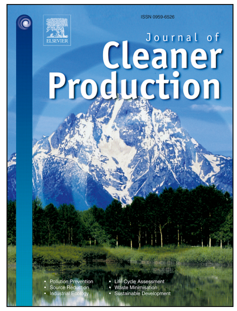

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Industrial Ecology and Carbon Property Rights

ABSTRACT

This paper examines the potential for property rights in carbon to affect industrial ecology opportunities. Given that emissions trading schemes for greenhouse gases are becoming more widely implemented, the definition of the carbon property right can affect barriers and opportunities for industrial ecology, alongside other factors. The paper uses legislation for emissions trading in Australia and two possible scenarios for the future of energy generation in the Latrobe Valley, Australia in 2050 as an illustrative case study to identify issues for industrial ecology arising from ill-defined carbon property rights. Currently, electricity generation in the region is reliant on coal-based generators. Scenario one focuses on bio-industries and renewables with no coal usage; and scenario two focuses on electricity from coal with carbon capture and storage resulting in moderate to high coal use. If a carbon property right for soil carbon emerges before a property right for subterranean carbon, then bio-based industrial ecology opportunities could be enabled ahead of a regional symbiosis involving carbon capture and storage. A generalised framework for considering the intersection of industrial ecology and carbon property rights is presented with a focus on tensions in: contributing to sustainable development, system boundaries and finally exchange mechanisms.

Keywords: Industrial ecology; property rights; carbon trading; biomass; coal; backcasting; life cycle; regional planning; regional synergies; industrial symbiosis.

Industrial Ecology and Carbon Property Rights

1. INTRODUCTION

The research question for this paper is: how might uncertainties regarding carbon property rights affect industrial ecology opportunities in energy producing regions? Industrial ecology offers a mechanism for realising the future structure of industry in a resource constrained world, including through resource efficiency and the cooperative use of waste material and energy between co-located industries (see, for example, Deutz et al., 2007; Golev and Corder, 2012; Korhonen, 2002). However, the implications of carbon property rights and trading systems on the barriers and opportunities for industrial ecology remain unexplored. The creation, type and distribution of carbon property rights (CPR) have been identified as critical in determining how the greenhouse gases (GHG) associated with carbon pollution are used (United Nations, 1998) and managed (Boydell et al., 2009a). Despite the importance of the mechanisms provided by industrial ecology and CPR, to date there has been limited discussion of the relationship between industrial ecology and property rights (see, for example, Dijkema and Basson, 2009).

Both 'industrial ecology' and 'CPR' engage with notions of achieving environmental goals to support sustainable development and it is important to understand where CPRs assist with the implementation of industrial ecology and where they introduce new barriers. In this paper we utilize a backcasting case study which describes possible future energy scenarios in the Latrobe Valley, Australia (which currently uses brown coal to generate electricity for over four million people in and around Melbourne) to make the concepts and implications explicit. In addition to advancing discussion regarding the role of CPRs in enabling or constraining industrial ecology under current legislation in the Latrobe Valley, the illustrative case study demonstrates the importance for broader industrial ecology research of including and assessing the implications of CPR.

2. METHODOLOGY

The research presented within this paper used an adaptive theory approach (Layder, 1998). Adaptive theory differs from deductive approaches which collect empirical data to test an *a priori* theory or hypothesis: "adaptive theory attempts to incorporate the insights of general theory into the practical and strategic thinking of researchers who are collecting and analysing empirical data with a view to coming up with new theories, concepts and insights" (Layder, 1998). The adaptive theory approach used for the research involved three steps; this paper presents the research findings from each step in sequential order as shown in Figure 1.

We commenced the research in Step 1 by exploring the generalised theories and concepts of (i) industrial ecology and (ii) CPR, and (iii) their similarities and differences. The focus of this exploration being on the formation of a 'working' theoretical framework outlining initial theoretical ideas on the intergration of CPR and industrial ecology and how uncertainties in CPR might affect the industrial ecology opportunities. This initial framework is refined following analysis of illustrative scenarios. Its first purpose is to guide the researchers in deciding the nature of the field data to be selected during step 2, and to make sense of that data. This involved a review of current concepts and theories detailed in refereed journal literature for CPR and industrial ecology, which were reviewed together by the research team. We used the findings from this first step in our research to define the scope of the field work in step two.

Following an overview of the current context for carbon property rights in Australia (iv), and guided by the findings from Step one (see section 3.3) the second step in the research explored the intersections of geographical industrial ecology and CPR through case study scenarios in the LaTrobe Valley, Australia (v). The illustrative senario case studies were deemed to be appropriate for two reasons. First, at the time of the research their were no Australian cases of industrial ecology in energy producing regions affected by CPR to examine. Secondly, the use of scenarios within the research is in line with their demonstrated role in “creating a reframing of the issues involved, through the introduction of new perspectives” (van der Heijden, 1996). We restricted our senarios explored in this paper to geographically based industrial ecologies. Hence the two case study scenarios described possible futures in 2050 for the industry structure of the energy-rich Latrobe Valley, Australia from earlier research (Giurco et al., 2011b). This research overlayed CPR onto these senarios, and then analysed the potential CPR implications through a series of research team workshops.

The third step in the research examined data emerging from the case study scenarios, with the aim of refining the ‘working’ framework of theories, concepts and insights on carbon property rights and industrial ecology developed at the outset of the research project. This was a reflective and iterative research process that was carried out by the researchers in parallel with the second research step.

TAKE IN FIGURE 1 HERE

3. CONCEPTUALISING INDUSTRIAL ECOLOGY AND CARBON PROPERTY RIGHTS

3.1 Industrial Ecology

On the theory of industrial ecology, Korhonen (Korhonen, 2004) classifies this into two elements. Firstly, the systematic consideration of (cyclical) flows of matter and energy within and between industrial systems and ecosystems to support sustainable development. A central focus of industrial ecology is on *exchange* of materials and energy between firms, in particular the utilisation of flows which would have otherwise gone to waste. At the overall goal level, he recalls Daly's operational principles of sustainable development (Daly, 1990), namely:

- harvest rates of renewable resources should equal regeneration rates
- rates of waste emissions should equal the assimilative capacities of ecosystems into which wastes are emitted; and that
- the quasi-sustainable use of non-renewables requires that an investment in the use of a non-renewable resource be paired with a compensating investment in a renwable substitute.

Secondly, the consideration of structural and organisational properties of industrial ecosystems, including the decisions made by individuals and groups working in businesses, but also implicitly covering instutional arrangements and regulations. Industrial ecology remains an evolving field of scientific endeavour.

In seeking to optimise material/energy flows and the inter-organizational structures and characteristics of industrial ecology, industrial ecology adopts two common system boundaries: 'product-based' and 'geographical' industrial ecology (Ayres and Ayres, 2002; Korhonen, 2002). Each is a systemic perspective with different elements foregrounded. The 'product based focus' identifies material flows and environmental impacts along the life cycle of a product, with a focus on potential for promoting cyclic flows of resources. The geographical approach, which is the dominant focus of the research in this paper, seeks to minimise and integrate material and energy flows within an eco-industrial park or region, also known as industrial symbiosis (Chertow, 2003) or regional synergy (Giurco et al., 2011a; van

Beers et al., 2007b). For example, the waste product of one industry may become the feedstock for a nearby industry. A further example is where shared water, material heat or energy generation and reuse infrastructure may provide efficiencies within the geographical region which could only be achieved by exchanges between companies (rather than within the company's individual site of operations).

