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Value-driven partner search for *Energy from Waste* projects

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Abstract

Energy from Waste (EFW) projects require complex value chains to operate effectively. To identify business partners, plant operators need to network with organisations whose strategic objectives are aligned with their own. Supplier organisations need to work out where they fit in the value chain. Our aim is to support people in identifying potential business partners, based on their organisation's interpretation of value. Value for an organisation should reflect its strategy and may be interpreted using key priorities and KPIs (key performance indicators). KPIs may comprise any or all of knowledge, operational, economic, social and convenience indicators. This paper presents an ontology for modelling and prioritising connections within the business environment, and in the process provides means for defining value and mapping these to corresponding KPIs. The ontology is used to guide the design of a visual representation of the environment to aid partner search.

Keywords: Value chains; Ontologies; Business networks; Triple bottom line; KPIs

1. Introduction & motivation

Our problem domain concerns *Energy from Waste* value chains. Energy from Waste projects take waste products, such as agricultural, food or municipal solid waste (MSW), and use them to generate energy and other valuable by-products. If well designed and run, a waste to energy system is an economic and environmental win-win, with waste producers finding beneficial solutions to their waste disposal problems and plant operators producing useful outputs.

However such projects are complex. At the planning stage, operators need to prove compliance with relevant environmental legislation, and gain community support to get planning consent. The underlying processes are relatively novel and technologically complex; setting a plant up requires engineering partners to build and run it properly. In operation, the plant must be matched to a consistent supply of wastes over a long period to achieve return on investment.

Identifying a value network which provides all the required competencies is therefore essential and a potential barrier. The European Bioenergy Research Institute (EBRI) at Aston University, UK, has identified more than thirty types of partners which may be required in an Energy from Waste (EfW) value network [1, 2]. These include technical

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services, such as engineers, plant operators, construction, safety systems suppliers and lab services. Ancillary services include finance, accounting, legal services, accreditation consultants and IT. Logistical support is required to transport waste, and collection and concentration services are needed to accumulate and safely store waste until it is needed.

Arguably, the most crucial link in the value network for Energy from Waste projects is matching feedstock suppliers to plants. Both parties have specific needs which must be met for them to extract value from the partnership. In general, the plant requires a consistent supply of the right kinds of feedstocks at an affordable cost. The waste producer needs a convenient disposal method, ideally one in which the plant pays, or does not charge, to remove the waste. Geographical location may therefore play a significant role in the design of value networks, in order to minimise transportation costs. Section 1.1 provides a couple of examples that show how these relationships might play out.

1.1. Use cases

A relatively simple type of plant is an on-farm anaerobic digester (AD) [35]. This is a system in which bacteria are fed on shredded agricultural waste products, mixed in water, to produce biogas (methane) and heat. ADs need a start-up phase during which the bacteria responsible for the digestion stabilise. After this the digester has to be fed steadily, at the rate it can consume the waste, and with a "diet" of the right mix, of e.g., manure and dry wastes such as straw. Therefore, to keep a digester running for all twelve months of the year a farmer may need to partner with neighbours whose crops and livestock produce wastes in different seasons. Technical advice will be needed on the most appropriate type of digester, the mix and the feedrate required to be efficient. The supply chain, delivering from feedstock producers, needs to match the technical requirements for the plant.

If the complexity of this small-scale scheme seems daunting, consider how much more difficult the situation might be for a partnership between a hospital and a tri-generation (combined cooling, heat and power, or CCHP) combustion plant [12]. Here MSW is the feedstock, the setting is urban, the combustion process has a historically poor reputation for polluting, and the regulatory framework is tight in a healthcare setting. The hospital, sited in a city, needs to be partnered with a combustion plant, which, as a potential polluter, is likely to be in an area with low population density, in order to get planning consent. This will not meet the hospital's heat/cooling needs since the plant will be too far from the hospital site to efficiently pipe hot water to it. Therefore the plant needs to ensure other consistent demand for its outputs, e.g. a partner with a need for heat and/or cooling, located near by. An efficient logistics network will also be required to move hospital waste to the plant at an affordable cost. For a more detailed consideration of the full value network we direct the interested reader to, e.g. [1, 35].

At the planning stage, potential partners need to identify each other and assess the fit between their strategic objectives, in order to ensure mutually beneficial relationships [33]. Continuous awareness of other organisations in the network is also required to ensure that value can continue to be extracted from relationships over the long term. A typical example is that EfWplants whose business models rely heavily on gate fees (charges per load arriving at the plant) can suffer rapid drops in feedstock supply if competitors with lower or no gate fees join the market. EBRI is facilitating the networking of potential Energy from Waste project partners in the West Midlands region of the UK, taking a Digital Business Ecosystems (DBE) approach [36]. DBEs can be defined as "evolutionary, self-organising systems which create an on-line, digital market place to seamlessly connect organisations, companies and individuals that do business with each other" [40].

This paper reports the design and prototyping of a semantic information system to help organisations identify strategic partners within a DBE. The assumption was made that partner selection is based on value they can deliver. The foundation of the prototype is an ontology derived from user-centred design sessions undertaken by the authors in collaboration with researchers at EBRI. The ontological model bridges the general business concept of value, modelled as KPIs, to the specific application domain of Energy from Waste projects in order to support the visual exploration of different kinds of value.

