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Resilience and Livelihoods in Supply Chains (RELISC): An Analytical Framework for the Development and Resilience of the UK Wood Fuel Sector

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Abstract: Bioenergy is an important renewable energy source in the UK, but the bioenergy industry and in particular the wood fuel sub sector, is relatively under-developed. Socioeconomic factors have been identified as critical for facilitating deployment levels and sustainable development. However, previous studies have mostly assessed these factors using quantitative methods and models, which are limited in assessing pertinent contextual factors such as institutional/regulatory governance, supply chain structure and governance, capital resource availability as well as actor decisions. As a step further, this research engages with these under-explored aspects of the system by developing a new analytical framework: the Resilience and Livelihoods in Supply Chains (RELISC) framework, which was designed by linking Value Chain Analysis, the Sustainable Livelihoods Approach and a supply chain resilience framework. Its application to a UK wood fuel supply chain produced useful insights. For example, the structure of the chain revealed a high level of dependency on a particular end user and contractor. Key institutional governance was critical in sustaining natural resources and providing access to finance. Internal supply chain governance was limited in ensuring the sustainability of resources and lack of actor awareness and interest were also limiting factors. In addition, five capital analyses revealed gaps in skills, networking and physical infrastructure. Finally, the design of the novel RELISC framework enables it to engage with diverse aspects of the system holistically and its application generated practical recommendations and strategies for supply chain resilience and sector growth, which are useful and applicable to other emerging sectors.

Keywords: wood fuel supply chains; bioenergy; socioeconomic factors; resilience; development; energy policy implications

1. Introduction

It is recognised that bio-energy has a significant role to play if the UK is to meet its low carbon objectives by 2020 and 2050 [1]. As a result, the UK Government is committed to increasing penetration levels of bioenergy from its current low level of 7.3% of total energy [2]. Presently, bioenergy contributes 70% of all renewable energy with woody biomass and plant biomass (energy crops and straw) constituting the largest share of all bioenergy resources [3]. However, the bioenergy industry in the UK is still an emerging sector. In particular, the wood fuel sector, which is the focus of this paper, is characterised by slowly growing demand and a fragmented supply base [1]. Much attention has been given to bioenergy's environmental credentials but it has also been recognised that the growth of the sector depends on its impacts on individuals and communities [4]. Several studies have identified social and economic barriers within the wood fuel sector such as lack of cost competitiveness;

institutional, infrastructural and social constraints; and benefits such as increased income, positive livelihood impacts, job creation and security of energy supply as being critical to its development and resilience [4–7]. Accordingly, people perceive socioeconomic benefits as more important goals for implementing bioenergy projects than its environmental benefits, possibly because of the immediate and visible impact on their lives and communities [4].

Socioeconomic impacts of bioenergy can be classified along different dimensions such as macro level, social aspects, supply side, and demand side [8]. In previous research, these have been assessed by a wide variety of socioeconomic frameworks and models, and in studies ranging in scope from small case studies to regional or national scale. Studies have for the most part been based on a combination of different quantitative assessment methodologies. For instance, macro level socioeconomic impacts have been assessed using input-output analysis based on national and regional level statistical data, to produce indicators such as percentage sector contribution to GDP, products exported, investment in the sector, jobs creation and infrastructural development [6,9–11]. Other frameworks have employed partial and general equilibrium optimisation methods to evaluate the impact of different energy and bioenergy policy on the sector at the national level [12,13]. For social aspects, indices such as increased standard of living and social cohesion and stability have been derived using national statistics, surveys and focus groups at the macro level. At the micro level, social impacts such as working conditions, gender, land and food issues to name a few are generally derived from company records, interviews and focus groups [10,14]. The supply side impact assessments may involve cost benefit analysis and feasibility studies [15,16]. Typical financial indicators such as Net Present Value (NPV), Internal Rate of Return (IRR) and Simple Payback Period are also used [17]. Finally, for demand side effects, indicators such as employment, income and wealth creation as well as growth of related industries can be measured using methods based on the Keynes multiplier effect [10,18] using national, regional and local statistics [19].

Some of the quantitative methods outlined above are limited by the emergent and fragmented nature of the sector given that wood fuel resources are often produced as by-products of related industries in an informal and fragmented manner. Comprehensive analysis is also constrained by a general lack of understanding of UK bioenergy institutional and supply chain configurations and [20,21] along with the short time horizons, difficulties in obtaining bioenergy specific data and sometimes a lack of reliable empirical field data [4,19,22]. Furthermore, it has been recognised that the extent of any socioeconomic benefit within such chains depends upon a range of additional factors such as:

- Policy/regulatory/institutional contexts
- Company and organisational structure, practices and processes [4,14,22,23]
- Level and nature of capital investment
- Availability of resources [19,24]

For example, the need to consider consumer preferences as well as barriers in the implementation of relevant policies to determine the actual impacts of the policies was identified in a partial equilibrium study [12]. For the Keynes Multiplier, it is recognised that the percentage of expenditure spent on local goods and services is entirely dependent upon the availability of skilled labour and equipment in the region [25].

To date the aim of most socio-economic methods and models has been to quantify or describe the potential socioeconomic impacts of a bioenergy sector or project. However, tackling the factors highlighted above has been recognised as an important focus for future research [4,8,19,23]. This paper proposes that it is also necessary, if not more important, to determine how socioeconomic benefits can be derived and sustained, by shifting from mainly quantification and description to exploring the dynamics underpinning socioeconomic benefits and their impacts on sector growth and resilience. This widening of perspective requires the development of a new analytical framework, which can engage with and determine the extent to which institutional processes, resource management and

social context factors may affect the actual realisation and longer term sustainability and resilience of socioeconomic benefits in the bioenergy sector. Therefore, the primary aim of this paper is to set out a new analytical framework called “Resilience and Livelihoods in Supply Chains” (RELISC) designed to address this gap. The paper first sets out the structure of RELISC and the assumptions behind it. The paper then moves on to illustrate its application to the UK wood fuel sector, in order to determine its utility. The results indicate that the novel framework is useful on its own or as a complementary tool used alongside more quantitative approaches, because it can engage with diverse contextual issues holistically, in order to understand and address their impacts and then determine the factors and strategies required to derive and sustain socioeconomic benefits and sector growth. It also indicates the applicability of the framework to other emerging sectors.