3.2. Carbon Property Rights

CPR as conceptualised as *real* property rights as opposed to *intellectual* property rights. Real property rights can be defined as the formal and informal institutions and arrangements that govern access to land, buildings and other resources including water and carbon. Real property rights, obligations and restrictions can be found in and change across the full range of human societies, both in time and space (Emigh, 1999; Hann, 1998; Herskovits, 1940; Hoebel, 1954; Horwitz, 1992). CPR is the title given to the property rights, obligations and restrictions placed on a range of GHG. As a result CPR cover substances which do not contain carbon (e.g. SF_6) but which have a global warming potential which can be expressed in CO_2 equivalents. (e.g. terrestrial carbon and also in greenhouse gases: CO_2, CH_4, N_2O, HFCs, PFCs and SF_6). Like all other property rights, CPR arise from law, custom, and the operation of markets, and are subject to a range of claims – by individuals, corporations, and countries, amongst others – that are held on them and on the benefits and impacts they generate. The purpose of the creation of CPR is to allows trading and exchange of rights, obligations and other restrictions between buyers and sellers to underpin GHG management programs and policies (e.g. carbon offsetting and emissions trading schemes) to meet environmental goals as part of a broader commitment to sustainable development.

Traditionally real property rights have had an anthropocentric focus, whilst affording little or no protection to other modes of being. When nature and real property meet within this context, the law has traditionally favoured economic interests, even when those rights externalise damages onto the environment (Gluckman, 1965; von Benda-Beckmann et al., 2006). Eric Freyfogle argues that this has lead to a 'tragedy of fragmentation' (Freyfogle, 2003)where millions of owners can not achieve sustainable development. Traditionally the concept of 'property rights' and 'sustainable development' have been considered as inherently in tension, and in recent decades real property rights theorists have argued that substantive changes are needed in our approach to real property rights if they are to provide an institutional arrangements that humans can use to promote sustainable development (Berkes et al., 2003; Berkes and Folke, 1998). The recent emergence of CPR, along with other forms of property rights such as, for example, fishery rights, water, and in Australia Native Title seek to support sustainable development. The economics of CPR are intended to assist in monetising GHG externalities allowing them to be brought into economic and social development considerations form which they were previously excluded; as, Hanna and Munasinghe (Hanna and Munasinghe, 1995) note "the correct economic valuation of environmental and sociocultural assets [such as GHGs], and their internalization in the price system is one means of ensuring that market forces lead to more sustainable resource use".

3.3 Industrial ecology and carbon property rights: the intersection

Despite the potential coming together of industrial ecology and CPR to address resource management, to date there has been limited discussion of the relationship between them. Core texts in the field of industrial ecology make no mention of property rights (Allenby et al., 1999; Ayres and Ayres, 2002; Graedel and Allenby, 1995; Manahan, 1999) with acknowledgement of the issue occurring only in more recent works (see, for example, Dijkema and Basson, 2009). Building on the industrial ecology and CPR theories previously discussed (see sections 3.1 and 3.2), this section outlines a 'working' theortical framework for understanding how uncertainities in CPR that might act as a barrier to industrial ecology opportunities. These possible barriers that might be generated by CPR sit amongst an established list of barriers to industrial ecology that have been identified over the years by a range of authors (Heeres et al., 2004; Van Beers et al., 2007a) and have been synthesised by Golev (Golev, 2012) into the following eight categories: (i) commitment to sustainable development by the organisations involved; (ii) information; (iii) cooperation; (iv) technical; (v) regulatory; (vi) community (and social); (vii) economic; and (viii) geographic. The various aspects of the 'working' theoretical framework we discuss in this section are summarised in table 1 below. Whilst it is possible that the intersection of CPR and industrial ecology could be challenged by the broad range of these barrier already identified by Golev (Golev, 2012), here we would like to explore challenges within three specific areas: *sustainable development through resource optimisation*, *system boundaries* and those related to *exchange*.

Based on the theortical components of industrial ecology and CPR discussed in section 3.1. and 3.2, they would appear to be complementary in purpose when it comes to supporting sustainable development through resource optimisation. Whilst industrial ecology offers a means for realising the future of industry in a resource constrained world, CPR is intended to provide institutional arrangements to help change the use of one particular set of resources GHGs, by avoiding their emission to air. Whilst CPR have the potential to make significant contributions to sustainable development goals, their remains considerable uncertainty about the appropriate institutions and policy programs that are needed to ensure that the creation of CPR can effectively manage GHG emissions. In this respect CPR could be something of a two edged sword. If exercised and applied appropriately, and in accordance with ecological limits the assigned CPR could be an effective tool to supporting sustainable development and a complement to industrial ecology; if not exercised and applied appropriately it could have the adverse effect and be sidelined by industrial ecology. As yet, despite the economic development of emissions trading (Emission Trading Scheme (ETS) - cap and trade) schemes and the introduction of carbon taxes around the globe, their remains an institutional disconnect between the well-intentioned purpose of CPR and the regulatory, economic and technical system in which they are embeded. The ETS and carbon tax models still grapple with uncertainty in articulating the underlying asset, the CPR, upon which the price of carbon is secured. Both approaches offer 'blunt tools in attempting to offset GHG emitting economic activity against environmental protection (decarbonisation)' (Boydell et al., 2009b, 105).

Industrial ecology emphases the need for a systems perspective in decision-making regarding the use of resources in ways which respect ecological limits. Of central importance to this systems perspective is the clear definition of the boundaries – around energy, materials, waste, companies, populations, regions, and sectors amongst other entities – that are used to manage the circulation of resources through industries and society for sustainable development. Whether it be geographically focussed or product-based industrial ecology, the aim of these boundaries is to foreground important variables, and more importantly, guard against a partial analysis giving rise to unintended consequences. Specific mechanisms have evolved to allow systems analysis such as life cycle analysis and material flow analysis. Given that the intersection of CPR and industrial ecology remains unexplored, uncertainties remain over how the bounds of industrial ecology systems will be able to accommodate CPR. For example the national or intertational boundaries that constitute CPR systems could be problematic for geographically specific forms of industrial ecology.

When conceptualising the integration of industrial ecologies and CPR, consideration needs to be given to the exchange capacity of CPR within industrial ecologies. Industrial ecology is founded on the exchange of energy, materials and waste between companies, either geographically or along the product supply chain. Similarly CPRs are conceptualised as mechanisms to allow society to govern access to, use of and exchange of GHGs. Current uncertainties in articulating the underlying science, economics and legalities of different CPR assets could present challenges to how GHGs are embedded within the web of exchanges that constitute industrial ecologies. For example if CPR are not adequately developed to allow GHG exchange to be incorporation into cyclical or linear material and energy flows within industrial ecologies, they may become backgrounded within industrial ecology systems either through their restriction to sinks that absorb and store GHG waste or through GHG credit systems.

