend to question: many aspects of crop agronomy (establishment, pest management, yield potential), financial returns on marginal land (which is often steep, waterlogged and has poor soil), the opportunities to integrate with livestock or into agroforestry systems, the potentially damaging impact of willow roots on drains, the cost of crop removal for reversion to arable, and the effect on land value.

Many growers had observed benefits of PBC to biodiversity and soil health, while supply chain participants present an enthusiastic picture of biodiversity impacts reporting many observations: "…*you can sit here and you can listen to the wildlife in these areas and it just fills you with happiness really*" (MG1). Workshop participants felt that the biodiversity benefits of PBC crops have been largely ignored to date in the ELMS development process, despite lobbying and "*30 years of literature, on the positive impacts of biodiversity in perennial crops*", according to one workshop participant. The barrier is seen as persuading Defra to take account of this evidence.

However potential growers and stakeholders (conservation advisers, etc.) demonstrated very limited knowledge of potential GGR or ecosystem benefits and were unaware of evidence to support this, as one conservation adviser remarked "*I've not seen really good research evidence that shows that [biodiversity gains]*" (YSH10). Participants held different levels of knowledge about GGR, specifically carbon storage. Many farmers queried *Miscanthus*'s role in carbon storage, for example, one grower remarked "*I mean they're pushing the carbon negative but, unless you've got very bad soil it's not really*" (MG1). Other farmers and advisers questioned how, with the carbon footprint of haulage and the process of burning for energy, these crops could contribute to GGR.

Participants also wanted to know more about how PBC compared with alternative land uses, and what happened to the soil carbon when and if PBC were removed, this conservation stakeholder explained:

> "*We need to know more about the benefits delivered in terms of carbon capture which is important and the amount the soil could ultimately hold on to from permanent grassland species rich grassland, as well as Miscanthus. And so, there's a fair comparison that could be made [….] How do we shift from Miscanthus to other habitats? Does it really need to be ploughed up afterwards? Because that would be tragic*"
>
> MISH3

Conservation stakeholders were concerned that large scale PBC cropping would be to the detriment of biodiversity, although acknowledged that some benefits might accrue (shelter to small mammals and certain birds, and willow providing pollen for insects) from small scale mosaic planting. Overall there was a call for more evidence about the long-term impacts, particularly in the context of the GGR narrative for these crops and their role in supplanting biodiversity use on non -productive land:

> "*So, I'm very nervous personally someone who sells Miscanthus as a solution to a number of different ways of developing different ecosystem […] where farmers would have the opportunity under ELMS [agri-environment schemes] let's say to grow, water quality and water quantity, water regulation, and flood risk management to grow biodiversity, to grow carbon instead of grow crops [….] we'd hate that [biodiverse non-productive land] to be displaced by grow energy crops to feed machines rather than people or grow non-native crops*". MISH3

A small number of growers felt they were more knowledgeable and convinced about the soil health and soil carbon benefits of PBC, arguing that these do not disturb the soil for some 20 years, as illustrated by this remark:

> "*[with Miscanthus] you're sucking carbon out of the air and it's ending up in the ground and it's ending up in the rhizomes […] , in the soil if you're burning it then you know the carbon released it should be no more than should be less than the carbon captured in its growing in theory*".
>
> WF3

5.3. Networks and knowledge diffusion (F3)

The bioenergy actor networks (R&D, supply chain actors and other intermediaries) are small in number and described as closed and not sufficiently linked into the agricultural or land use sector domains. Equally, mainstream agricultural organisations that support farming sectors rarely engage in knowledge exchange about these crops. Consequently, there is limited interactive learning between people from different backgrounds (advisers, academics, NGOs, forestry, biomass industry practitioners/entrepreneurs, agri-environment, conservation). Influential farm consultants help farmers with strategic planning and agronomists (the "last mile advisers") who build up trusting relationships with farmers, are not part of biomass knowledge networks, nor do other farm advisers working in conservation, woodland, and catchment management or land agents tend to engage.