2. The RELISC Framework

The RELISC framework (Figure 1) integrates two key approaches that have been used extensively within developmental studies, namely Value Chain Analysis (VCA) and the Sustainable Livelihood Approach (SLA) in addition to a supply chain resilience framework. VCA is a tool developed by the Institute of Development Studies, University of Sussex, UK, designed to explore the set of activities that a company performs in order to deliver its product(s) and service(s) to the market. VCA includes the suppliers that provide inputs necessary for the company to deliver its product(s) and services(s) along with their own suppliers [26]. SLA was brought to the fore by the UK Government White Paper on International Development. The aim was to develop sustainable livelihood strategies, which promote human development and help to conserve the environment [27,28]. VCA and SLA are very much people-centred approaches, but they have a key difference in that VCA is applied to actors in supply chains whilst SLA in its original form was designed to assess household livelihoods.

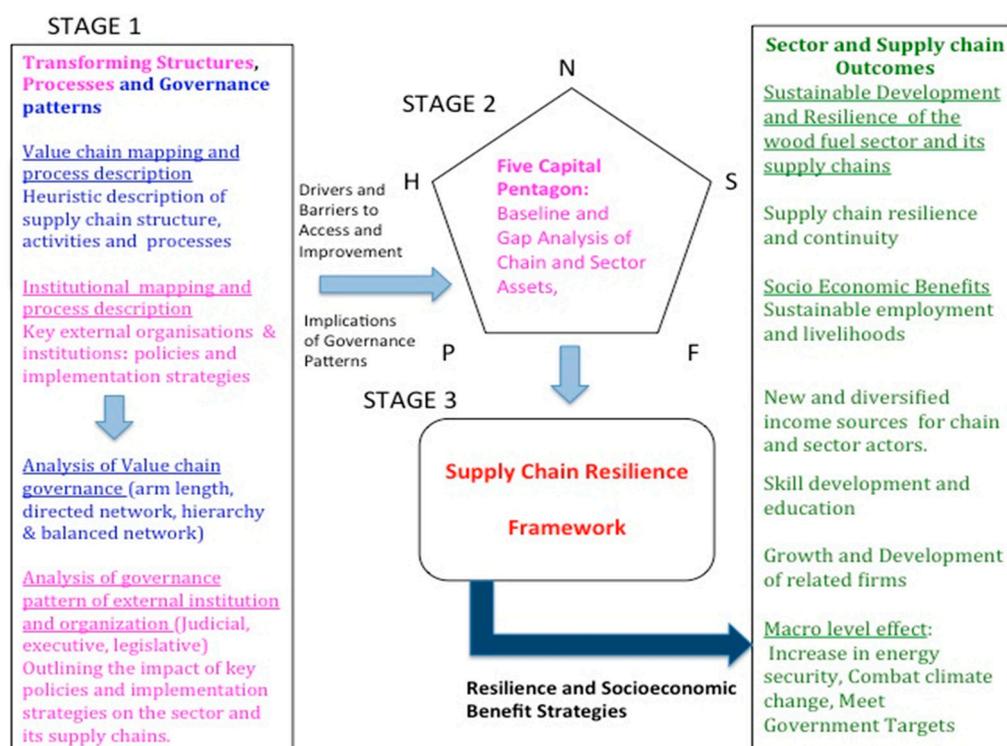


Figure 1. Outline of the “Resilience and Livelihoods in Supply Chains” (RELISC) framework.

RELISC adapts two major VCA concepts: value chain mapping and governance pattern analysis. Value chain mapping is a heuristic tool, which in the current application provides an avenue to describe wood fuel supply chains, to give a better understanding of the activities and the type of enterprises

within the emergent and fragmented supply chains in the sector. Governance pattern analysis helps to examine the inter-firm relationships and institutional mechanisms through which coordination of activities in the chain takes place [29]. RELISC also adopts three key components of the SLA, namely the five capitals assessment, the transforming structures and processes and the vulnerability context. The five capitals (Natural, Human, Social, Physical and Financial) assessment helps to identify the available or scarce capitals of different types and how they affect the current or potential socioeconomic benefits, as well as helping to identify adverse trends and events as vulnerability factors. For example, in wood fuel chains, natural capital can refer to the amount of sustainable woodland resources available to the supply chain while human capital can represent the skills and knowledge that are available. SLA attempts to bridge the gap between macro and micro levels by acknowledging the importance of macro level policy and institutions to the socioeconomic options of communities and individuals using the transforming structures and process component [30,31]. Finally, the vulnerability context examines the resilience of these socioeconomic benefits to a variety of trends, shocks and stresses within and outside the system. The latter can include a change in policy, economic trends, natural disasters and competition [32]. As stated earlier, in addition to the two approaches, concepts from another existing approach “the Supply Chain Resilience Framework” (SCRF) [33] is used to determine the capacity for an enterprise to survive, adapt and grow [34]. This supply chain resilience aspect is particularly important given the emerging nature of the UK wood fuel sector [35]. SCRF was first employed in response to transport disruptions and the outbreak of foot and mouth disease in early 2001 [36], but here the focus is upon risks or vulnerabilities internal and external to the supply chain as a result of process and control (governance) patterns [37].

To determine factors and strategies that could help to achieve and sustain livelihoods and socioeconomic benefits, a version of a SCRF was derived from capability factors identified by [33,37] and recently reviewed by [38]. These include flexibility, visibility, adaptability, anticipation, recovery, dispersion, collaboration, market position, security and financial strength. Figure 1 now shows how the different components from the VCA, SLA, and the supply chain resilience framework are integrated in the RELISC framework by using the following colour code. The Value Chain Analysis: Blue, The Sustainable Livelihood Approach: Pink and the Supply chain Resilience Framework: Red. Finally, the outcomes are described in green.