Overall Dimension	**IE theoretical dimension**	**CPR theoretical dimensions and uncertainities**	**Uncertainty in CPR affects IE opportunities**
Resorce optimisation for sustainable development.	To manage the circulation of physical resources and energy through industry within society for sustainable development	Seeks to management the circulation of GHGs with the intention of supporting sustainable development by achieving environmental goals.	Uncertainty in the current institutional structures of CPR make they types of industrial ecology opportunnies most suited to supporting environmental goals difficult to prioritise.
System boundaries	Geographical industrial ecology (e.g. Local and regional focus across several industry types) and product based industrial ecology.	CPR is an emerging system that seeks to manage carbon, but also non-carbon GHG (e.g. SF_6) at times, across state, national and international scales.	Uncertainties remain over how product or geographically-bounded industrial ecology systems will be able to accommodate emergent boundaries of CPR.
Exchange mechanisms	Industrial ecology involves exchange of resources, energy and waste between companies, either geographically adjacent or along the product supply chain	CPR seeks to provide a mechanism for the exchange of GHG. There are contextual differences in operating exchange mechanisms.	The web of exchanges that constitute industrial ecologies will be prioritised to those CPR for which there is lower uncertainty in the science or regulations or ability of companies to claim credit.

Table 1. Summary of the various aspects of the ‘working’ theoretical framework for the intergration of industrial ecology and CPR discusse in section 3.3 (Source: authors)

To further explore and develop these initial conceptual insights into the intergration of industrial ecology and CPR, and the uncertainities that might act as a barrier to industrial ecology opportunities as a result of intergration, we use scenario case studies.The scenarios in the following section of this paper focus on the integration of CPR within the closed loop systems of energy and material exchanges within geographical-based industrial ecologies.

4. LATROBE VALLEY ENERGY SCENARIOS: EXPLORING INDUSTRIAL ECOLOGY AND CARBON PROPERTY RIGHTS

In the case study which follows, the two geographically-based industrial ecology scenarios for energy generation in the Latrobe Valley were developed using a backcasting approach, namely, considering a desired end-state and the path to get there. Backcasting is an established approach to consider the impacts (and feasibility) of alternative futures (Quist and Vergragt, 2006; Robinson et al., 2011). When discussing CPR implications of these future scenarios, the current Australian context for carbon property rights is used as the starting point. Whilst it would be a useful topic for further research, the paper does not explicitly elaborate (in a backcasting sense) an ideal configuration for carbon property rights in the future case study scenarios as they are currently hypothetical (possible) future scenarios. Rather, it identifies through the case studies, points of tension regarding carbon property rights and connects this to more generalised implications for promoting or constraining industrial ecology opportunities relating to energy futures in the Latrobe Valley context.

4.1 Carbon Property Rights in Australia

In Australia, a clean energy legislative package was rolled out in 2011 as a Federal response to reducing carbon. The *Clean Energy Act 2011 (Cth.)* set up a carbon pricing mechanism that commenced on 2 April 2012, dealing with assistance for emissions intensive trade exposed industries and the coal fired generation sector. The legislative frameworks also included the *Clean Energy Regulator Act 2011 (Cth.)* and the *Climate Change Authority Act 2011 (Cth.)* The associated *Carbon Credits (Carbon Farming Initiative) Act 2011 (Cth.)* provides for carbon sequestration in land, but does not address how a separate legal platform will be created in the inter-jurisdictional property rights milieu for land based carbon. Over the past decade in Australia, CPRs have emerged at the State level, with legislation in place in all six States (Queensland, Victoria, New South Wales, Tasmania, Western Australia, South Australia) – but not in the two Territories (Australian Capital Territory, Northern Territory) – to define Carbon Sequestration Rights (CSRs) (Boydell et al., 2009a), with only Western Australia *Carbon Rights Act 2003* actually creating an independent piece of legislation to articulate the carbon right as a new statutory property interest (Hepburn, 2009). CSRs have also been promoted at the national and international level as parts of the mechanisms that have been set up in response to the Kyoto protocol. Critical to this process in Australia, the emergence of secure and clearly defined carbon property rights are still marked by a diversity of hurdles which range from appropriate legal frameworks (Boydell et al., 2009a; Hepburn, 2009) through to the fact that science is currently unable to define it sufficiently (API, 2007; Sheehan and Kanas, 2008). These challenges and constraints facing emergent carbon property rights are compounded by the inherent conservatism of prevailing legal systems, where the incorporation of new property interests into the common law framework is approached with judicious circumspection (Arnold, 2002).

4.2. Latrobe Valley in carbon contrained era

The Latrobe Valley has substantial brown coal deposits that are currently mined for use in coal-fired power stations, supplying 85% of Victoria’s electricity. A carbon constrained society places demands on the ‘carbon intense’ industries in the Latrobe Valley for a just transition to a greener future (see, for example, Evans, 2007; Evans, 2008; Giurco et al.;

Giurco et al., 2009). Response to international aspirations for carbon constraint are being supported by governance responses at (i) the Federal (National government), (ii) State government, and (iii) Local (regional and city) government levels in Australia.

As explained above, the Australian Federal Government implemented a carbon trading mechanism which began with a fixed price of AUD 23 per tonne of carbon dioxide for at least a three-year period (2012-2015). Compensation schemes are underway for emission-intensive trade-exposed sectors (EITES), which includes coal exports, but not coal fired electricity (a separate compensatory scheme is being rolled out for domestic coal fired electricity). At the same time, the Victorian (state) Government has committed to reducing emissions by 60% by 2050 (based on 2000 levels) and, in response to stalling of the federal CPRS in late 2009, the Victoria Parliament passed the Climate Change Act in September 2010 with broad support. This state legislation was a major milestone in responding to climate change with a target to cut emissions by at least 20% by 2020 (compared to 2000 levels), but the aspirational target of 20% was subsequently rescinded by the incoming State government in 2012. Victoria has established a Near Zero Emissions Policy Framework to provide a high level strategic policy framework for the development of the brown coal resources in the State with near zero greenhouse gas emissions (Victorian Department of Primary Industries, 2007; Victorian Government Department of Premier and Cabinet, 2009). Within these various policies, draft legislation and the research informing their development, regions such as the Latrobe Valley have been singled out as requiring particular attention given that emission reduction schemes will have considerable impact on the valley's 'significant coal-fired electricity generation industry and a number of other emissions-intensive industries' and more broadly on the businesses and communities they support (Commonwealth of Australia, 2009, 13).

The Victorian Government has indicated the Latrobe Valley is likely to be the region in Australia that will be most strongly affected by carbon constraining legislation (Commonwealth of Australia, 2009; Victorian Government Department of Premier and Cabinet, 2009). At the local governance level, strategies driving change in the Latrobe Valley include the Latrobe City Economic Development Strategy 2004–2008 and Latrobe 2021 (Latrobe City, 2006, 2007), which emphasise that the future of the Latrobe Valley lies in industrial diversity: energy, forestry, timber and paper, food and agribusiness, advanced manufacturing and aviation, services, tourism and events, and tertiary education.