2. Value chains & value networks

DBEs conceive of information and communication technologies (ICTs) as facilitating and supporting mechanisms for companies facing the challenges posed by the 21st century business environment. The challenges of increasing scarcity and cost of resources, and rising transaction costs encourage collaboration within networks of organisations, to

pool (core) competencies, physical, knowledge and other resources; capitalise on shared synergies; share and therefore defuse risk and reduce uncertainty; increase agility, sometimes simply to survive [3, 33]. The overriding goal is to trigger innovation through diversity and increase competitiveness, to generate value above that each actor could in isolation, for both (internal) stakeholders and (external) customers [9].

Gereffi and Fernandez-Stark [23] highlight the importance of *global* value chains, to allow smaller, more disadvantaged players – communities and organisations – to access resources. They consider the entire length of the (value) chain, from input of raw material to final goods and services delivered, to identify where and how value is added. We consider chains on a smaller, local level; however the factors that play into global chains still have impact, albeit on a lower scale. For instance, Abreu and Camarinha-Matos [3] posit imbalance of power within supply chains as a driver in buyer or supplier advantage. An example in our case is the hospital; as a year-round, mid- to large-sized feedstock supplier it has substantial control over cost. On the other hand, smaller community plants, with much lower (political and economic) power and reach, have correspondingly lower bargaining power in sourcing feedstock, complicated further by a limited range (geographical distance and supply cycle) beyond which cost may exceed gains. In such cases, mutual gains are often achieved by uplifting waste (feedstock) from multiple, smaller, local suppliers, such as offices, schools and small-to-medium enterprises (SMEs), at low to no cost, in order to achieve the scale needed to break even or make a profit. The reverse also applies, where smaller waste-generating organisations in a locality may drive down transaction costs while increasing service levels for waste disposal with a shared contract.

The value chain in this case evolves to resemble more of a network, with greater inter-dependency between organisations, working together to create value shared across contributors [29]. Fig. 1a illustrates where value may be added along the Energy from Waste process, highlighting also where mutual gains can be found.
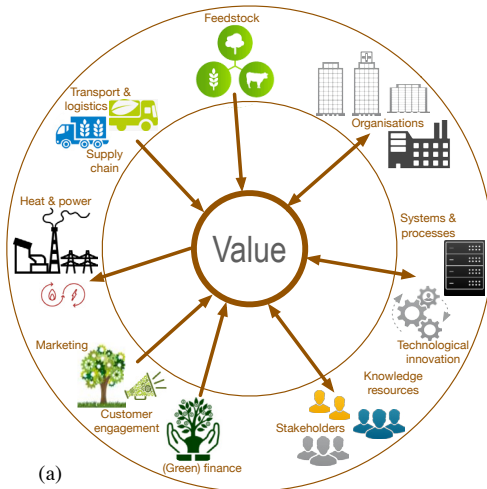
```
PREFIX  so:     <http://schema.org/>
PREFIX  geo:    <http://www.geonames.org/ontology#>
PREFIX  efw:    <http://www.ebri.org/efw#>
PREFIX  kpionto: <http://kdmg.dii.univpm.it/kpionto#>

SELECT DISTINCT ?organisationUri ?organisationName ?value ?valueType ?
performanceIndicator ?businessObjective ?metric

WHERE   {
    ?organisationUri so:legalName ?organisationName ;
        efw:hasValue ?value .
    ?value efw:relatesTo ?businessObjective ; # defined by organisation
        efw:type ?valueType ; # e.g., Operational, Economic, Convenience, ELSI
        efw:hasMetric ?performanceIndicator .
    ?performanceIndicator efw:isA ?kpi .
    ?performanceIndicator rdf:type ?metric # Social/BusinessMediaMetric

} GROUP BY ?valueType
    ORDER BY ?organisationName?performanceIndicator ?businessObjective
```

(b) Formalising value using an ontology (see Fig. 6) supports organisations in capturing and aligning values across a single and multiple organisations, to identify where mutual gains may exist, across organisations and between stakeholders.

Fig. 1. The value network for small-scale, local Energy from Waste plants, showing the role of different stakeholders in creating and sharing value.

To reap fully the benefits in a value chain requires unambiguous definition and alignment of the values of the sometimes disparate organisations that must work together and trust that value is fairly distributed [7, 33]. Abreu and Camarinha-Matos [3], Graça and Camarinha-Matos [26] find that value alignment has the benefit of simplifying the derivation of Key Performance Indicators (KPIs) that may be used to measure added value sought by each organisation and that gained by the group as a whole. As in our model (see section 4 and Fig. 6), value seen may vary from increasing economic return to more qualitative assessment of reputation, by considering social and ethical factors in business operations. Fig. 1b illustrates how formalisation of different values against business objectives aids alignment, and therefore, querying data about the network to determine (relative) similarity across organisations.

The definition of value for an organisation may change with external context. While economic and social value may be correlated, in some cases explicit tradeoffs may be required between (immediate) economic and social return. This is typically seen where community support is critical to business operations and the regulatory environment, or where action is required to build social capital to repair negative reputations in an organisation or industry. Here, reducing waste and pollution serves as ethical and social capital, contributing to value.