Stage 1 of RELISC is the “Transforming Structures and Process” (TSP) stage, which has been modified to include value chain and institutional mapping and process description which describes the structure and processes within the supply chain as well as the network of key external organisations relevant to the chain.

Stage 1 (TSP) also involves the analysis of value chain and external institution governance to determine the type of governance these organisations exert on the supply chain as well as governance patterns within the supply chains.

The information derived from Stage 1 (TSP) are presented as drivers and barriers to access and improvement in terms of the implementation of institutional policies and the implications of external and internal governance patterns. This information is used to inform the baseline and gap analysis of capital in the five capitals pentagon (FCP), which is Stage 2.

The gaps in Stage 2 (FCP) and the trends and events that may adversely affect each capital or indeed the sector are identified as vulnerability factors and these are further analysed in Stage 3, based on concepts of “the Supply Chain Resilience Framework” (SCRF) [33] including flexibility, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organisation, market position, security and financial strength. These factors have been merged into natural groupings described in Section 3.3 to form the supply chain resilience framework, which is Stage 3 of the RELISC framework, as shown in Figure 1.

Finally the RELISC framework outlines outcomes of a sustainably developed and resilient wood fuel sector; these include supply chain resilience and continuity, socio economic benefits such as sustainable employment and livelihoods, new and diversified income sources for chain

and sector actors, skill development and education, growth and development of related firms as well as positive macro level effects such as increase in energy security, combat climate change and meet government targets.

3. Application of the RELISC Framework

3.1. Choice of Case Study

In order to test the utility of the RELISC framework, it was applied to a wood chip supply chain selected as a case study. The chain was selected because woodchips represents over 60% of all the wood-fuel processed and used in the UK and the supply chains are arguably the most established amongst the different bioenergy types.

The location of the case study was in the South East of England. Woodland cover in this region amounts to about 322,683 hectares and comprises a mix of traditional broadleaved trees (Beech and Oak) as well as conifer trees (scot pines) and traditional coppice species such as sweet chestnut and some mixed woodland. Total standing volume for both conifers and broadleaves is about 68,686,000 m³ [39]. It should be noted that less than 300,000 m³ per year of wood is currently being harvested from woodland in the South East of England [40]. The current timber production is less than 20% of the potential annual increment of 1,492,187 m³ per year and less than 1% of the total standing volume of both conifer and broadleaves in the South East [41]. Thus resource availability is not limited by availability of trees but depends on increased timber production. One of the major reasons for the low timber production in this region is that private owned woodlands are generally not actively managed. However, current campaigns by the Forestry Commission to bring 75% of the forests into management would yield a potential sustainable harvest of about 1,000,000 m³ annually; consisting of 270,000 m³ conifer sawlogs, 70,000 m³ broadleaves and 730,000 m³ poor quality wood. This amount of poor quality wood when seasoned can supply about 1,500,000 MWh of heat to about 100,000 homes [42].

3.2. Data Collection

Semi-structured and questionnaire-based interviews were the principal modes of data collection (Appendix A). The fieldwork was conducted over a period of three years from 2011 to 2014. The lead firm was visited three times to conduct semi-structured interviews and to observe their operations. Key members of staff interviewed include the owner of the lead firm, field and logistics manager, forestry and operations manager and the business development manager. Afterwards telephone interviews were conducted with the owner of the firm and his forestry and operation manager to verify and update some of the information. Semi-structured interviews were also conducted with other key actors in the supply chain, based on a snowballing sampling approach, where referrals and contact information were derived from lead firm interviewees. The actors interviewed were three chipping contractors, two harvesters as well as two personnel in the transport and haulage firm. Further, to determine the transforming structures and their influence on the sector as a whole, interviews with stakeholders in six key external organisations, identified by supply chain actors using the same snowballing approach as above were conducted. They include the Forestry Commission, where two woodland programme officers and three regional woodland advisors (covering the South East, South West and East of England) were interviewed. Members of a woodland cooperative were also interviewed, including the co-ordinating officer, three woodland owners, one local authority representative and two owners of independent wood-fuel processing firms to gain insights on their functions and the impact of social capital. Furthermore, three wood-fuel training providers in three wood fuel training companies, HETAS, Lantra and Ignite (Rural Development Initiatives), were interviewed. Finally, two personnel from the UK Government's Department of Energy and Climate Change, dealing with the Renewable Heat Incentive and Bioenergy policies respectively, were interviewed.

The Questionnaire-based interviews were conducted to clarify responses to open-ended questions in questionnaires that were sent to 30 end users and 10 woodland owners. Six woodland owners and 15 end users responded and then were interviewed based on the questionnaires. Key questions for woodland owners include: drivers and reasons for owning woodland, its management and experiences with the Forestry Commission and the UK Forestry standard, and the motivations for going into wood fuel production. For the end-users, the key questions were: description of their wood fuel system, drivers for installing the system and challenges and problems at various stages, i.e., planning, installation and use.

This makes a total of 28 semi-structured interviews and 21 responses received from the questionnaire-based interviews.

3.3. Data Analysis

In order to map out the supply chain structure, responses to interview questions on chain structure as well as observed activities during visits were the key sources of information on the organisations and processes within the supply chain. To determine the governance pattern of the supply chain and external organisations, responses to relevant questions designed according to the criteria of typical Internal and external governance patterns described in Table 1 were used to determine both external and supply chain internal governance pattern.

Table 1. Typical Internal and External Governance Patterns and Criteria (adapted from Kaplinsky and Morris, 2001).