In response, the Victorian Government has indicated the need to transform the Latrobe Valley into a 'hub for clean coal research and development and exploring technologies and building expertise in carbon capture and storage methods, such as geo-sequestration' (Victorian Government Department of Premier and Cabinet, 2009, 52) to help businesses and communities within this vulnerable region to adjust to a carbon price. Trial carbon capture and geological storage (CCS) – geo-sequestration – is already underway in the Latrobe Valley and has been explored internationally (see for example the Tees Valley Region, UK (Element Energy and Carbon Counts, 2010)).

4.3. Overview of scenario generation

Drawing on research commissioned by the Victorian Government (Giurco et al., 2007) we use two hypothetical but possible scenarios to discuss the opportunities that industrial ecology plays in underpinning the future structure (2050 and beyond) of industrial activity in the Latrobe Valley. Illustrative CPR issues for each scenario are presented, in particular, noting how uncertainty regarding CPR may affect industrial ecology opportunites. Do CPR uncertainties represent barriers or enablers in the scenario? Are the uncertainties dominant across the scenario or relating only to particular exchanges?

The future scenarios for industry ecology are centred on two deliberately distinct themes[1]:

- Bio-industries and renewables (no coal usage); and
- electricity from coal with carbon capture and storage (low to high coal use options exist within this scenario).

Through these scenarios, we explore the carbon-constrained management of resources with the goal of stimulating broader discussion about the interdependence of applied industrial ecology and carbon property rights (see Figure 2).

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Figure 2. Overview of drivers, cluster elements and coal utilisation for each scenario (Source: authors)

4.4 Approach to assessment of scenarios

The level of analysis we have adopted in this research is akin to that present in sustainability assessments (Nijkamp and Vreeker, 2000). The objective of assessing each scenario from a life cycle thinking perspective is to offer, insight into potential differences between the scenarios more than absolute results.

We acknowledge the limitation of seeking to apply comparative assessments as there is no common 'functional unit' between the two scenarios presented; that is, one may produce more energy, one may produce products,. The aim of using a life cycle thinking perspective in the assessment is to capture the 'product focussed' industrial ecology considerations along the life

[1] Note a third scenario was developed by Giurco et al. 2011 around coal to products (e.g. hydrogen, ammonia, diesel, methanol, plastics, char with medium to high overall coal use relative to current levels)

cycle, and connect them with 'geographically focussed' considerations within the proposed industrial symbiosis. Simplified life cycle stages along the value chain are:

- mining / raw material inputs
- production / processing
- use / disposal.

Assessment of indicative environmental impacts and property rights considerations was based on the authors' judgement to elicit key insights about impacts across stages and providing a framework that could be extended to a more comprehensive analysis.

The assessment adopts a standardised approach, framed around life cycle stages:

- each stage of each activity is characterised in terms of its degree of impact on the abatement of, or contribution to, greenhouse gas emissions or water use. These impacts are denoted visually as −−/− and +/++ respectively, in tabular format. That is, in terms of GHG, a negative contribution in greenhouse gas emissions represents abatement, while a positive contribution represents an emission. Likewise, for water use −−/− represents a saving, whilst +/++ represents an increased consumption (irrespective of the supply constraints that prevail over water property rights);
- brief comments on technical, social and economic and property rights considerations are represented in tabular format, supported by an explanation of the institutional arrangements that are necessary to achieve workable carbon property rights in each scenario;
- the way in which uncertainty regarding CPR affects industrial ecology opportunities is described with reference to the working theoretical framework presented in Table 1, namely with respect to issues of supporting sustainable development and in particular,

but is not explored further in this paper.

environmental goals; with respect to issues of system boundary and exchange mechanism.

4.5 Scenario Analysis A – Bio-Industry & Renewable Focus

The configuration of cluster elements in Scenario A is given in Figure 3.

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Figure 3. Configuration of Scenario A: Bio-industry & renewable focus (source: authors)

Scenario A is bio-focused, in terms of both energy generation and product perspectives. Other renewable technologies will be drawn upon to supplement energy production. These include solar, wind and geothermal power.

In order to supply the necessary biomass, the agricultural and forestry sectors will be expanded to include specific, purpose-grown crops. In this scenario, residues and crops are used for two purposes (i) carbon sequestration (which complements soil sequestration activities) and (ii) to fuel the co-generation plant and provide inputs for producing ethanol and methane. Residential waste can also provide inputs to produce algae.

Wind, geothermal and solar systems can produce energy for the region and export any unused electricity to the national grid, thereby creating an additional revenue stream. Local manufacturing firms can benefit from lower distribution costs and the skills that exist in the aviation industry could be used to design and manufacture wind turbines.

In addition to this energy production, there is a focus on products. Biodiesel and bioethanol will be manufactured, as will inputs into processes making chemicals, plastics and other composites. Biochar will also be manufactured and used both to sequester carbon and improve soil quality in the region.

Table 2 presents an assessment of the first scenario focussed on bio-industry and renewables.

Table 2. Scenario A Analysis: Bio-industry & renewable focus

		Life Cycle Stage			Analysis of Property Rights (PR)	Summary
		Mining / Raw Materials	Production / Processing	Use / Disposal		
Environmental impacts	Greenhouse gas Emissions	+ aviation manufacturing + other manufacturing −− forestry and agriculture −− algae production	+ aviation manufacturing + other manufacturing + wood and paper pulp industry + bio-based processing	−− renewable energy −− biochar + biodiesel −−biocomposites −− waste management	PR in soils as yet unproven as a separate right Bio-sequestration & carbon sink PR potential in forests PR implications for future generations in waste management – contamination risks in nutrient streams	Overall major contribution to abatement through bio-based focus and renewable energy
	Water consumption	++ forestry and agriculture ++ fish farming ++ algae production	++ wood and paper pulp industry + cooling for biomass power station	no major impacts of use and disposal	Contested water PR Contested PR in rights based fishing	Water requirements increased from bio-based focus
	Other	−− fertiliser use from biochar			PR in soils as yet unproven as a separate right	
Further Sustainability Impacts/Risks	Technological	No major technology risks in providing raw materials for bio-based industry	Biochar, biocomposites , biodiesel and biochemicals, plus renewable energy at differing stages of development curve – further innovation needed	Other downstream innovation required to adjust to new inputs	Intellectual PR (not a focus of our particular analysis of 'real' property rights)	Significant technological risks need to be addressed through concerted efforts around breakthrough innovation
	Socio-political	Changes to land use could have social implications	More production facilities at a large scale will impact on amenity	Major use will not occur locally, however increased transport requirements	Transport issues engage PR over land acquisition, disturbance and infrastructure development	Social changes will occur and extensive stakeholder involvement required to manage transition
	Economic	New production systems required to improve competitiveness	Innovation breakthrough needs financial resources which could be difficult to attract	Purpose of clusters is to use 'wastes' as inputs – so low economic impacts from disposal	Land related PR a key contested economic component Carbon sink potential has export / carbon PR trading potential for income generation	Achieving innovation breakthrough will deliver economic benefits to region, however this needs to be financed in the start-up stage

CPRs in soils are, as yet, unproven as a separate right. The capacity of soil to sequester carbon varies according to the molecular structure, rank, class as well as land management, rainfall, topography and localised conditions (Sheehan and Kanas, 2008). Whilst the science of soil carbon and associated sequestration is still evolving, the notion of separating soil and vegetation from the basic land property right is a difficult conceptual legal task that has yet to be resolved, with no genuine titling provisions currently in place for such a circumstance despite a number of localised agreements being negotiated in private schemes. This uncertainty in CPR relates to the science in in turn extent to which CPR could be considered as supporting environment goals. It also affexts the exchange mechanism and the uncertainty most affects the industrial ecology exchanges shown in dotted lines in Figure 3.