3. Partner selection

The creation of partnerships in such value networks has been operationalised variously as supply chain design, supplier selection or as Partner Search and Selection (PSS). Supply chain design concerns the siting and capacity of plants and the selection of suppliers [34]. Green supplier selection includes consideration of potential partners' environmental performance [25]. PSS is a special case of supply chain design deployed in Collaborative Networks to identify logistics partners for Virtual Organisations (VOs). A VO is a specific kind of business ecosystem in which an alliance of business entities, often small or medium-sized enterprises, come together for a period of time and pool their capabilities in order to take advantage of a particular business opportunity.

A wide range of methods have been researched for these partner selection techniques. These do not necessarily mention value, per se, but they are typically framed by identifying the criteria which an organisation desires its supply chain partners to meet. Chai et al. [8] review decision making techniques for supplier selection, classifying them broadly as multi-criteria decision making, mathematical programming and artificial intelligence methods. Govindan et al. [25] review the literature in green supplier selection in particular. They identify the use of quantitative processes, such as the Analytical Hierarchy process, Data Envelopment Analysis and fuzzy set theory. They draw attention to the need for methods to reflect "the organisation's specific requirements" and conclude that, in green supply chains, selection decisions can be socially sensitive.

The problems associated with turning "soft" criteria into quantifiable metrics has been identified by commentators on the Triple Bottom Line (TBL) approach to organisational reporting. TBL was introduced by Elkington in the 1990s as a framework for businesses to assess their performance against economic, social and environmental criteria [18]. Although metrics have been proposed for all three parts of the TBL, e.g., [38], critics have argued that it would be "impossible to formulate a sound and relatively uncontroversial methodology to calculate a social bottom line" [37]. Ahi and Searcy [4] have noted that most of the metrics published in the literature on sustainable supply chains were only used once, implying there is little consensus on how to measure performance in this area. Further, Hassini et al. [27] identified the difficulty associated with developing reliable metrics for performance in sustainable supply chains.

Based on these reported issues with quantifying metrics, we argue that, in the DBE context, it is not reasonable to ask organisations to undertake a standardised reporting process simply to network with potential suppliers/partners and monitor the competitive environment. Therefore a design decision was made to develop a methodology which could handle multiple selection criteria, without relying on quantitative methods. An ontology would be used to capture this multi-criteria, value-driven ecosystem, and to model and prioritise connections within the business environment, to guide the design of a visual representation of the environment to aid partner search.

4. Ontology

The proposed ontology will provide the backbone for the system in the form of a model of the business environment. This will support the description of projects, stakeholders, timelines, service providers, connections between organisations, types of waste material and so forth. The core purpose of the ontology is to model value, as it relates to key business objectives, through these different components. This is to support users in identifying potential partners who can deliver value against their desired objectives. We make the assumption that value for a particular organisation, while it will be of different types (economic, social, environmental etc.) can be described using KPIs. Therefore, we explore relevant work on modelling value via KPIs, which informed the design of the ontology, considering first the business literature, and then literature published by the ontology community.

The business literature proposes a number of theoretical frameworks for performance metrics. These higher level categorisations help to make sense of the multitude of indicators, and can be used strategically for business performance monitoring. One such is the Triple Bottom Line [18] discussed in section 3. Another is Kaplan and Norton's well-known Balanced Scorecard [30], with its four perspectives of financial, customer, internal business processes, and learning and growth measures. Environmental frameworks include the Sustainable Balanced Scorecard proposed by Hubbard [28], which adds social and environmental performance measures to Kaplan and Norton's original four perspectives, and the Natural Resource Based View of the firm, with its framework of pollution prevention, product stewardship, and sustainable development [e.g. 24, 17]. These high level models reflect the diverse kinds of value that businesses aim to create.

As seen, partner selection involves the setting of criteria, operationalised as KPIs or other measures, which reflect organisations' objectives for value creation. Such KPIs need to be understood by both parties; a number of supporting frameworks have been proposed. Krathu et al. [32] address this need with their framework and ontology, aimed at measuring high level KPIs to evaluate inter-organisational relationships. Their framework deploys the Balanced Scorecard methodology [31], an approach also employed by Graça and Camarinha-Matos [26]. Correia Alves and Rabelo [10] give an example of competency-based selection of logistics partners using a model based on fifteen pre-defined KPIs. Baldo et al. [6] propose an ontology-based method for cataloguing performance indicators, which they state may differ in subtle ways because they are supplied by different companies, to provide a searchable index.

For information exchange in established supply chains, standard definitions of common metrics are published by professional organisations and standards bodies, [e.g. 5, 19]. Within these, the widely used Supply Chain Operations Reference model (SCOR) [11] includes definitions of KPIs. Graça and Camarinha-Matos [26] propose the definition of indicators that extend traditional supply chain management to consider also (environmental) sustainability, an increasingly important and in some cases a regulatory necessity, in business operations in the modern era. By ontological standards, some of these are informal definitions; however, they provide a basis for formal conceptualisation.

Several schemas have been proposed to define, measure and evaluate KPIs. At the process level, integration of performance indicators with the Business Process Modelling Notation (BPMN) is proposed by Friedenstab et al. [22] to support process monitoring. The PPI (Process Performance Indicators) Ontology [13] also defines performance indicators which can be linked to BPMN process models. ScoreML [21] was developed as a language for specifying indicators, which integrates with the MEMO languages for organisation mapping [20].