Internal Governance Pattern and Criteria	
Market based / Arm's length	Many customers/many suppliers Repeat transactions with suppliers or customers No technical assistance given to suppliers or producers
Balanced Network	Supplier has various customers Supplier has few customers, customers have few suppliers Intense information flow in both directions Both sides have capabilities hard to substitute Resolve problems through negotiations rather than threats or exits
Directed network Buyer driven/producer driven	Customer or producer defines the products (design and technical specification) Main customer or supplier takes or supplies at least 50% of output Monitoring of performance by customers or suppliers Providing technical assistance to suppliers or producers
Hierarchy	Vertical integration of several chain stages within the firm Supply enterprise is owned by customer Limited autonomy to make local decisions, instructions from "headquarters" required.
External Governance Pattern and Criteria	
Legislative	Setting standards and laws for participation in the supply chain or sector mostly in terms of quality, environment and performance
Judiciary	Monitoring the performance of supply chain actors in meeting standards and obligations
Executive	Providing support in supply chain operations and management to meet standards and improve performance

The five capital gap analyses and sector wide vulnerability factors were derived from direct interview responses from supply chain actors and sector actors on the availability or scarcity of key capital resources as well as from secondary statistical sources. Further, a range of responses were derived from the interviews on the impacts of the governance patterns, these were coded according to different emerging themes to derive the implications of the different governance patterns. Finally, natural groupings of the capability factors in the supply chain resilience framework as shown below

were used to analyse the information derived from the first two stages of the RELISC framework to derive factors and strategies for enhancing supply chain resilience.

- Visible Capacity: Improvement, availability and visibility of capacity and reserve capacity;
- Flexible Adaptability: Ability to quickly change in processes, sources and thinking;
- Collaboration in Dispersion: Decentralisation of capital and markets + cooperating within the network and risk sharing;
- Anticipate and Recover: Ability to discern potential events and situations + ability and plans to return to normal or better; and
- Securing Market position: Identifying, defending and improving firm or sector market share, cooperation and lobbying with governments and the public. Identifying and involving end users and meeting their needs.

4. Results of Applying the RELISC Framework

4.1. Value Chain Mapping and Internal Governance Patterns

The case study supply chain consists of the lead firm and other firms or individuals involved with the sourcing, chipping and supply of wood fuel chips to the customers of the lead firm. The lead firm has 10 permanent full time staff, consisting of two co-owners, administrative and accounting personnel as well as operations, business development/marketing, timber and project managers. Part-time members of staff include a delivery driver and a wood chip handler.

A typical supply chain process begins when a timber manager locates woodland resources within a 20 mile radius of demand and contacts the woodland manager/land agent/woodland owner to buy the wood which may be standing or at the road side. A harvester fells the trees with a felling license and harvesters or forwarders take the timber (round wood of about 14 cm or less) to the roadside. Afterwards, timber hauliers take the trees to a hub where a chipping contractor processes the seasoned wood into chips that are transported to the end-user using a bulk haulage company. The supply chain delivers to about 30 customers comprising schools, leisure centres, care homes and airports on three-year rolling contracts. The airport terminal accounts for about 80% of business turnover. The supply chain consists of about 80 individuals. Based upon the criteria in Table 1, the governance patterns of the firms in the supply chain are described in relation to the lead firm in Figure 2.

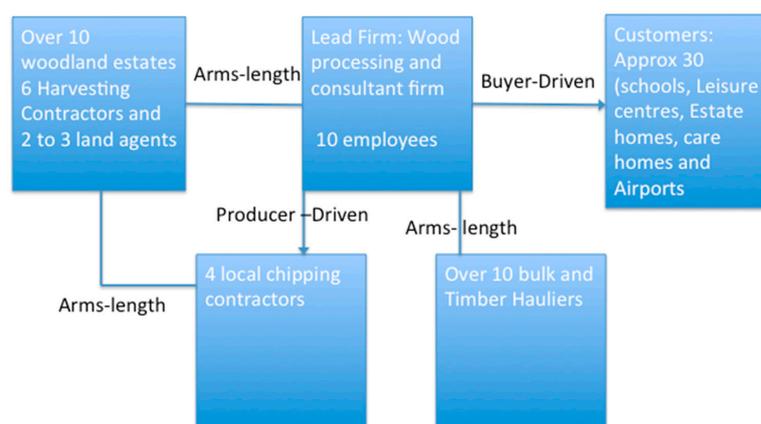


Figure 2. Supply chain structure and internal governance patterns.

Since there are over 10 woodland estates within the chain, the relationship between the woodland estates and the lead firm could be described as “arm’s length” because within reasonable distances there are a number of wood land estates where the lead firm or its harvesting sub-contractors could source wood and purchasing practise is on a “pay as you go” basis. On the other hand, the lead

firm exerts a producer driven governance over the wood chipping sub-contractors as it specifies the requirements for the chipped wood in accordance with customer preferences. One wood chipping contractor mentioned that the lead firm is his main client, thus he is largely dependent on the lead firm for his wood chipping business which is more than 60% of his total turnover. Further, arms-length associations characterise the relationship between the timber hauliers and the lead firm because of the large number of hauliers, lack of contracts and pay as you go basis for transactions. All the timber haulage firms contacted report less than 10% of their turnover from their wood fuel business. Finally, since demand is a main driver for establishing supply chains with hubs close to the end-user, and wood chip specifications are set according to customer needs, the overall internal governance pattern of the supply chain is buyer-driven, as shown in Figure 2.

4.2. Implications of External and Internal Governance and Five Capital Gap Assessment

The implications of supply chain and institutional governance patterns, as well as the impact of gaps in the five capitals on different processes relating to the sustainability and availability of natural resources are shown in Table 2. The results highlight the significant role of the Forestry Commission's governance and the need to create awareness and interest amongst private woodland owner given that resource availability depends on timber production from unmanaged woodlands as earlier stated and there is a general lack of skill and interests in this group.