There are farm walks and demonstrations hosted by industry actors, and existing growers were cited by the participants as influential figures in their decision to grow the crop, some local and some sought out from across the country. Seeing the crop in the field, talking to established growers and "*get[ting] a bit of their knowledge*", was described as very useful (WG7). However overall informal networking between PBC growers to share any experiential knowledge through peer to peer learning, the usual route for farmers to learn, appears limited. Without the momentum and opportunity to observe others successfully growing PBC, many farmers remain unconvinced:

> "*I would like to see a lot more people putting it in and talking positively about it I before I would take that leap of faith*".
>
> YF8

Perceptions of poor awareness among the farming population in general are attributed to low dissemination, as one farmer said: "*Most people are still not thinking about biomass, because the crops are not being promoted to them*" (WF1). Although there are regular farm walks organised by the main *Miscanthus* supply chain company, and research station demonstration and project field events, it is felt that demonstrations could be utilised more, as one farming knowledge exchange expert remarked "*you need to really take time to show how it can be fitted into an integrated farm business*" (YSH10). Awareness is greater in the east of the country where these crops are more familiar due to the proximity to biomass power stations. There was also a sense that the message is not reaching farmers about the potential GGR benefits, nor the scale and urgency of the net zero challenge.

5.4. Guidance of the search (F4)

There is a strong consensus among industry stakeholders that the government has no long-term strategic direction or vision for upscaling PBC, and that there is little indication of forthcoming supportive policy instruments (e.g. establishment grants) or other mechanisms to stimulate uptake. One grower referred to the short-term nature of policy: "*Government don't look beyond five years*" (MG1). Participants described how overall this leads to industry hesitancy, undermining market and farmer confidence. This poor convergence of signals translates to uncertainty and erodes expectations and stakeholder enrolment. The 10 year interval between the two government biomass strategies was seen as indicative of the absence of a vision for PBC, as well as the lack of action points and clear support measures. Delay in details of the post-Brexit agri-environment schemes reinforced this uncertainty during this period.

Participants remarked on contradictory signals as well. From the supply chain perspective, the government support for anaerobic digestion (AD) which needs maize feedstock is seen to be in direct competition, as one industry stakeholder explained:

> "*So this is where government policies are just nonsense, we have plans for power station to run for 20 years but we're running out of fuel [biomass] because AD plants are coming in at a better subsidy regime*."
>
> YSH5

This is exacerbated by previously poor coherence between government departments notably Defra and DESNZ, as an industry stakeholder observed:

> "*I think my wider observation is there's a mismatch between the different departments and the different funding streams and farmers. I'm just kind of stuck in the middle with lack of clarity*."
>
> HSH2

Whilst they believe that DESNZ are doing a lot in terms of biomass feedstock innovation, "*actually getting people to grow on farm*", is where support is needed (MISH4). The feeling among some growers was that Defra gives the crop little attention, regarding it as niche, having "*grown up entirely outside the government, outside Defra's influence and experience*" (MG2). One workshop participant stakeholder remarked that "*ultimately it's all going to come down to Defra*".

Perceived lack of government direction for developing PBC heightens the level of uncertainty that farmers and stakeholders are already facing and reinforces the main barriers for farmers, as a famer in Wales observed in relation to the poor government support "*When peoples livelihoods are involved they need more surety*" (WF7). Furthermore, farmers want to avoid the prospect of being locked into a system and losing the opportunity to be adaptable and respond in the future to more favourable arable crop prices or agri-environment schemes. This is particularly pertinent given global politics and the UK agricultural transition:

> "*I think the worry about this stuff would be that costs a lot of money to bring it back into arable production if you know there a war and something changes, food prices go absolutely crazy and then you're locked a load of your land into this thing that you then find is quite difficult to destroy*". YSH10

The government is seen to give inconsistent messages about food security and energy crops. Moreover, there are stronger signals to farmers from an established food production and agri-environment institutions (public agencies, NGOs and grants) delivering farming policies and instruments. The food versus fuel debate was salient for some and expressed by a range of farmer values, identities and expectations. While for some food production was described as "*hardwired into them*" (HSH2), with interviewees adhering to the view and social norm that the priority is food (not energy) production, others were happy to take on a different identity of an energy producer, for example, "*I would say I'm an energy crop farmer as opposed to a food farmer*" (YF1). Some reconcile inconsistent messages and act as pragmatists doing "*what's best for me and mine*" (WG4), growing PBC despite a belief in the importance of food production.