The science concerning forest sequestration and retaining carbon in trees is more developed than soil sequestration, yet there is similar confusion over the institutional arrangements managed to deal with the carbon property right. Forestry property rights and forest CPRs have erroneously been articulated as a *profit à prendre* in several Australian states, with only Western Australia having CPR legislation (for a full explanation, see Boydell et al., 2009a; Hepburn, 2009). The *profit à prendre* is a clear example of the anomaly that can occur when lawyers drafting legislation are reliant on historic legal terminology and precedent, rather than conceiving a 'new' way to articulate what is a 'new' form of interest. A *profit à prendre* is a legal right to take something (e.g., minerals, produce, fruit) from land that someone else owns. A *profit à prendre* is the antitheses of carbon sequestration, the precise nature of sequestration being to leave carbon in trees or vegetation (as in bio-sequestration), or under the land (as in geo-sequestration). As a result of the confused and conflicting language used in various legislation, there are many examples of localised sequestration arrangements developing that separate the tree, or often just the carbon sequestration benefits of the tree, from the land property right. These localised arrangements have created one hundred and fifty year carbon rights, obligations and restrictions over the land, which in many states is not required to be registered and recorded on the underlying land title. There is still a great deal of work required on the institutional arrangements to ensure that the CPRs are secured by the States and can be transacted both nationally as well as on international carbon offset markets.

Importantly for Victoria and the Latrobe Valley, the Victorian Climate Change Act 2010 repeals and replaces the existing Forestry Rights Act 1996 in an attempt to make it easier for private landholders who wish to trade land and trees separately to the carbon stored in their trees and soil. This jurisdictional difference affects the system boundary of CPR.

The Victorian Climate Change Act 2010 defines a *carbon sequestration right* as 'an exclusive right to the economic benefits associated with carbon sequestered by vegetation other than vegetation that has been harvested, lopped or felled' (at Pt.4 s.22). The Act (at Pt.4 s.23) separately defines a *forestry right* as an exclusive right to plant, establish, manage and maintain vegetation on land and take and deal with harvested, lopped or felled vegetation as well as providing rights of access/entry. Importantly, in addressing our concerns above, a *soil CPR* is defined (at Pt.4 s.24) as 'an exclusive right to the economic benefits of carbon sequestered underground, excluding carbon stored within plants'. The intention of the Victorian reforms is to ensure that the rights of carbon investors are recognised and able to be recorded on land title as an 'interest in land'. The rather confused former system of Forest Property Agreements and Carbon Rights Agreements under the Forestry Rights Act 1996 have been replaced with a single agreement called a Forestry and Carbon Management Agreement. The management obligations of all the parties concerned – landowners, forest property owners and carbon investors – are to be spelt out in these new Agreements (see Pt.4 Division 3).

The pollution arising from Scenario A is more localised under a bio-industry and renewables oriented future than the much broader contamination of the global commons under the existing arrangements or those in Scenario B. However, our industrial ecology model has to ensure that there are no contamination risks from waste management that could impact on the property rights of adjoining land users or, in the case of nutrient streams and water courses, those elsewhere within the catchment / basin.

4.6 Scenario B – Electricity from coal focus

The configuration of cluster elements for Scenario B is given in Figure 4.

TAKE IN FIGURE 4 HERE

Figure 3. Configuration of Scenario B: Energy from Coal focus (Source: authors)

This scenario is based upon coal-fired power generation. Carbon emissions are then captured and stored underground. Some carbon dioxide is also used to manufacture chemical products and (with the use of some of the waste heat) crops, such as hydroponic tomatoes. The ash produced as a by-product of the energy generation can also be used in products such as glass, ceramics and soil conditioners.

Table 3 presents an assessment of the second scenario focussed on electricity from coal.

Table 3: Scenario B Analysis: Electricity from coal

		Life Cycle Stage			Analysis of Property Rights (PR)	Summary
		Mining / Raw Materials	Production / Processing	Use / Disposal		
Environmental impacts	GHG Emissions	+ Brown Coal mining − Forestry / agriculture	++ Coal gasification plant ++ Coal fired power station ++ Cement manufacture (+ Geopolymers) − CO2 to chemicals − Solar thermal pre-heating − Greenhouses	−− CCS	Unclear PR for CCS – resource sector has extraction rather than geo-sequestration rights Bio-sequestration PR in forest carbon sinks	Low overall emissions
	Water consumption	+ Brown Coal mining + Forestry / agriculture	++ Coal gasification plant ++ Coal fired power station + Paper and pulp industry + Greenhouses	- for residential (coming from IGCC)	Bio-sequestration PR in forest carbon sinks Carbon offsets (requiring carbon PR) required for power station & gasification	Moderate water usage, depends on newer technology
	Other	Mined land impacts	Fly ash, heat, air emissions		Multiple PR over mining and exploration interests	
Further Sustainability Impacts/Risks	Technological	Forestry and agriculture may be adversely impacted by climate change	CO_2 to chemicals and geopolymers requires further technological and market development	Development of CCS as long term solution subject to technical risk	Unclear PR for CCS – resource sector has extraction rather than geo-sequestration rights Soil science unclear on PR in soil & related impact of soil conditioners	Requires technological breakthroughs- potential to export CCS know-how and technology overseas
	Socio-political	Potential for backlash both against continued mining and mine closure (GHD, 2005 p.205)	Coal fired power subject to future regulation nationally / internationally	Public acceptance of CCS and required licence to operate	Conflict potential over unclear PR for CCS	Potential to extend from status quo
	Economic	Coal price may change	Potential that other forms of energy (e.g. distributed) are more cost-competitive in a carbon constrained environment	Carbon price affects competitiveness of CCS and technology development is capital intensive	Clearly articulated and tradeable carbon PR need to be agreed nationally & internationally	Technology development is capital intensive - other options may be cheaper

This scenario, which is an extension of the current situation, impacts primarily in the Latrobe Valley. If CCS technology is developed, manufactured and exported, then the benefits of reduced impacts can also indirectly occur overseas, positioning the region and Australia as a leader in the development of CCS technology (although the labour pool will require the necessary technical research and development skills to realise this outcome). The principal risk for this scenario is the technological risk associated with CCS becoming cost-competitive Whilst carbon property rights regarding storage remain uncertain, the CPR uncertainty is not the principal factor in realising such an opportunity, rather it is techno-economic.