The implications of supply chain and institutional governance patterns, as well as the impact of gaps in the five capitals on different processes relating to people and networks are highlighted in Table 3. The results illustrate how the overall buyer/end user governance of the chain and accreditation organisations requirements, governs the need to improve skill for wood chip quality and boiler installations. Further, the analysis highlights key sources of social capital namely the local "Wood Fuel Group" and a Government lobby group. The "Wood Fuel Group" aimed to promote income diversification for woodland owners and contractors; and reduced costs of heating for the buyers. It comprised about 20 individuals including wood fuel suppliers, end-users, local authority representatives, forestry commission representatives and workers in conservation bodies, and met every six months. The group was sponsored by a conservation charity. The lobby group, on the other hand, engaged with the local and national Government on various issues associated with wood fuel supply and management and were actively involved at the time of the research in the successful renewable heat incentive campaign. Finally, the role of local government legislation in facilitating the uptake of biomass heating by asking developers and builders to consider biomass as a default option was also noteworthy.

The implications of supply chain and institutional governance patterns, as well as the impact of gaps in the five capitals on different processes relating to financial access and infrastructure are highlighted in Table 4. In terms of financial resources, the lead firm reported a turnover of about £3 million in 2013 (Interviews 1, 4) and this was said to have increased steadily from 2007 when the firm was established. The lead firm was also said to provide the chipping contractor with 60% of their turnover. In general, all actors reported that their profit margins were narrow. Therefore, capital investment is largely dependent on financial grants and interest free loans. For instance, most of the supply chain actors interviewed, except for a few woodland owners and the haulage company, had at some time received financial aid from regional or local funding sources as well as the Department for Environment, Food and Rural Affairs (DEFRA) and the Forestry Commission. The majority of grants issued to the wood fuel sector appeared to be used to improve physical capital as shown in Table 4. Further, the results highlighted the role of OFGEM (Office of Gas and Electricity Markets) in determining eligibility for the Renewable Heat Incentive (RHI) Program as well as the hurdles and restrictions faced by supply chain actors in accessing funding and the sustainability requirements of the RHI. The RHI is an incentive for end-users to take up renewable energy technology such as wood fuel boilers [43] and helped to increase demand, which in turn stimulated growth and job opportunities, a reflection of the buyer driven governance of the sector.

Table 2. Sustainable resource availability and sourcing: Implications of governance patterns and capital gap analysis.

Process	Governance Pattern and Actors	Implications of Governance Patterns	Gap Analysis of Capital and Vulnerability Factors
Sourcing of sustainable resource	<i>Arms-length</i> Lead firm to woodland owners, harvesters and land agents.	The arms-length governance means that the lead firm has a number of woodlands (10) to source resources, However, it implies that the lead firm has little influence on ensuring compliance to sustainability standards (Interview 1, 2).	Limited availability of adaptable harvesting equipment for hard to access terrains reported by harvesters (Interview 8, 9).
Monitoring and issuance of felling licenses	<i>Judicial and Executive</i> Forestry Commission to Woodland owners, land agents and harvesters.	Only woodlands with felling licences are used by the lead firm as a result of the judicial and executive governance of felling licences.	Limited number of people (human capital) to monitor compliance as reported by woodland officers (Interview 13, 15).
Campaign to bring woodland into management	<i>Executive</i> Forestry Commission to Woodland owners, land agents and harvesters.	The Forestry Commission supports the campaign by providing financial capital in form of grants and human capital in form of woodland advisors to draw up woodland management plans.	Lack of awareness, skills and interest amongst woodland owners and general public. Risk of Job loss for woodland officers because of lack of demand for woodland management plans by woodland owners (Interviews 12, 13). A woodland programme officer states that “ <i>My job is actually at stake unless there is an improvement in the uptake of this programme</i> ”
Administering the forestry and sustainability standards	<i>Legislative and Executive</i> Forestry Commission to Woodland owners, land agents and harvesters.	Monitors and updates the Forestry standard, Promotes and provides information on best practice.	Lack of skill and different objectives and plans for the land limits small private woodland owners from implementing best practice (12, 19, 20). A woodland owner states that “ <i>I use my woodland for family recreation, I suppose I manage it to my standards, I am not sure what the forestry standard can do for me</i> ”
Promoting wood fuel and woodland management	<i>Executive</i> Conservatory bodies and Trusts.	Provides financial capital in form of grants for wood fuel establishments i.e., woodland owners and supply chain actors.	Limited use of existing human capital to monitor environmental impacts of wood fuel as reported by woodland owners (18, 19, 20).

Table 3. People and networks: Implications of Governance Patterns and Capital Gap analysis.

Process	Governance Patterns: Supply Chain Actors and Institutions	Implications of Governance Patterns	Gap Analysis of Capital and Vulnerability Factors
Investment in building human capital	<i>Hierarchical</i> Lead firm to Employees	Decision to outsource and invest less on physical capital, such as trucks and vehicles in order to increase financial investment on human capital (Interview 1, 4)	The lead firm requires more suitably qualified biomass heat engineers for installation and systems design in addition to qualified and experienced plumbers and site supervisors (Interview 1, 4). "There are only about 30 good and experienced heat engineers in the UK that I can currently depend on, that is not enough" (lead firm owner (Interview 1)) Lack of suitable apprentice opportunities in UK means that it is expensive to send technical employees to Europe (Interview 1, 4).
Training, monitoring and building human capital	Lead firm to wood chipping contractor (producer driven) End user to woodchip contractor (buyer-driven)	Increasingly stringent requirements from end-users for wood chip quality certification drive the recruitment of skilled personnel (Interview 1)	The chipping contractor requires more trained personnel in machinery operation, including chainsaw, harvesting and forwarding and also skills to manage wood chip quality (Interview 5, 6). Narrow profit margins for chipping contractors limits funds for formal training so most training is done on the job (Interview 5, 6, 7) one chipping contractor on low profit margins states that "I fear, I may need to close shop and let the bigger players have the field!"
Achieving accreditation certification and chartered status as wood fuel suppliers	<i>Executive and judicial</i> Training, accreditation, chartered and certification organisations: to supply chain	Provides training to improve skills as well as monitor service and product quality. Provide assurances to end-users of supplier capabilities, leading to continued custom and increased customer base. Lead firm, chipping and harvesting contractors are wood fuel quality accredited. However, only the lead firm has achieved chartered status.	Lack of collaboration between the different certification schemes and training providers means there are some overlap in training provided (Interview 25, 26) The financial cost of accreditation, time and the complex process for achieving a chartered status means that small-scale contractors and woodland owners are not able to derive benefits from such qualifications (Interview 18, 23)
Creating awareness and supporting the sector	<i>Balanced</i> Lobby groups to the supply chain	Supports and facilitates growth of the sector.	Requires skills that may not be available within small firms so their interests are not represented
Exchanging information and expertise and resources	<i>Balanced</i> Local wood fuel group to the supply chain	Collaboration and networking opportunities,	Limited funds for administrator affected the effectiveness of the group (Interview 17)
Supporting the development of the sector	<i>Legislative and executive</i> Local authority to the supply chain and wood fuel sector	Provides supportive legislation such as a default to biomass heating for new development	Lack of facilitation and awareness campaign personnel (Interview 21)