Many farmers are embedded in agri-environment support institutions and rationalise their choices with reference to these schemes. Farmers and the community that support them (advisers, land agents, unions) regard SFI or CS for three years as a more versatile option for non-productive land. They also offer the symbolic value of a multi-species grass or a wildflower meadow for example compared to a PBC monocrop. *Miscanthus* was seen as being at a disadvantage to other opportunities under ELMS, where farmers may get "*£650/ha for growing bird food2* (WS participant) These options represent a guaranteed income in a system which fits with arable rotations [and does not require specialist machinery or contactors, the prospect of borrowing money for the initial outlay, nor having payment tied to yield of an unfamiliar crop]. Indeed, SFI now competes with PBC for low grade agricultural land which might have previously been used for PBC or woodland, as this forestry stakeholder noted.

> "*That marginal land, which has sort of traditionally been the source of woodland creation areas, is becoming ever more squeezed with various constraints, you know, biodiversity, species, habitat*".
>
> HSH3

5.5. Market formation (F5)

Participants made a clear link between limited policy support, confidence in the industry and slow growth in the market. It was felt that the government had done little to create a market, and this had been left to emerge by itself. One industry stakeholder noted that this has been an ongoing issue: "*…the crops have not broken through commercially, the government has had repeated opportunities to intervene and try and create a market but for all kinds of reasons. It just hasn't happened*" (Workshop participant).

Farmers need some assurance about the markets, as one stakeholder remarked "*I think it would be the longer-term security of market and a multiplicity of markets. And obviously, how much you get paid for it*"(HSH2). As one grower explained:

> "*But there's two parts to this product aren't there, there's the growing of the crop which is one thing and then there's the selling of it, so its joining up those two…* [it's the lack of markets and] *the lack of diversity of markets especially*".
>
> WF5

One industry stakeholder supported this view alluding to the historic volatility in demands from power stations and the dominance of the largest biomass power station (Drax):

> "*If I was a farmer, I think, you know, if you're told, can you grow something? And there's, there's at least five different markets. That's more attractive than when there's only one market. It's called Drax power station and if they changed their mind again, like they've done before, then you'll be left high and dry*."
>
> HSH2

Spatial distribution of end markets is a clear determinant for PBC planting and local support. Absence of local markets was a disappointment for many. A farmer in Wales described his experiences and concerns about haulage where there was no local market:

> "*We're farming in West Wales, we chopped or cut it* {willow} *into shredders we put it in a lorry and they drive it to Newcastle right. So by the time we went all the way to Newcastle we've burnt all the energy we had generated […] nobody really wanted to transport it and nobody really wanted to harvest it*".
>
> WF5

Current grower contracts are deemed reliable but the legacy of the collapse of former supply chain companies still impacts farmers' trust and confidence. From the willow growers' perspective, some were concerned about variable demand, and the difficulties of finding alternative markets if demand from power station stopped or was interrupted, others were reassured by having a contract with a business they perceived as well-established. For *Miscanthus*, risk has been mitigated to some extent by more local biomass power plants being built and alternative markets, such as animal bedding, becoming available. Growers did, however, feel they were at the mercy of their buyers' timetables, specifications and complications of different markets. The key point raised is about confidence and assurance, as an industry stakeholder explained: "*It's not just the money. Farmers need the assurance of other people doing it first and the assurance of what's going to happen at the end and then the assurance of the contract*" (MISH2).

Overall participants saw the need to strengthen and expand companies in the supply chain, as *Miscanthus* is dominated by one centralised intermediary company. Willow is described as a slow growing industry characterised by a small and fragmented supply chain with less promotional activity overall compared to the relatively harder sell approach of the *Miscanthus* intermediary. From the grower viewpoint, a common sentiment was that there is a monopoly for *Miscanthus*, and more intermediaries would be advantageous, as one remarked: "*[X company] are effectively the only people buying it [meaning there was] no competition*" (MG5). In support of this, another grower described feeling "*obliged to sell through them*" (MG4). One farmer said he did not like to be committed: "*I don't like to be stitched into one contract*" (YF4). Pointing out the risks, other farmers and growers said "*With only one buyer you're a bit vulnerable*" (WF5), or "*at the mercy*" of contractors and buyers (WG5).