Regarding carbon property rights under Scenario B, additional to those detailed in Scenario A above, include extraction, carbon capture and storage, and, more broadly, the global commons. In the Latrobe Valley, the state government has the power to grant exploration licences and extraction rights over (and under) land owned by the citizenry. Multiple arrangements can be in place over individual parcels of land, and modest compensation provisions have been formulated both by negotiation and through the courts. The new institutional arrangements relating to carbon capture and storage, and in particular geo-sequestration, fall under the Victorian Greenhouse Gas Geological Sequestration Act (2008). This legislation identifies that the superior interest of subterranean geological sequestration opportunities remains vested in the Crown (which is in reality the State of Victoria on behalf of the Crown), and details the rights and obligations relating to exploration permits, retention leases, monitoring licences (2008). In terms of the global commons, the State of Victoria has articulated its obligations for carbon pollution reduction under the Climate Change Act (2010), which was discussed above.

If not all carbon dioxide can be sequestered with CCS, then the purchase of offsets would be necessary, potentially from overseas. Given the current lack of legal clarity and the economic fragility of the carbon property rights upon which such offset arrangements are grounded, this may undermine the perception of the industrial ecology opportunity contributing to ecological goals, in part because of the difference between the system boundary pertaining to the CPR and the industrial ecology opportunity.

The influence of the CPR uncertainty over the opportunity, in part (as illustrated in this scenario) depends on the influence of the CPR uncertainty relative to other techno-economic or socio-political barriers in progressing the opportunity. That is, as CCS is currently uneconomic, CPR uncertainty is not the principal barrier to implementation. This raises an important consideration about the changing role of CPR uncertainty over time in enabling or hindering industrial ecology opportunities for different technologies which link to distinct CPRs. It could also be that the creation of a CCS property right facilitates technological lock in to a linear economy, rather than carbon capture and use in an industrial ecology of converting carbon dioxide to products (e.g. the methanol economy).

5. CONCLUDING DISCUSSION

In this concluding discussion, we first reflect on the key insights from the illustrative case study scenarios, from the Latrobe Valley. We then reflect on the theoretical implications for industrial ecology identified in the working theoretical framework of the uncertainty regarding CPRs as revealed through the analysis of the scenarios. Next we discuss the limitations of the study, in particular the one-directionality of the study, namely the focus of CPRs on industrial ecology (rather than the reverse).

5.1 Discussion of scenarios

The scenario analysis undertaken in this paper has identified that CPRs and systems for their trading provide both barriers and opportunities for industrial ecology. These are now discussed with reference to a schema of barriers and enablers for industrial ecology identified in Section 3.1 as shown in Table 4. The fact that these barriers have only recently been systematically examined, shows that the science of industrial ecology is still evolving itself as a science.

CPRs particularly affect information, regulatory and economic barriers and to some extent commitment to sustainable development[2] and cooperation. For example, if regulations are not in place to guarantee an unambiguous property right, carbon trading is hampered, if information about how CPRs (such as efficiency savings made between companies) and the underpinning costs and benefits are to be shared, this can hamper cooperation necessary for industrial ecology. In some cases this tension present in regional industrial ecology occurrences is present with respect to sharing financial benefits, however, there is currently much greater certainty over financial exchange and value. More importantly, the abatement of greenhouse gas emissions via an industrial ecology opportunity can only succeed if land based CPRs are created in a manner such that they can support mortgages (namely, that there is a legal, transferable title to the CPR that is guaranteed, or enforced by, the State). This is necessary for banks and financial institutions to be willing to provide debt to purchasers or transferees of land-based carbon. This paper argues that future industrial ecology opportunities will need to focus more on the influence which uncertain carbon property rights may have on the enduring success of regional synergies. Furthermore, the capacity to develop a clear understanding and approach to CPR is contingent on our ability to comprehend their complexity and the underlying science (Prior and Boydell, 2010)

[2] A company committed to sustainable development may be motivated to participate in an emissions trading scheme for motives beyond economic motives

Table 4: Overview of carbon property rights links to industrial ecology barriers

Industrial ecology barrier or enabler	Scenario A importance	Scenario B importance	Comment regarding carbon property rights, including how uncertainty in CPR affects industrial ecology barrier/enabler
1.Commitment to Sustainable development	similar for both		Seeking to engage in reducing carbon, prompted by certain CPR, may be an enabler for carbon-intensive industrial ecology opportunities aimed at environmental goals.
2. Information	important for both		Historically information on technical feasibility has been an important component of success for industrial ecology opportunities; now a knowledge of economic, legal, social and cultural dimensions of carbon property rights will also be important and how rights are regarded is in flux.
3. Cooperation	more small-medium enterprises	larger anchor tenants may facilitate cooperation	Cooperation is underpinned by trust, both between companies and in the stability of the regulatory environment. If transactions involving carbon property rights become a larger component of the viability of an industrial ecology opportunity, the areas that are well defined and the areas that are not could influence which potential economic opportunities are pursued.
4. Technical	Techno-economics of algae and algae-pyrolysis, soil sequestration..	Large technical barriers with CCS and CO2 to chemicals	New technologies may develop more quickly in areas where carbon property rights become well defined. The maturity of the technology and its techno-economics affects the extent to which uncertainly regardinig CPR could affect industrial ecology opportunities which will change over time, for example CCS is currently held back more by techno-economic considerations than lack of CPR certainty.
5. Regulatory	Definition of forestry and soil carbon rights critical	Whilst CCS is not an industrial ecology opportunity in itself, the definition of CCS rights are critical	The legislative sequence by which carbon property rights come to be well defined could influence industrial ecology opportunities pursued, for example some forestry rights are already defined, whereas sub-terranean rights needed for CCS are still emergent.
6. Community		Social licence to operate for CCS problematic; if this is linked to the use of CO2 for manufacturing chemical products, the social licence of the manufacturing plant may also be comprimised	Community trust and associated investment in emissions trading schemes could be undermined if property rights are not well defined, or if offsets get double-counted or are non-additional. This influences the risk factor of the industrial ecology opportunities.
7. Economic	both scenarios currently uneconomic		The volatility in the economics of carbon trading can affect opportunities under both scenarios explored. For example, the floor price of carbon in Australia is currently artificially held at AUD$23 (= US$210) per tonne, whilst the post GFC global market is currently trading at significantly lower levels.
8. Geographic	similar for both		The degree to which 'local' carbon savings are pursued (versus buying overseas offsets) or being liable for exports of coal burned overseas could affect opportunities, this issue of system boundary was highlighted in the working theoretical framework .

Regarding the specific examples from the case studies, industrial ecology involving forestry and biomass confronts the barrier of insufficient and incongruous articulation of CPRs across jurisdictions, with some involving localised sequestration arrangements that separate the tree, or often the carbon sequestration benefits of the tree, from the land property right. On the other hand, carbon capture creates a concentrated stream which could encourage industrial ecology. This could take the form of geographical industrial ecology where coal fired power stations and cement producers joining together for capture and storage options. However, a product focus could also be enabled such as in using fly ash cement for geopolymers which has significant greenhouse benefits (McLellan et al., 2011) or using the concentrated carbon dioxide stream as a feedstock, for example to grow algae for biofuels or even tomatoes in hot-houses or as a feedstock to methanol production. Additionally, areas such as soil carbon are identified as an area of high uncertainty with respect to CPRs, however, soil applications have not featured heavily in industrial ecology projects developed to date.