Table 4. Financial Access and infrastructure: Implications of Governance Patterns and Capital Gap analysis.

Process	Governance Patterns: Supply Chain Actors and Institutions	Implications of Governance Patterns	Capital Gap Analysis
Setting up wood fuel production hubs	<i>Executive</i> Local authority to Supply chain	Provides planning approval for infrastructure	Lack of knowledge and awareness in the Planning approval delays especially for wood fuel hubs, which is an unfamiliar concept to local authorities. (Interview 1, 21,)
Applying for financial grants	<i>Executive</i> Funding bodies to Supply chain	Supports with financial resources for physical capital. Examples of funded capital include a wheeled forwarder for harvesters, timber and wood chip storage facility for the lead firm and two Jenz chippers for the chipping contractor	Complex application process. Lack of knowledge on how to successfully apply for grants. Chipping contractor said “ <i>applications process are too complex for a simple guy like me</i> ”. Restrictions on use. Funded equipment cannot be used for non-wood fuel aspect of business.(Interview 5, 6, 7) Lack of excavation-based harvesters as well as 16 t and 12 t wheeled forwarders for harvesters in the chain (Interview 8, 9)
RHI applications and sustainability requirements	<i>Legislative</i> OFGEM (Office of Gas and Electric markets)	The RHI funds which facilitates uptake in wood fuel heating	Stringent data requirements Complex application process, sometimes requires consultants to help end-users thus adding to cost.(Interview 22, 23) Additional sustainability requirements for wood fuel suppliers including inclusion in the approved wood fuel suppliers list and the need to report on supply chain sustainability

4.3. Sector-Wide Vulnerability Factors

A major vulnerability factor within the wood fuel supply chain are diseases such as the Red band needle blight, regarded as an economically important disease that affects the yield of conifer trees in Britain [44]. Given that its incidence has increased significantly since the late 1990s, it could potentially affect the availability of forest resources for wood-fuel. Further, the UK climate with its rainy wet winters and high humidity is said to be a concern because the access and extraction of timber as well as the conditioning of wood chips are adversely affected by the weather.

A second vulnerability factor relates to a general lack of key skills such as experienced biomass heat engineers as well as plumbers, builders and developers. According to the lead firm owner (Interview 1), only about 20–30 people in the UK are reliable biomass heat engineers. There is also a lack of general management abilities such as supply chain management, business planning (forecasting and risk management) as well as a lack of understanding of key policies and poor customer services [40] (Interview 4). Other general trends include a lack of motivation to improve skills because of limited highly skilled jobs as well as low skill requirements from potential employers. In addition, an older workforce in the forestry sector means that the image and profile of jobs within the sector were seen as unattractive to young people [45] (Interview 14, 15) and this may have a limiting effect on the development of the sector in the future. Furthermore, diversity of interests, knowledge, skills and business cultures as well as competing commercial interests within networks and groups limits effective interactions (Interview 17, 20 & 23).

Thirdly, supply chain actors are heavily dependent on financial aid because profit margins are low, and the frequent breakdown of biomass installations has a major negative impact on customer confidence and adoption rates (Interview 1, 3, 4). According to an operations manager, “one in five biomass installations breakdown within six months of operations”. Uncertainties regarding the duration and level of support of the renewable heat incentive was viewed by some supply chain actors as a significant risk (Interview 1, 4, 5). Given all of this, there was understandably a concern that current supply chain capacity may not be ready for a sudden increase in demand and this may exacerbate the incidence of boiler breakdowns and adversely affect market confidence.

4.4. Enhancing Supply Chain Resilience and Socioeconomic Benefits

There is a need to improve awareness and visibility of the Forestry Commission’s campaign to increase resource capacity, especially for woodland owners who stand to gain significant additional income of at least £12 m annually from 730,000 m³ poor quality wood generated. The campaign can also increase the uptake of woodland management plans thereby increasing job security for woodland advisors. It is also necessary to increase capacity for skilled jobs due to the increasingly stringent standards exerted by the legislative and buyer-driven governance of external institutions and end users respectively. This should lead to more value added services and more income for the sector. For example, the lead firm has improved skills and capacity to including consultancy and e-commerce services. Finally, it would help to publicise favourable legislation and build networks with key organisations. For instance, the local authority’s legislation for biomass to be a default option in new development has been a major driving force for the wood fuel sector in the region. However, a general lack of awareness and visibility of this legislation means that its effect is limited; this could be enhanced by the employment of local public liaison officer.