5.6. Resource mobilisation (F6)

Resources in terms of both finance and human capital are necessary as basic inputs to all the activities within the IS. The poor government signals and market formation have a direct impact on biomass supplies. Without a more established industry (and mature market) farmers are hesitant to grow the crops, yet without a critical mass of growers in an area, industry is not attracted to increase capacity. For some participants, these issues were directly related to limited development and siting of small-medium sized (40 MW) power stations in key, accessible locations, as well as a limited vision with respect to the diverse uses of these crops, beyond energy.

Intermediary companies encounter difficulties in securing biomass supplies from farmers as one supplier said "*we would burn more if we could access more*" (YSH5). This is attributed not only to the poor uptake by farmers, but to the intermittent supply from existing growers. A grower, also a farm consultant who recruits farmers to grow *Miscanthus*, explained that currently with no government grant and alternative options open to farmers, there is no positive message to relay to farmers. It was argued that biomass crops have got to be more obviously, and actively supported, as highlighted here by an industry stakeholder:

> "*Where the government needs to step in, is with a policy framework that makes this economically viable or economically attractive to early adopters, number one, and to put his money where his mouth is if that's the strategy you want to reduce carbon on farm, Miscanthus is a great way of doing it*".
>
> MISH2

There are also few supporting organisations or structures in the mainstream agriculture community to provide advice about PBC. With absence of support for these crops from government departments "*The industry is doing it by itself*" according to one stakeholder (WISH1). With regard to managing the shortfall and planning strategically, an intermediary supplier remarked that even if he was successful in signing up new growers, there is a long time period before the first harvest, saying "*I can't afford to wait 5 years*" (YSH5).

Considering other incentives, perennial crops are eligible within SFI for undersowing or margin planting actions but payments are small. Future opportunities for monetising the carbon stored in the soil with PBC through voluntary carbon markets was of interest to participants but currently there is reluctance as this is not standardised. Stakeholders suggested that, if the government is "*going to get serious about carbon*", they will eventually have to bring back some sort of planting scheme.

Some problems with current growers delivering on their contracts has impacted feedstock supplies, resulting in a shortfall in supply to power plants. Growers are often small scale and scattered (an inherent feature of non-productive parcels of land used for PBC in the farm landscape) leading to logistical issues for intermediaries making contract harvesting and collection inefficient and uneconomic. Quality of the biomass for feedstock can be a further issue as some growers were described as not valuing the crop, and sometimes storing it outside. Participants agreed that capacity would need to grow throughout the PBC supply chain if there was an increase in demand or policy incentives emerged. Being prepared for any new targets or market stimulus was considered essential. The risk of new intermediaries entering the supply chain as "*inexperienced opportunists*" in response to any incentives was highlighted by some industry stakeholders.

5.7. Lobbies, support from advocacy coalitions (F7)

Limited collaboration within industry, and between energy, biomass, forestry and farming regimes restricts any coherent lobbying to government. The NFU (for England and Wales) has partnered with the Drax group (the largest biomass power plant in the UK) and lobbied government but has become frustrated by the lack of response. As well as strengthening advocacy coalition to effectively influence policy making, it was agreed that there is a need to create new business models for farmers, taking into account local contexts and facilitating collaborative networks to mobilise support, resources and commitment.

PBC as an alternative land use and revenue lacks legitimacy compared to mainstream food production and agri-environment scheme support. The community that supports and influences farmers, advisers and land agents, are themselves described as conservative and are often locked into agrochemical and grain supply chain processes and sales (which would be negatively impacted if their farmer clients grew low input PBC), or committed to large landowner land use strategies. These aspects were identified by industry practitioners as one of the reasons that the PBC have been slow to upscale, since the advisory community can be very influential. Furthermore, the agri-environment NGO community who support government biodiversity and ecosystem service targets implemented through SFI, regard PBC as being in direct competition with their goals for low grade agricultural land.