As a basis for the KPI model in this ontology, we reuse the `kpionto` schema proposed by Diamantini et al. [14, 15]. The `kpionto:Indicator` class supports rigorous representation of dimensions, formulae, units of measurement, business objectives and aggregation functions. It was designed to support uses including search and comparison of indicators, and was demonstrated in a data exploration tool aimed at facilitating data exchange between organisations in Virtual Enterprises [16]. Hence it is a good fit for the partner selection task.

4.1. Ontology Structure

The ENERGYFROMWASTE ontology (EFW) captures the environment in which EBRI, as a hub, serves as a knowledge broker and a *connector* between (potential) business partners. The ontology must serve two purposes: (1) provide a structured approach that supports automatic annotation and enrichment of scenarios and relevant documents; (2) support human-readable representation, to allow reuse by domain experts who are not technology experts, to define value for their organisation and, therefore, their networking requirements. Fig. 2 shows the top level of EFW, structured to capture a set of core concepts, each detailed in a sub-ontology (see also DOI: 10.6084/m9.figshare.c.4172009).
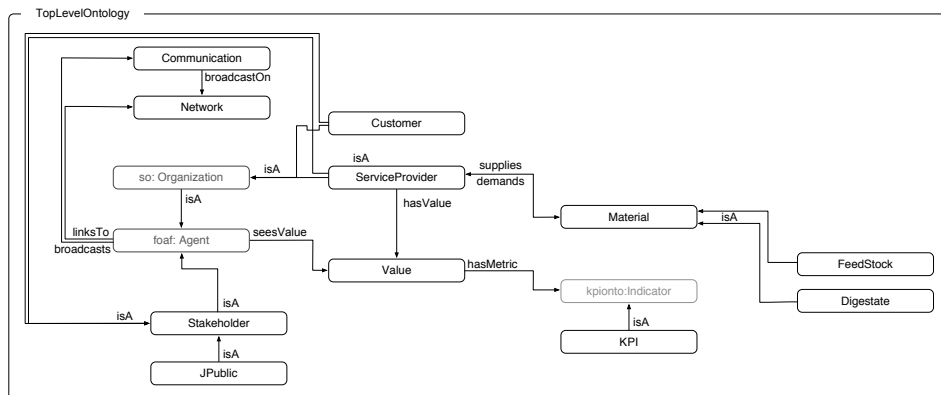

Fig. 2. Top level EFW ontology

`org:Organization` to aid classification (see Fig. 3), and therefore partner selection, to feed into building a:
`Network` of organisations within the ecosystem, which may contain sub-networks focusing on the requirements of
     businesses (`ServiceProviders`), customers and/or the interested public.

`ServiceProviders` may be `PlantOperators`, `FeedstockSuppliers` or `AncillaryServiceProviders`. Some `Customers` are also `ServiceProviders`, e.g., a hospital that provides `Feedstock` for a `Plant` and also feeds off the energy generated. The `LevelOrGrade` of the `ServiceProvider` is in this case determined based on the quantity and frequency of its `Feedstock` supply, along with distance from a `Plant`.

`Feedstock` is generated from a variety of `FuelCrops` and different types of `Waste` (see Fig. 4), depending on the `ConversionTechnology` in use at a `Plant`.

Fig. 3. Sub-ontology showing how different `org:Organization` types link to different `ServiceProviders` in business, customer and/or public networks.

Fig. 4. The `Feedstock` sub-ontology illustrates the impact of a `Plant`'s `ConversionTechnology` on suitability of input `FuelCrops` and type of `Waste`.

`KPIs` provide a means to measure `Value`, using both qualitative (e.g., ELSI – Ethical, Legal, Social Issues, as part of CSR – Corporate Social Responsibility) and quantitative metrics, e.g., distance–quantity–frequency weightings to calculate relative cost of `Feedstock` for a range of `ServiceProviders`. In this scenario we classify further metrics based on whether they focus on economic return (`BusinessMetric`) or *social capital* [3, 26, 23] (`SocialMediaMetrics`).

`Communications` sent across the `Network` are contained in different kinds of `Messages`. Depending on the source, `Message` type and target(s) (`ContactType`), a specific `Action` may be triggered. For example, an `Operational` message broadcast to solicit `Feedstock` for an anaerobic digester should trigger an `Action` from `ServiceProviders`, organisations generating waste on the scale required, to satisfy the request.

A `ProjectOrScheme` must be defined, as shown in Fig. 5, following `Research` to make a business case that ensures legal, financial and societal/community requirements are met for a new `Plant`. The scheme also considers which `Stakeholders` may pose a `DevelopmentBarrier`, in order to identify what measures may be required to remove these. The overall aim is to ensure the `PlantOperator` is able to optimise the `Network` to create partnerships in line with its `BusinessObjectives`, to sustain operation throughout its `LifeCycle` along its (pre-defined), optimal `ProjectTimeLine`, and return `Value` to all `Stakeholders`.