Agility and adaptability in terms of structure, attitude/thinking, and governance patterns are necessary. For example, the structure of the supply chain reveals that the airport customer of the lead firms provides almost 80% of turnover for the lead firm and the chipping contractor depends on the lead firm to provide over 60% of turnover. This indicates that both actors are over-reliant on a particular actor in the chain and there is a need to introduce some diversity in their customer base to improve resilience. Some 60% of privately owned woodlands have largely been left unmanaged (Woodcock, 2012), mainly because of the low value of the resource as well as an attitude which sees the felling of trees as a “bad thing”. A change of attitude and approach is necessary to derive the value from wood

fuel. Indeed, a new attitude towards skills improvement is also necessary as the current attitude is not sustainable or aligned with the increasingly stringent institutional and end-user requirements. Wood fuel and forestry courses need to be adequately adapted and integrated into higher education as this would help to encourage the younger generation. Relevant external organisations need to quickly adapt some of their executive and legislative governance practices to accommodate the requirements of the wood fuel sector and its actors. For example, the limitation of grants to only woodlands over three hectares given that majority of woodland owners have less than three hectares of land is not fit for purpose. Furthermore, the large amount of information for woodland management grants, the complex accreditation/certification processes, the delayed planning approval by local authorities due to lack of understanding of wood fuel hubs discourages potential actors and limit sector development. A lack of proper governance may also limit the development of the sector. For example, the local wood fuel group in the supply chain lacked formal rules and regulations, which limited its role and effectiveness as a source of social capital. Such informal networking and groups are common in the sector, it is suggested that more formal and organised alliances would bring about greater benefits for actors.

Collaboration within the fuel wood supply chain would generate benefits and this could be enhanced via the establishment of a local hub where woodland owners could collate resources and information, share skills and facilities and represent the diverse interests of all involved could help to harness potential additional income. Harvesters, land agents and the lead firm could form a more balanced governance pattern rather than arms-length associations by collaborating with woodland owners in the management of resources. Human capital would be enhanced by a supply chain cooperative which could fund and train key actors in the chain such as the chipping contractor and his employees, who are limited by low profit margins. Furthermore, joined-up planning and administration of training and certification schemes would help address uncertainty, encourage standardisation and promote confidence. Finally, the local wood fuel group showed that commercial interests and lack of transparency hampered its effectiveness. According to a former member, *“there was a need for collaboration due to the diverse nature of the sector”*. Financial capital could be generated if local wood fuel actors cooperate to source funds and investment, and this may eventually reduce the dependency of the sector on subsidies and grants.

The ability to anticipate, plan and action a recovery plan is important given that an emerging industry is prone to uncertainty and unexpected events. One of the major threats to the sector cited by actors is uninformed public perception about the impact of the sector on the environment, especially concerns over air quality and deforestation. In anticipation, the sector requires good public relations officials to effectively communicate the steps taken by the sector to mitigate some of these impacts. For instance, some wood fuel appliances and boilers are restricted in smoke controlled area and others can be fitted with different types of technologies such as scrubbers and thermal oxidizers to reduce air polluting emissions. It should be widely publicised that felling trees as part of the management of woodlands is beneficial to the environment and improves biodiversity. In addition, the treat and spread of tree disease such as the Red band needle blight needs to be effectively managed. Forestry Research, an arm of the Forest Commission in charge of disease management, is said currently to be under-resourced and requires more human and financial capital to operate effectively. The frequent events of biomass boilers and systems breakdown needs some kinds of regional repair centres or call centres where fully qualified heat engineers can be easily contacted. Information from end-users indicate that response times and required skills for repair and recovery are generally poor. Plans should also be made to improve skills and increase capacity in areas of current weakness such as supply chain management, forecasting and risks assessment, in anticipation of the expected growth in domestic wood fuel demand as a result of the renewable heat incentive. Avenues by which the sector can reduce its dependency on subsidies and financial grants should be identified and explored, in anticipation of a future when financial aids are no longer available or limited. This would improve the image of the sector, attract investors and secure the future of the sector.

Securing market position refers to activities to secure, defend and improve the market shares and the ability to meet end-user and other stakeholder preferences. The wood biomass and energy crop provides a significant share (75%) of the renewable heat in the UK with its share set to grow by 2020 because of the renewable heat target. The fact that renewable heat is highly dependent on woody biomass and energy crops puts the sector in a good position within the renewable heat sector. In comparison, the other major source for renewable heat is heat pumps, which contributed only about 4% to renewable heat. However, to secure and increase market shares, the significance of the sector for renewable heat, climate change reduction and energy security should receive wider publicity. In addition, wood fuel for renewable heat should be regarded as distinct from wood fuel for renewable electricity as renewable electricity from wood fuel requires a much larger amount of woodland resources, which may have a negative impact on the availability and sustainability of local wood fuel resources. Therefore, developing an effective lobbying and communications strategy with governmental bodies at the local, regional and national levels as well as the general public could help to defend and improve the market position of the sector by showing its importance and benefits. Knowledge of customers' requirements and market segmentation is critical for sector development.

5. Discussion

The aim of this paper is to describe the development and application of the Resilience and Livelihoods in Supply Chains (RELISC) framework, designed to engage with factors that have been underexplored in traditional socioeconomic assessment methods. These factors have been identified by a wide range of researchers as crucial in understanding and guiding biomass energy development. Knowing how socioeconomic benefits emerge will allow better facilitation of supply chains and sector resilience and growth. Key aspects include institutional processes and policies, supply chain governance and structures, resource constraints, stakeholder perceptions and decisions as well as vulnerability factors. The RELISC Framework was developed to provide a holistic approach to exploring this diverse landscape by adapting and integrating key components in the VCA and SLA framework. It offers improvements in four main ways. Firstly, it offers a structured approach to address gaps in the understanding of bioenergy institutional and supply chain configurations. Secondly, it helps to highlight the impact of resource limitations and other local conditions, which have been identified as key factors in assessing the ability to derive socioeconomic benefits and improve sector resilience. Thirdly, the framework offers an approach to evaluating how policy implementation and governance processes impact socioeconomic benefits. Finally, it should be noted that RELISC utilises a people-centred approach, and strategies derived from the point of view of actors are likely to be more effective.