6. Discussion

Results from applying the IS approach are consistent with previous research, that is, "the success of the introduction of PBC is not only determined by the crops themselves, but also by the social system that develops and implements them" [51]. This approach also reveals the multi-sectoral dimension of biomass crops which brings together actors from different areas operating at different scales, as noted by others in this context [28]. Using the seven IS functions as a heuristic to analyse results at both a macro-level, and farm context (micro-) level offers a rich understanding of the PBC IS and improves the explanatory power of IS function analysis. The findings show that PBC are enacted across levels, and that the 'innovation' in this sense is both an individual and a collective act [55]. Farmers are crucial actors in the IS as they produce biomass to meet feedstock demands, and their enrolment is shaped by interaction of IS functions with their own motivations (extrinsic, intrinsic), values, identities and social norms, as well as their capacity to act, to change and learn about different cropping systems and supply chains. The stakeholders operating at the farm level supporting and influencing farmers as well as across scales, equally have diverse perspectives and goals and these need to be aligned for IS functions to be achieved.

6.1. Reinforcing IS functions

Bioenergy scholars have argued that IS functions need to interact and reinforce each other to incite other system functions to be fulfilled, and that build-up of an IS requires the interplay of several actors within the system [54]. Overall the developments around PBC crops have been largely unsuccessful in fostering aligned networks and enrolment among the participating actors (such as farmers, researchers, supply chain actors, policy makers, environmental and NGO groups) suggesting that the IS functions are not reinforcing each other sufficiently to enhance the PBC system performance.

There is a small entrepreneurial supply chain sector (with various intermediaries), where competition is limited and networks are often fragmented. Some growers can be entrepreneurial, but many farmers are unconvinced that PBC represents a business opportunity (F1). Knowledge development occurs within a narrow energy-oriented domain, with limited cross sector interaction and a perceived absence of scientific evidence about PBC benefits and value, creating credibility concerns (F2). Centralised expert knowledge resides in the energy domain and is largely disconnected from mainstream farmer and adviser networks. Growers miss independent advice from within the agricultural regime and peer to peer or more diverse networks are not fully used for sharing knowledge. In general, farmers and the wider agricultural community (advisers and land agents) have limited awareness of the potential yield, income, ecosystem and GGR benefits and impacts of PBC (F3). With respect to guidance of the search (F4), perceived poor political commitment to biomass crops, or long-term strategy creates misaligned expectations and uncertainties among all actors. For farmers, this influences (entrepreneurial) decisions about long-term commitments, risk and investment. Poor policy signalling also creates industry and market uncertainty (F5) and undermines farmer confidence impacting mobilisation of biomass supplies, compounded by absence of government grant support for farmers, and leaving the industry to do it "*by itself*" (F6). Industry stakeholder lobbying has limited impact and legitimacy is questioned by the farming community in the context of competing agri-environment and food production regimes (F7).

This misalignment of functions can result in what Negro and Hekkert [54] call a vicious cycle where lack of consistent government signals and guidance (F4), results in the absence of a market (F5), and consequently limited confidence in and incentives for entrepreneurs to expand production (F1). In turn, this can lead to reduced support and lobbying (F7) for better institutional conditions and knowledge development (F2) and reduced networking (F3). Only addressing these collectively, they argue, can the IS function well. Applied as an explanatory model from a macro-scale perspective as Negro and Hekkert intended [54], the assumption is that for PBC, once these functions are fulfilled, upscaling will follow. However, when overlaying this big picture model with insights from farm level context analysis, more nuance and complexity emerges, showing how achieving IS functions is iteratively entangled with farm and individual actor level processes and decisions. Fig. 2 illustrates this relationship, inserting the voices of the interviewees shows how micro-level actors both respond to and shape each function outcome.

6.2. Exploring the micro- and macro-level linkages

Regarding entrepreneurs (F1), the importance of supply chain intermediaries in developing market and industrial capacity, building confidence in the farming community and lobbying government is clear, and this is consistent with other findings [6,11]. They can act as influential 'middle actors' who embody agendas of change in different areas and promote PBC [68,69]. Farm advisers and land agents act as influential intermediaries, many resistant to change and often cautioning farmers about the risks of growing PBC, highlighting more familiar revenue options (reflecting institutional norms), while some identified entrepreneurial opportunities for farmers with respect to stacking different revenue streams with PBC. Evidence for the benefits from such strategies integrating PBC into the farming system is now emerging [15].