`Value,` which captures an organisation's strategy, is expressed using `BusinessObjectives`. Value cycles and/or chains are created in the process of converting `Waste` to `Value`, as illustrated in Fig. 6. In line with the multi-faceted approach in the Triple Bottom Line, we define multiple facets that an organisation may consider in measuring `Value` to its `Stakeholders`, beyond economic return and including social and convenience factors, especially with respect to the wider community in which a `Plant` is situated.
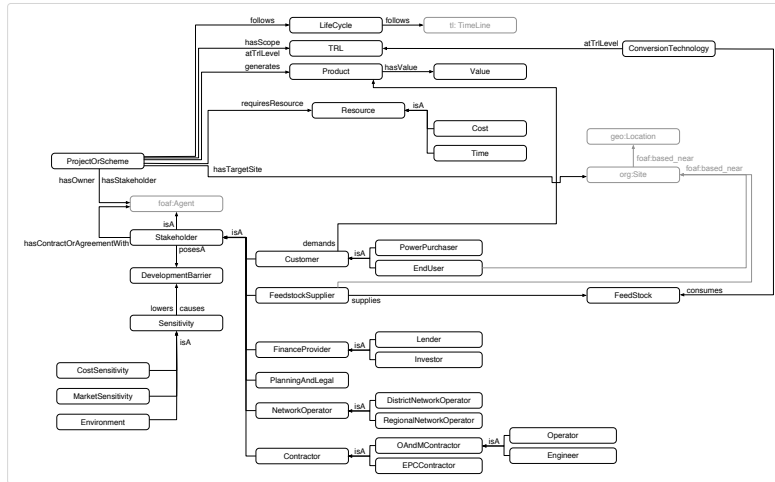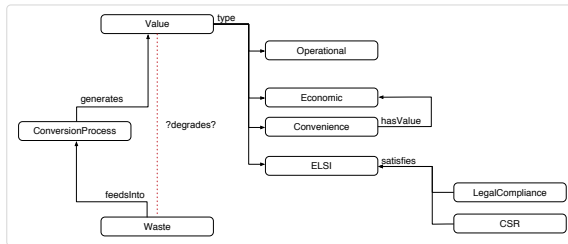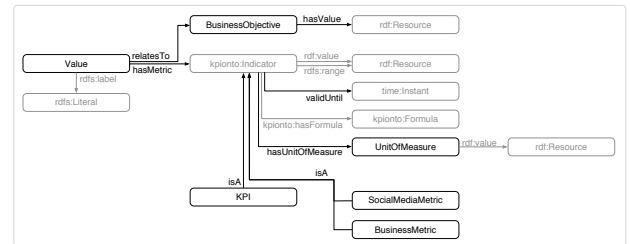
Fig. 5. Sub-ontology illustrating the path followed to develop a new project/scheme, legal, regulatory and financial factors that impact success, and barriers that may be faced during planning and operation.

(a) Sub-ontology for the waste–value chain.

(b) Sub-ontology showing, at a high level, how KPIs may be used to measure value, using qualitative and quantitative metrics.

Fig. 6. The `Value` (6a) and `KPI` (6b) sub-ontologies illustrate the multiple facets that feed into measuring value for organisations and stakeholders.

5. Application

Modeling the business ecosystem using EꜰW provides a structure on which to build an online space for the hub and other organisations to carry out partner selection, based on their strategic objectives and shared values. We describe the outcomes of the participatory design process (section 5.1), carried out with domain experts, and the resulting inter-active, knowledge visualisation prototype (section 5.2). Working in tandem with domain experts supports a process of iterative evaluation, to ensure the design, working prototypes and the DBE delivered to end users meet their require-ments for knowledge acquisition, translation of organisational values to measurable, shareable KPIs, and therefore, optimal partner selection and maximisation of value gained.

5.1. The design process

Macedo and Camarinha-Matos [33], among others, define a relatively fixed lifecycle with specified stages through which business networks are formed, to ensure collaboration persists such that each organisation, and the group as a whole, see added value in the long term. We consider identification of potential partners where different kinds of partners are needed at the different `LifeCycle` stages, from commissioning, construction and operation to decom-missioning. Therefore, we take a different approach, proposing instead an ecosystem in which organisations may dip in and out, what Graça and Camarinha-Matos [26] describe as "*goal-oriented . . . ad-hoc collaboration*", to form al-liances of varied strength and duration within an ecosystem that complements business acumen with knowledge and social capital [9]. These are in essence more compact, sometimes rolling, `LifeCycles` that evolve with actors' ca-pabilities and requirements for `Value` returned. To support this we provide a central, persistent hub – what Clarysse

et al. [9] aptly call an "*anchor tenant*" – within a digital value network, through which connections are identified and followed, and which doubles as a knowledge and resource broker (EʙʀɪHᴜʙ, centre, Fig. 7a). The design sketches in Fig. 7 reflect the business model captured in EFW to illustrate support for classification of organisations, and hence, placement within the network to satisfy emerging business needs.
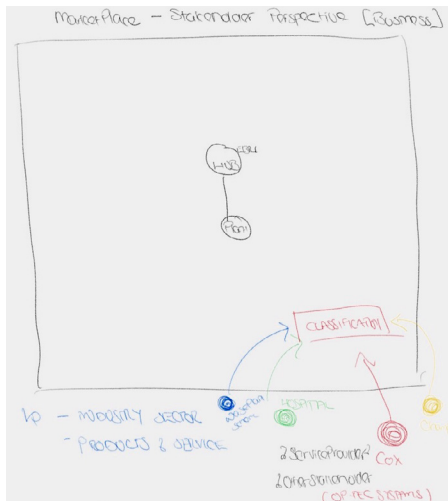

(a) Sketch illustrating the start of the classification and network population processes, for the `Plant` registered with EʙʀɪHᴜʙ (centre).
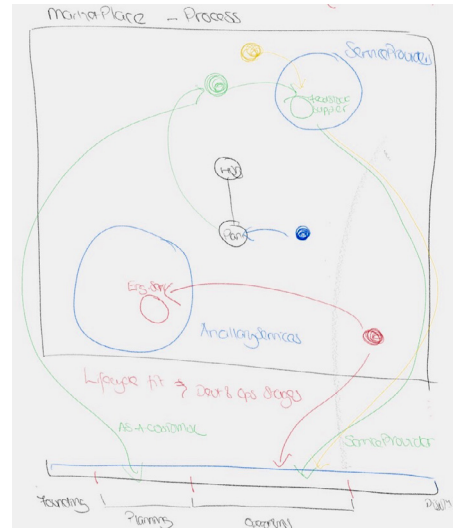
(b) Bringing additional actors into the network; progress is mapped on the `ProjectTimeLine` (bottom).