Beyond the application to biomass energy, RELISC helps to derive strategies for achieving resilience in an emerging sector characterised by change and uncertainty; this can be applied in other emerging sectors. The framework provides a valuable complementary analysis to quantitative socioeconomic assessments, by engaging with the dynamics that influence socioeconomic benefits and sector development.

In terms of the case study, mapping the structure of the supply chain and its internal governance patterns revealed the high level of dependency of the lead firm on the airport customer and the reliance of one of the chipping contractor on the lead firm. If there are any problems in either relationship, it will have a considerable effect on income and the resilience of the particular chain. The results also highlighted the key external institutions and the impact of each governance pattern on supply chain activities and benefits. For instance, the importance of the UK Forestry Commission and its programmes were noted in relation to the sustaining of resource availability, producing statistical data as well as providing human resources to aid actors (e.g., woodland owners) to generate additional income from improved resource availability. A further important finding with regard to vulnerability of the wood-fuel supply chain is the inadequate number of good biomass engineers and lack of skills in providing value-added services, and hence better paid job, and the limitations from low profit

margins and lack of necessary infrastructure in building skills and increasing production levels for more income. Some organisational practices and laws clearly need to adapt to the needs of sector, such as the delays in approving planning approvals for wood fuel hub due to lack of awareness in local authorities and the impractical restriction by funding bodies to use funded equipment for only wood fuel activities as well as the prevalence of informal associations in building social capital instead of more formal and productive associations. Results also highlighted some of the hurdles faced by supply chain actors in meeting some institutional requirements, such as wood fuel accreditation, certification and obtaining a chartered status as well as the new RHI sustainability requirements.

An important advantage of the RELISC framework is that it provides pointers towards strategies that would help to achieve supply chain resilience and sector development. In terms of the case study discussed in this paper, these strategies include:

- (a) Improve visibility and increase capacity, especially for effective public campaigns and skills, respectively.
- (b) Change attitude towards the felling of trees. For instance, an adaptation in terms of some institutional laws and their applications to the wood fuel sector.
- (c) Collaborate in spite of the different interests and varying levels of commitments of different actors.
- (d) Improve end-user confidence given the uncertainty and emerging nature of the sector.
- (e) Secure market position using good communication and lobbying strategies given the importance of the wood fuel sector in providing renewable heat.

RELISC does require access to a considerable amount of confidential information, which may be difficult to obtain. It also requires access to a large number of actors, which can be challenging and time consuming. In some situations, access to information and personnel is relatively unrestricted such as an in-house assessment within the supply chain, and, in such cases, RELISC would be very useful. Furthermore, since the results are based on the perception of actors, there is an element of subjectivity, which can be overcome by triangulating some of the perceptions with secondary data or with similar actors in the sector.

Nonetheless, the RELISC framework is a valuable addition to the tools available for the analysis of value chains, and its holistic and people-centred nature offers important insights that help frame strategies to improve resilience.

6. Conclusions

The aim of this paper was to set out the development of the Resilience and Livelihoods in Supply Chains (RELISC) framework and to describe its application to an emerging but important renewable energy sector, the UK wood-fuel sector. Its application to an emerging sector characterised by change and uncertainty produced useful insights such as the types of actors and the structures of the chain given the inherent fragmented nature of the sector. It also showed how external and internal governance patterns limited or enhanced supply chain activities and benefits as well as the impact of limitation or availability of capital. Furthermore, it provided some useful strategies for resilience and sector development, which can be applied to other sectors. Finally, the ability of the framework to holistically engage with the under explored and diverse aspects of the system, namely institutional processes and policies, supply chain governance and structures, resource availability and constraints as well as stakeholder perceptions and decisions, has been illustrated. Thus it serves as a useful complementary tool to be used on its own or alongside more quantitative approaches, in order to understand and address the impact of pertinent contextual factors to gaining socioeconomic benefits, supply chain resilience and sector development. In conclusion, the RELISC framework represents a new and valuable analytical tool for supply chains and their sectors.

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Appendix A

Table A1. List of interviews, actor role and organisation in supply chain and sector.

Interview Number	Role of Actor	Organisation in Wood Chip Supply Chain
1	Lead firm manager and owner	Lead firm (wood fuel processing and consultancy)
2	Field and logistics manager	Lead firm (wood fuel processing and consultancy)
3	Forestry and operations manager	Lead firm (wood fuel processing and consultancy)
4	Business development manager	Lead firm (wood fuel processing and consultancy)
5	Chipping contractor	Wood Chipping firm
6	Chipping contractor	Wood Chipping firm
7	Chipping contractor	Wood Chipping Firm
8	Harvesting contractor	Harvesting partnership
9	Harvesting contractor	Harvesting partnership
10	Owner/Manager	Transport and Haulage firm
11	Driver	Transport and Haulage firm
Interview number	Role of Actor	External Organisations
12	Woodland programme officer	Forestry Commission
13	Woodland programme officer	Forestry Commission
14	Regional woodland advisor	Forestry Commission (SE)
15	Regional woodland advisor	Forestry Commission (SW)
16	Regional woodland advisors	Forestry Commission (E)
17	Coordinating Officer	Woodland cooperative
18	Woodland Owner	Woodland cooperative
19	Woodland Owner	Woodland cooperative
20	Woodland Owner	Woodland cooperative
21	Local authority representative	Woodland cooperative
22	End-user and producer of woodfuel	Woodland cooperative
23	End-user and producer of wood fuel	Woodland cooperative
24	Wood Fuel Training providers	LANTRA
25	Wood Fuel Training providers	IGNITE
26	Wood Fuel Training providers	HETAS
27	Bioenergy policy Advisor (RHI)	DECC (Department for Energy and Climate change)
28	Bioenergy policy Advisor	DECC (Department for Energy and Climate change)

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