The entrepreneurial role of growers is less clear. They are exposed to many uncertainties and risks as they negotiate PBC as a business opportunity and respond in different ways [70]. Capacity to absorb risks varies according to farming system characteristics (e.g. size, tenure, level of investment in other enterprises and a positive grower attitude towards innovation of new products and markets). Some growers might be characterised as entrepreneurs (innovative, risk takers) intending to grow the business [71]. This aligns, for example, with survey results in the USA showing that, when landowners regard bioenergy as a progressive technology, this significantly increases their willingness to grow bioenergy crops [72]. Others however grow PBC as a low maintenance

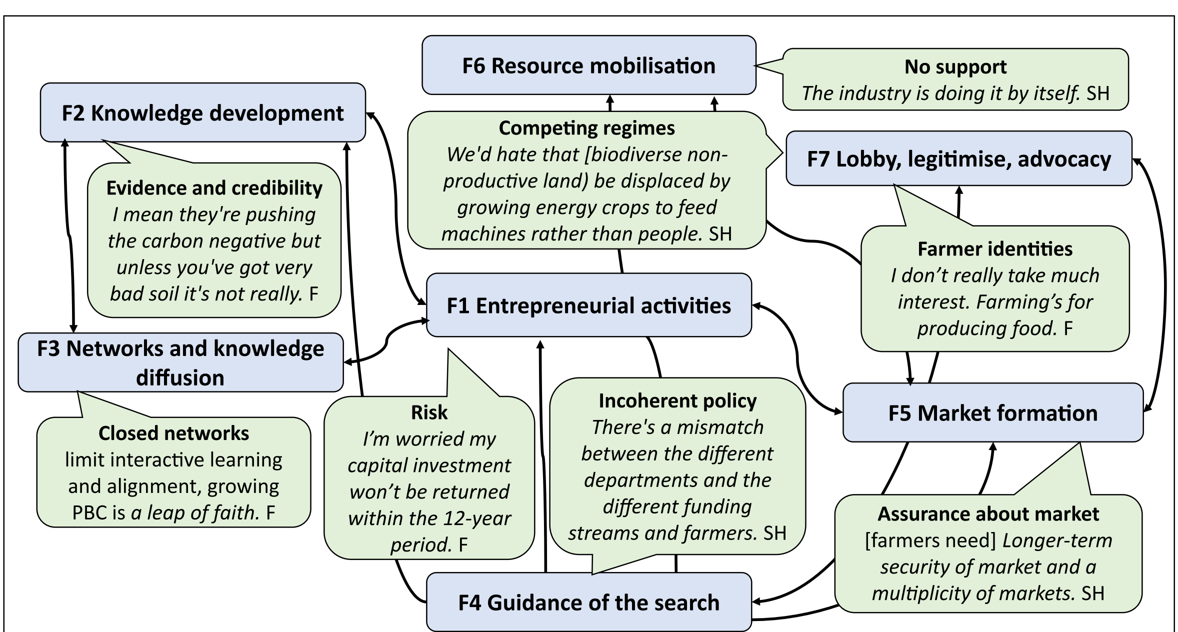

Fig. 2. Intersecting macro-level IS functions and micro-level actor level decisions (F = farmer, SH = stakeholder).

or derisking strategy [36,40]. Rather than entrepreneurs with a crucial role as business or 'farmer-actors' [73], diversifying to supply biomass resources, growers are more often regarded as passive suppliers with little inherent agency when biomass targets are set by (an energy-domain) policy. These results highlight the complexities of different roles with reference to innovation [74] and what it means to be entrepreneurial [75] particularly in the context of the 'new' functions which farmers are expected to engage in [76]. Given the call to widen the scope of who we include as entrepreneurs in the IS, there is a case for considering farmers and the various private actors in the networks who mobilise biomass resources, as entrepreneurs [77].

Regarding knowledge development (F2), significant research and development (R&D) investment in PBC has not translated to the wider agricultural community and learning processes are limited to a few actors across the supply chain. The disconnect across sectors narrows both the composition of actors and the scope of knowledge produced. Claims by those in the supply chain about revenues, impacts and benefits are contested by farmers and other stakeholders as they perceive reliable evidence to be missing. This has been noted elsewhere [14], for example profitability, real and potential yield and revenue estimates from growing *Miscanthus* has been questioned [48]. This in turn has a direct impact on entrepreneurial risk taking and business decisions (F1). Furthermore, farmers themselves have little opportunity for building their own experiential knowledge or learning by doing or learning-by-using which has been shown to be central to IS [12], and in other farming contexts [78].