Fig. 7. Design sketches illustrating, from the `Stakeholder` perspective, population of the business network to optimise partner selection.

To support differences in perspective and technological expertise we allow each organisation to define `Value` guided, but not imposed, by the structure in EFW. We require quantitative assessment only where standard definitions exist that cross industry and organisation (e.g., in defining profit margins). We are currently defining qualitative models to provide custom support for mapping end users' definitions of value to more formal representations. We expect these to evolve as our database grows and different organisation types contribute perspectives on value, based on their specific needs and those of their sector. The design sketches in Fig. 8 illustrate two examplars for qualitative assessment by a single organisation against others within a sub-network, based on shared KPIs.
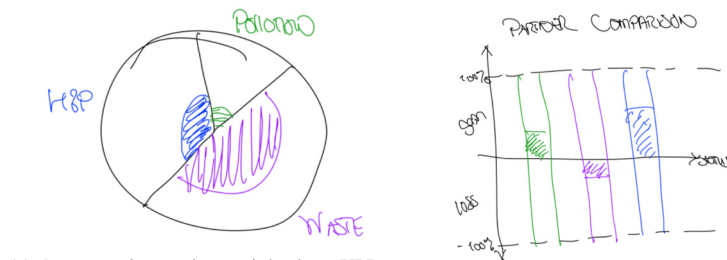
(a) An aster plot used to weight three KPIs – Heat & Power (H&P), `Waste` and reduction in pollution – against each other.

(b) Assessing loss vs. gain in value for the indicators in 8a using parallel coordinates.

Fig. 8. Exploration of qualitative value assessment models during the design phase, to provide support for organisations within the network in defining core and cross-network values, and map these to corresponding KPIs.

8a weights relative generation of (H&P) against `Waste` input and reduction in pollution for a selected `ServiceProvider`, to show how all three contribute to a composite representation of value. 8b uses a different perspective, a parallel coordinates plot, to compare the contribution of each from a cost perspective, looking at loss and gain in value.

5.2. Interactive visual exploration of strategic partner fit

We use the hospital scenario described in section 1.1 to illustrate how `Value` is added through support for partner selection within the business ecosystem. While based on real data, for privacy reasons the snapshots that follow use a dummy dataset. Fig. 9 visualises a scenario in which 26 organisations have expressed interest in joining the business ecosystem. The network that results, in Fig. 9(b), is centred on the network hub, EʙʀɪHᴜʙ (blue node). EʙʀɪHᴜʙ is

connected to virtual "parent" nodes corresponding to the `Organization` types defined in EᶠW. Each parent is colour-coded by type (see legend, top, centre), with relative size mapping to total number of `Organization`s of each type. Parents, distinguished by a light grey border, link to child/instance nodes. Contact count for each `Organization` instance, a measure of social capital [26], maps to relative node size.

Sub-networks comprising different `Stakeholder` types typically form around key `ServiceProviders` (orange), e.g., the energy consultancy *UO Energy Systems*, the most highly connected organisation in the ecosystem. Such organisations often serve themselves as a (direct or indirect) connector to other services and providers, by providing, e.g., knowledge resources that help other organisations identify where and how to obtain value through their own processes and from their `Stakeholders` (partners, suppliers and customers). The default perspective of the value network in Fig. 1a is an Energy from Waste `Plant`, the only `Organization` that has direct connections to all `Organization` types in the ecosystem. These (green) nodes should therefore see high connectivity, with different `Stakeholders` making and breaking connections through the different `LifeCycle` stages of each `ProjectOrScheme`, as they provide (value-added) services to or source value from each other. The ecosystem (in Fig. 9) includes one `Plant`, which forms a sub-network including the *Eastern General Hospital* and a second `Feedstock` supplier (purple) It is also connected to four `AncillaryServiceProviders` (red) and the (large) `ServiceProvider` *UO Energy Systems*.