The uncertainty of CPRs was shown in dotted lines for each scenario, and relates to soil, agriculture and CCS. Current discussions about new proposed government policy which includes a focus on improving soil carbon, may facilitate bio-based opportunities in scenario A.

5.2 Discussion of theory

Regarding the general concepts and theories presented in the initial theoretical framework, the following insights are relevant to generating a refined framework. Regarding the exchange mechanisms, the influence of uncertainty on industrial ecology opportunities is affected by both the lack of definitive science for CPR (for example regarding soil) and also the lack of definitive regulation (for example regarding CCS). The degree to which CPR uncertainty affects opportunities changes over time, in part dependent on the way the barriers and endablers illustrated in table 3 change and how influential the CPR uncertainty is relative to other risks.

With respect to system boundary, Scenario B which may involve the purchase of overseas offsets, highlights a general issue relating to system boundary, pertinent not only to industrial ecology opportunities. However, it is worth noting that should a new industrial ecology synergy seek ‘carbon neutrality’ then the mix of local or international CPR may affect social licence as well as the economics. Currently across the globe, the discord between geographical industrial ecology and CPR is lowered with the existence of state-based or national schemes.

As CPR trading moves to become more international, this will change the overlap between CPR and new industrial ecology opportunities. As an aside, the closing of interconnected industrial complexes and follow on changes to carbon property rights also needs to be considered. Additionally, globally traded CPR brings a whole new set of global actors onto the local landscape (for example in the Latrobe Valley), which may or may not connect to local conditions. There may be potential opportunities to export coal from 'carbon neutral regions' where local offsets have been undertaken.

At the framework level of resource optimisation to support environmental goals as part of the pursuit of sustainable development, uncertainty not only regarding the CPR mechanisms, but also for *the science of CPR and of industrial ecology*, affects the ability to prioritise industrial ecology opportunities, noting that reducing greenhouse gas emissions is but one of several meritorious environmental goals.

Finally, this paper has sought to develop a more explicit understanding of the relationship between CPRs and industrial ecology concepts and applications. A key limitation of this understanding, includes its one-directional examination of the effect of CPR uncertainty on industrial ecology opportunities. Further opportunities for researching this relationship should not only focus on expanding and challenging the insights from this article, but also seek insight into how industrial ecology can also influence new ways of creating CPR to support environmental goals, including using carbon capture to temporarily hold carbon as a future feedstock to create products rather than just storage, with an understanding the residence time of products-in-use and potential paths to reuse, whilst avoiding double counting.

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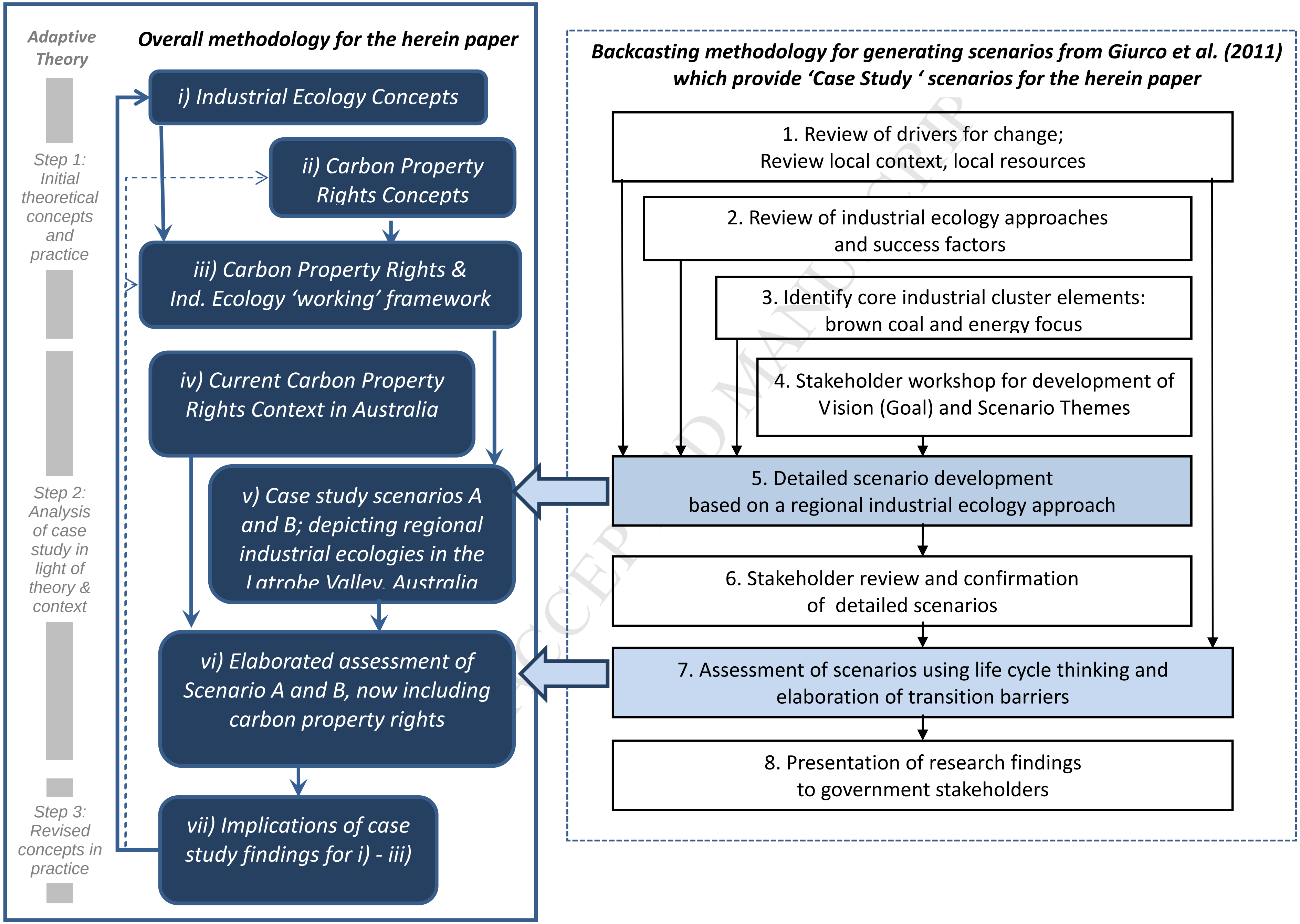
Figure 1: Overview of methodology for this paper