With respect to networking and diffusion (F3), network composition in the supply chain is narrow and closed and limited interactive learning opportunities constrain stakeholder enrolment as well as actor expectations [13]. At the farm level context, supply chain interaction with trusted farmer or adviser networks, which are typically used to acquire, share and consolidate knowledge with peers or farming experts [79] is limited. The importance of knowledge networks to support learning has been widely demonstrated in the agroenergy sector for farm biogas production [80] and more widely in transition studies [81].

Guidance of the search (F4) is the most significant of the functions impacting upscaling potential of PBC, and requires a more coherent and clear strategic policy in the direction of PBC for GGR to ensure stronger enrolment commitments from a wide range of stakeholders, and aligning expectations. Previous research identified a need for more joined-up policy support inclusive of all land use to create a sustainable market for the biomass produced [82]. According to Foxon [12] only unambiguous long-term support for new and renewable energy will have a self-reinforcing effect upon the IS. A shared vision can engender a cumulative process of exchanging ideas between supply chain actors [30] and is about creating a goal for the IS, to orient other functions such as entrepreneurial activities and knowledge development [53]. Our study has shown the importance of strong signals (F4) for farmer enrolment and entrepreneurship (F1) as well as the importance of fulfilling other functions (F5 and F6). Farmers confront a range of uncertainties while entering the bioenergy market [14], and this is exaggerated in a post-Brexit environment. This uncertainty reinforces the main barriers of high establishment costs and long-term commitment. These barriers are also entangled with the values, farming habits and identities associated with annual cropping cycles and food production. Whilst the cultural capital associated with conventional food production persists for many, some growers do identify as energy producers, or take a pragmatic decision to grow the crops. This dissonance between values and actions has been shown elsewhere where farmers become renewable energy producers although they believe it is 'not right' [83]. Incorporating an understanding of farmers as active agents in the biomass IS allows their divergent values and identities to be considered. Farmers also question government priorities and encounter multiple expectations at the farm level for nature, food, energy, carbon and water quality, which do not align. In response they tend to look to more familiar, versatile short-term support from schemes which are embedded and supported in the agri-environmental regime. Stakeholders were also found to have diverse value judgements on aspects of PBC and biodiversity and ecosystem services and attach different symbolic meaning to non-productive land in different ways, as shown by previous research [84].

Market formation (F5) is important to farmers (as entrepreneurs) and they need to have identified a market for the life of the crop [72]. Participants called for the reintroduction of ECS, but more as a sign of confidence from the government than as a financial incentive per se noting that farmers' annual cropping mindsets need to shift. Encouraging a greater number of trusted supply chain actors were also highlighted as areas for action. Diversified and local markets in particular would align with suggestions that PBC can be better integrated into farming systems and landscapes creating different revenues streams.

Resource mobilisation (F6) requires primarily the production and mobilisation of biomass. It also requires credit facilities already offered through banks being extended. Opening up access to local markets would allay farmer concerns about the carbon footprint of haulage, either with more large-scale power plants or small-scale biomass boilers or new markets. Building human capital across stakeholders in the supply chain and the agricultural domain would strengthen networking and investing in agricultural knowledge systems. As Turner et al. [53] argue, the ability to find and attract competent advisers in innovation trajectories is important.

The premise of F7, lobbying and legitimacy, is that the innovation meets resistance from established coalitions in the incumbent regime and needs advocacy to lobby for resources and support to create legitimacy [51,85]. This study has shown that for industry stakeholders there is frustration that despite lobbying, there has been little policy response. This is exacerbated with the incumbent agricultural regime in post-Brexit flux with multiple coalitions linked to different land use demands (food, biodiversity, forestry). The results also show that actors and networks within the agricultural regime, are largely conservative and have an interest in keeping the status quo both with respect to conventional agriculture and the agri-environment where established support mechanisms offer farmers more guaranteed and familiar transition pathways. There are disconnects between different regimes, and biomass production, and bioenergy continues to "sit outside the food and farming box" as Warren et al. ([31], p. 176) observed, with the cultural divides between farming and biomass (crops and trees) disrupting many functions.