Organisations fully registered with EʙʀɪHᴜʙ gain `Value` from additional services, among others, (1) business operations and technology support, including testing and technical services, identification of market opportunities and emerging technologies; (2) economic feasibility studies and risk assessment; and (3) (relevant) educational and informational events [1, 39, 40]. The corresponding components *Systems & processes*, *Technological innovation* and *Knowledge resources* in Fig. 1a all show two-way `Value` flows within the value network, between `ServiceProviders` and other `Organization` types. Two organisations (both `AncillaryServiceProviders`) are yet to formalise a link with the hub – distinguished by faded fill and a thin border in the network view. While such organisations may register to benefit from new knowledge about the sector and for push information from others, they cannot broadcast services to other organisations within the ecosystem, and may have limited access to services provided by third parties.
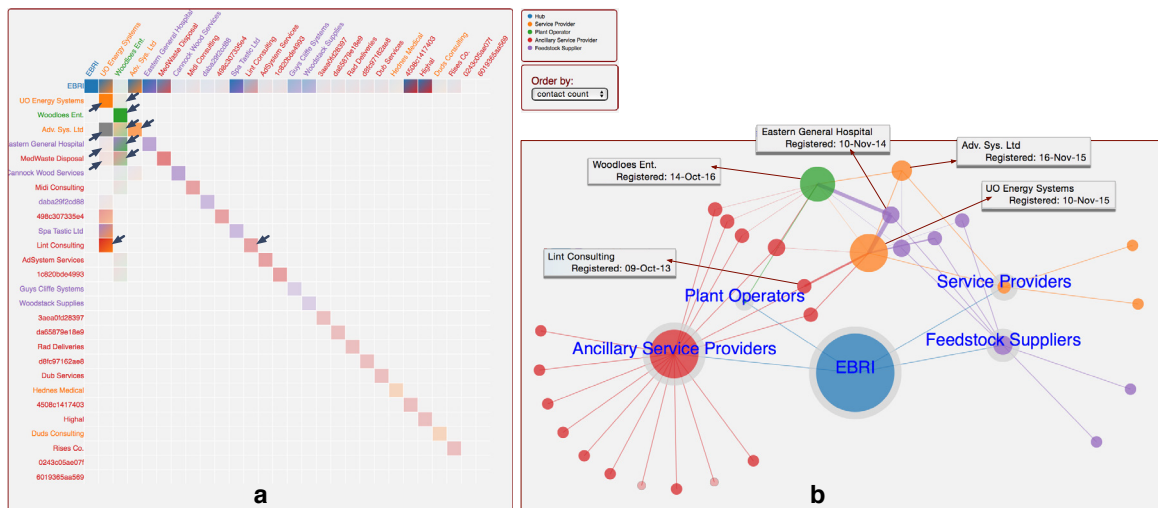

Fig. 9. Visual representation, using a matrix coupled with a network view to illustrate how relationships between node pairs change with perspective on value. Sub-networks generally cluster around each *parent* node; however, the strength of additional relationships pull different organisations away from their parents and into (temporary) business/operational sub-networks, as seen for the `Plant` (green, top, b)

Considering the value network in Fig. 1a from the perspective of a hospital, while they provide a year-round supply of MSW, even large hospitals are unlikely to generate enough `Waste` to power their own `Plants`. They therefore typically form cooperatives with other `Feedstock` suppliers to feed larger `Plants` [12]. Such cooperatives provide the scale to negotiate more cost- and time-efficient contracts with transportation & logistics businesses that uplift and preprocess `Feedstock`. Both processes indirectly feed `Value` into the ecosystem, through the Energy from Waste conversion process; this is visualised by the arrows pointing from *Feedstock* and *Supply chain* into the centre of

the value network. Such collaboration is especially beneficial for smaller businesses, who otherwise may struggle to enter the marketplace [1]. An additional benefit is the savings gained by uplifting `Waste` more regularly from smaller businesses [39], lowering the need for, and therefore cost of, storage facilities. Finally, the heat and energy generated by `Plants` is fed back to `Customers`. `Value` seen here varies by `Stakeholder`, dependent on the grade of the power generated and distance from a `Plant`. Hospitals, for instance, require heating at a minimum of 80-90% [12]; this level of quality both increases cost of production and requires proximity to the grid, to limit degradation as the heat travels through the distribution network. Environmental and health & safety requirements however typically restrict location of large Energy from Waste `Plants`, especially within built-up areas. Except where distance from the national grid is significant, or geographical location isolates institutions from the grid, lower reliability of `Plants` increases further cost to value. Smaller business and domestic `Customers` may therefore see relatively higher `Value` returns than large, complex `Organizations` such as hospitals (see also Fig. 10). The two-way `Value` flow between `Organizations` and other `Stakeholders` and the `Value` concept at the centre of Fig. 1a is visualised with a double-headed arrow.

Fig. 9(a – left) shows an asymmetric matrix used for pairwise comparison between organisations. This view, as does the network (9(b)), uses directional, weighted links, from the (*source*) `Organization` initiating the connection, on the left axis (L), to its *target* (top axis, T). Links in the network are colour-coded based on the source node, while matrix cells uses a gradient from T–L to B–R. Opacity in the matrix and link length and thickness in the network map to *connectedness* or *similarity* between organisations; the shorter and thicker the link and the less transparent the cell, the stronger the connection between `Organizations`. The `Plant`, for instance, is the target of ten businesses (colour-coded by type), with connections of varied strength. In the matrix, reading from source–target (L–T), down the column for the `Plant`, *Woodloes Ent.*, cells corresponding to these businesses are filled. The strongest (most opaque) link is to the *Eastern General*; this correlates with the visibly stronger (relatively thicker) link between the two nodes in the network, shorter also than that for the other `Feedstock` supplier. Other key links to the `Plant` include *Adv. Sys. Ltd*, which provides logistics and transportation services, itself directly linked to a `Feedstock` supplier. The `AncillaryServiceProvider` *Lint Consulting* stands out with its very strong connection to the energy consultancy *UO Energy Systems*. While not (currently) connected to any other nodes, this *Energy-from-Waste (EfW) brokerage* service is an example of a smaller organisation that seeks to maximise `Value` through the business network.