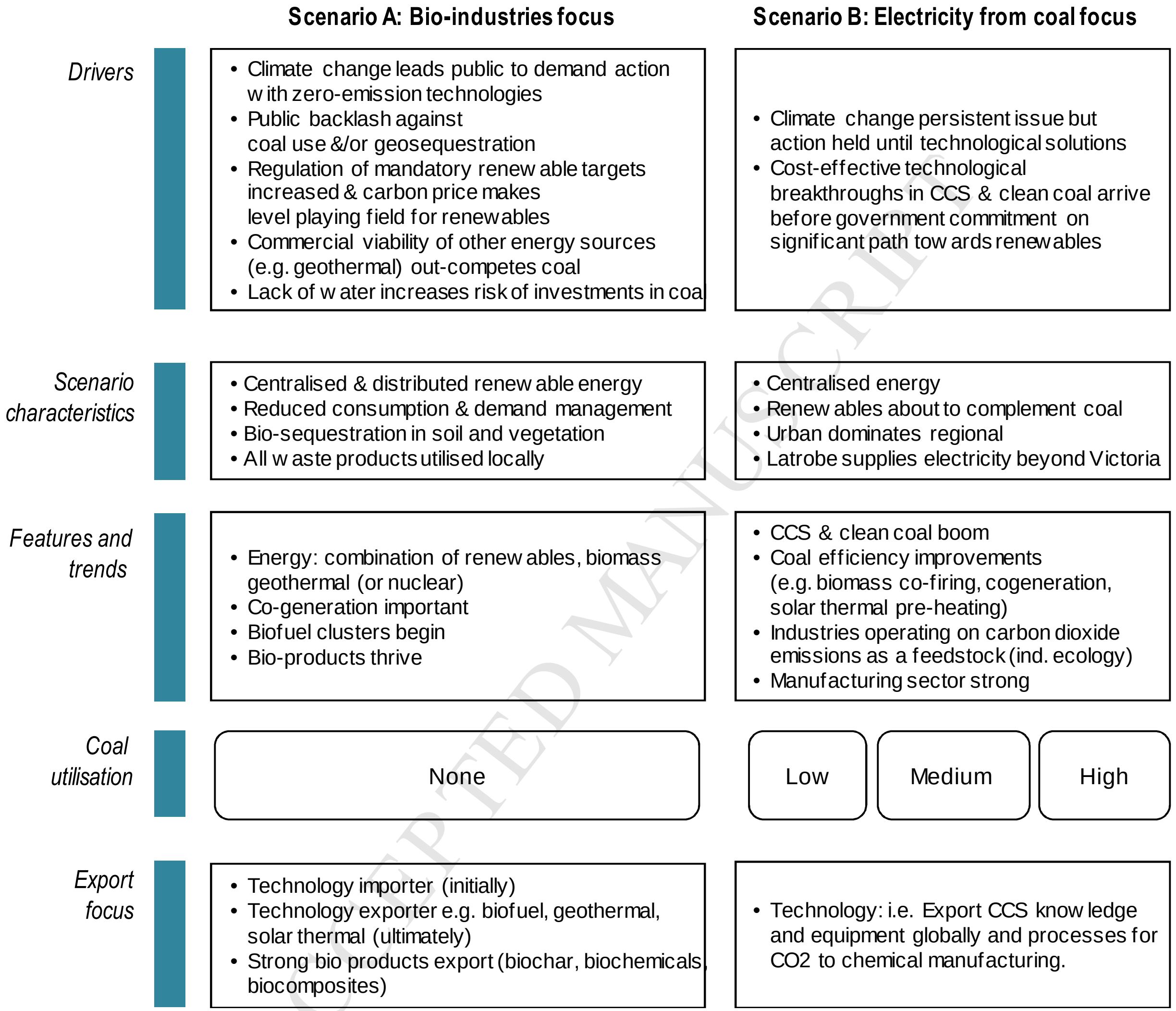
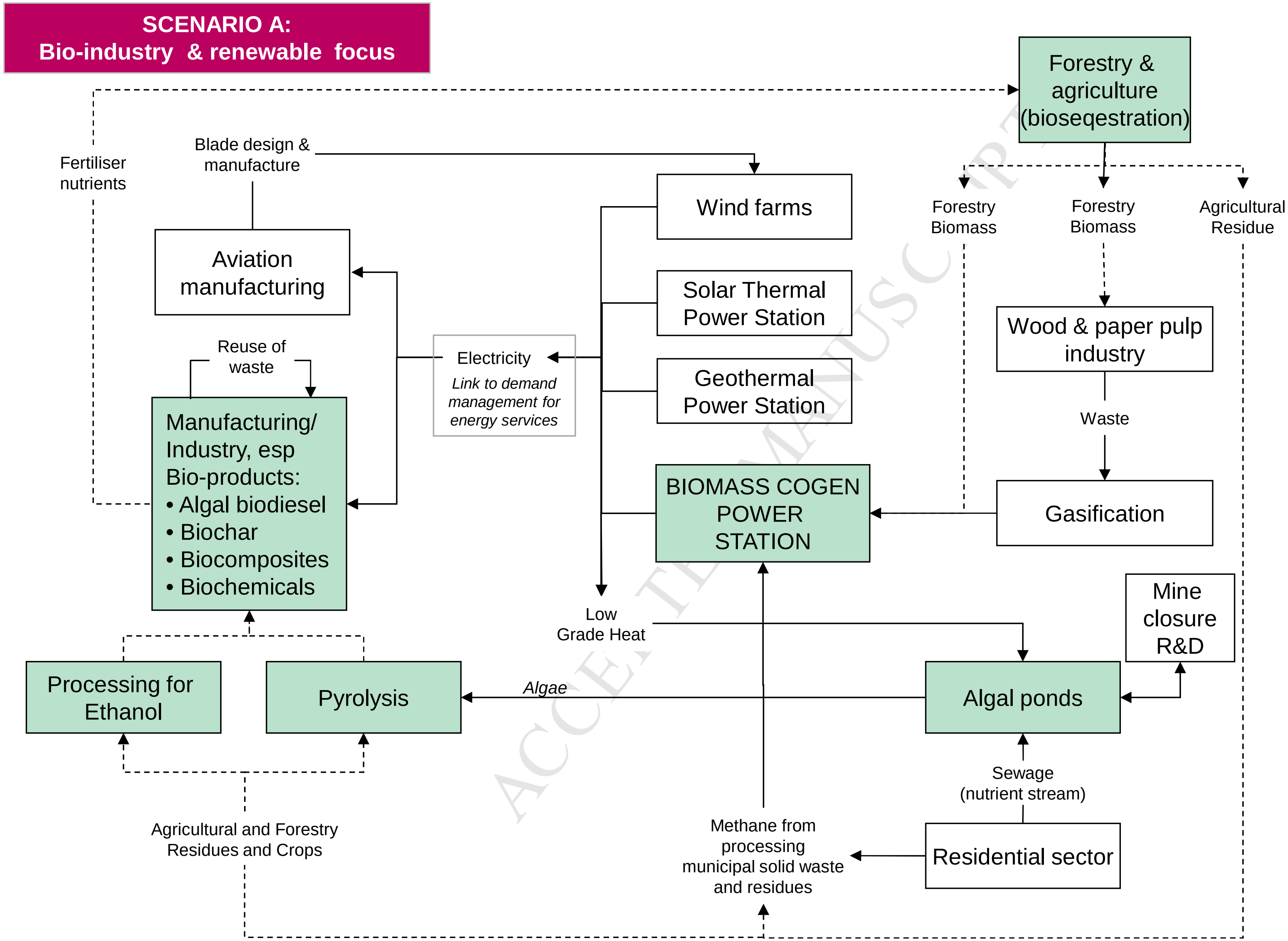


Figure 2. Overview of drivers, cluster elements and coal utilisation for each scenario (Source: after Giurco et al. 2007)

Figure 3: Configuration bio-industry & renewables scenario



(Source: after Giurco et al. 2011)

Figure 4: Electricity from coal scenario