New solutions imply displacement of old practices and dissemination of alternatives, often interfering with established practices among multiple stakeholders. Accordingly, stakeholder alliances are needed to advance new approaches and integrate them into existing production and incentive systems. Some participants were open to creative alternatives, for example, PBC options could be integrated into SFI actions, or be part of voluntary carbon markets to allow multiple revenues on farm. This would require cross sector knowledge development (F2) and policy alignment (F4) and be backed by credible evidence (F2). These suggestions align with those from emerging research which identifies synergies in PBC production, food, energy production and ecosystem services in farming landscapes [15].

7. Conclusion

Using the seven IS functions to structure macro-level analysis, together with micro-level analysis of the farm level context offers a deep understanding of barriers and enablers to PBC production. It allows us to understand the dynamic processes (functions) between the structural components of the system: actors, networks and institutions and to unravel linkages across scales which have hitherto been little understood or theorised in the bioenergy context.

Firstly, for actors, the findings demonstrate the significance of micro-level actors in the IS. Farmers and entrepreneurs look for assurance from policy and the markets, use their networks to explore and validate new information, and follow their own motivations, expressing different entrepreneurial behaviours in response to IS uncertainties, and in turn shaping function outcomes. Thus, with respect to Edquist's [86] observation that actors are the players and the institutions are the rules of the game, actors influence functions by performing innovation activities and institutions are rather passive and are made by or evolve as a result of the behaviour of actors [52]. Other actors operating at the farm level representing the agri-environment or the biomass industry also articulate and enact their own agendas, cognitive and formal rules and norms, and in doing so affect functions. Secondly, networks are important with many interactions and dynamic relationships among individuals or groups of actors and organisations. However they have been found to be insufficient, developed across regimes and scales which has limited knowledge development, sharing and learning opportunities [87]. Thirdly, whilst PBC is a cross cutting issue at the farm level, the relevant actors are often embedded in and influence distinct energy, food production and agri-environment regimes, each with their own institutional contexts, underpinning policies, funding instruments and incentives, sociocultural as well as technical norms, and shared expectations.

This research contributes to the field of IS, empirically by offering a comprehensive understanding of barriers and enablers to PBC upscaling in the UK based on extensive data collection from a wider range of stakeholders. Methodologically, it extends insights by drawing on analysis of contemporary data, rather than historic analysis which is typically used in IS studies. It also helps to order the multifaceted information from a number of qualitative data sources but at the same time allows the research to go beyond the boundaries of the functions identifying, for example, the importance of different interacting regimes. Theoretically, the approach advances perspectives from rural studies which hitherto have privileged farmers as the micro-scale actors, and focused on adoption factors and sociocultural influences. Geels [57] argued that focusing on a particular type of agency, such as the capacity of actors to construct their world-views, to act and to generate meaning, has restricted researchers to a relatively narrow analysis. Instead, other properties (e.g. routines, capabilities, resources, positions, business goals) of the capacity to act have been demonstrated in this study, such as farmers' entrepreneurial capacity to act and industry actors' capacity to act collectively. In highlighting these, the research contributes to wider debates about incorporating micro-scale actors and their agency into macro-scale transition models. The research also enriches IS function literatures which have focused on technological innovations and largely ignored social relations in the bioenergy domain.

IS can be a useful tool for informing policy makers in terms of identifying: intervention points to improve overall system performance, strategies of specific actors, and the extent to which resources are available [12]. This research supports past studies which have identified the need for continuity in bioenergy policy making, however we also note that coherence in policy is equally important, particularly given the competing land use demands in relation to the energy-food-environment nexus and the current context of uncertainty. How farmers and other actors at the farm level negotiate these demands is particularly relevant to policy makers' ambitions for large scale PBC planting and GGR projections.

Whilst the empirical data for this study was collected in the UK, the findings are transferable to international contexts where experiences with upscaling PBC production have been very similar. The theoretical development, which connects actor level to system level characteristics and combines rural studies and IS scholarship, is universally applicable.

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CRediT authorship contribution statement

Julie Ingram: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jane Mills:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Honor Mackley-Ward:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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