Axes may be (re-)ordered based on pre-specified criteria, with default (Fig. 9(a)) by *contact count*. This places EBRIHUB top, left. Cells along the diagonal map a node to itself; opacity here maps to total contact count for each `Organization`, therefore fading progressively to the bottom, right. The blank tiles for the bottom two confirm that they remain to register fully and link to other organisations. At this early stage in building the ecosystem we see the hub initiating links with `Organizations`, mostly through marketing and informational sessions. (Weighted) links from the hub to each registered node can therefore be seen along the top row. As the ecosystem grows we expect to see links moving in the opposite direction, with `Organizations` seeking to join the network, based on information broadcast on the public network, the ecosystem reputation and via connections with existing members.

As discussed, cost and value derived from the network will vary based on a service, the organisation providing it and physical criteria such as distance, location and logistics services available between businesses, e.g., a `Plant` and its suppliers. Fig. 10 illustrates how these relationships change with KPI. KPIs may measure a single `Value`, such as delivery cycles or gate fees. More complex KPIs may be defined to measure, e.g., shared values (see Fig. 8), and therefore potential for collaboration. Fig. 10b orders, for the selected `Plant` operator (top left), best fit for feedstock supply, by considering `Waste` type and relative cost, delivery cycles and amounts required for optimal operation. Non-matches (faded out) are ordered first by next best fit for all other `Feedstock` suppliers. Other organisation types are ordered by network strength, mapping here to potential to link to other suitable suppliers. Examples of other KPIs include the assessment of barriers, such as societal and environmental concerns, to the development of a new `ProjectOrScheme`, and the cost to remove these (a set of snapshots may be found at DOI: 10.6084/m9.figshare.c.4172009).

6. Discussion

Partner and supplier selection plays an important role throughout the lifecycle of a plant, as the ability to extract value, aligned with an organisation's strategic objectives, relies on ongoing long-term relationships which may need to adapt to changing market conditions. This paper describes the design of an innovative semantic application for the task of understanding the value network in a DBE and identifying potential partners. The backbone of the design is an

```
PREFIX  so: <http://schema.org/>
PREFIX  geo: <http://www.geonames.org/ontology#>
PREFIX  efw: <http://www.ebri.org/efw#>

SELECT DISTINCT  ?organisationUri ?organisationName ?location ?feedstock ?
feedstockType ?feedstockSource ?gateFee

WHERE   {
     ?organisationUri so:legalName ?organisationName ;
          geo:Location ?geoLocationUri .
     ?geoLocationUri geo:name ?location . # search within specified radius

     ?organisationUri efw:supplies ?feedstock .
     ?feedstock rdf:type ?feedstockType . # FuelCrop or Waste
     ?feedstockType efw:isA ?feedstockSource . # e.g., MSW, FoodWaste, Recycling
     ?feedstock efw:hasProperty ?cost .
     ?cost efw:isA ?gateFee # set by type, may vary by location

} GROUP BY ?location
     ORDER BY?gateFee ?organisationName

LIMIT 25
```
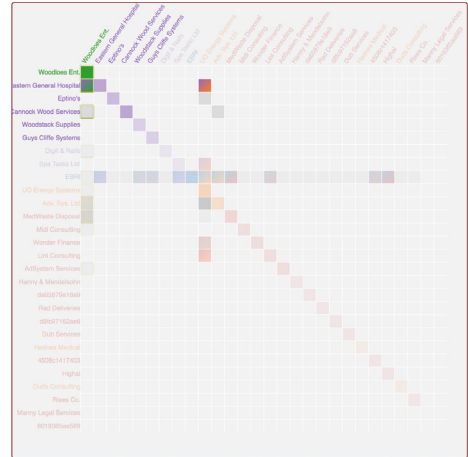
(a) Query to extract gate fees, a component of cost in sourcing feedstock; with supply chain charges, this feeds into calculating relative cost between suppliers.

(b) From top, left – best match for feedstock suppliers (type, delivery cycle and quantity) for the plant operator selected.

Fig. 10. Relative value gained through, e.g., collaboration, supply and cost optimisation, may be compared by reordering the matrix – *c.f.* Fig 9(a).

ontology that models different kinds of value as KPIs in the specific context of Energy from Waste value chains. This exemplifies how formal modelling can bridge different perspectives to create shared design artefacts.

We have demonstrated an ontology that structures knowledge about organisational values and guides human-accessible visual analysis. Our argument is that, for identifying potential partners, the performance criteria required for quantitative supplier selection methods are likely to be unobtainable or estimated. Hence methods where matches are presented using visual cues and metaphors better support application of business acumen to rate potential partners.

The ontology, the initial designs and the prototype were developed in collaboration with and assessed by domain experts, in a sequence of face to face design sessions over one month. In these sessions, various design sketches, conceptual maps, building up to the ontology itself, and low fidelity prototypes (some of which are reproduced in this paper) were used to facilitate discussion with the experts and build a shared understanding of the Energy from Waste domain and application requirements. The resulting prototype addresses a recognised need in the Energy from Waste business sector, with potential to support networking and a range of business services provided by EBRI. The next steps will test the existing prototype with domain experts and users, in order to further refine it into a viable system.

7. Acknowledgements

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