Fusing Life Cycle Assessment (LCA) and Value Chain Analysis (VCA) in the Informal Economy

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1. Introduction

Informal activity dominates the economy of many developing countries like India and its importance appears to be growing globally as the formal sector struggles to cope with the economic downturn in western markets. In India the informal economy is estimated to be responsible for between 83% and 91% of the labour force, producing around 60% of GDP (Harriss-White, 2003; Harriss-White et al., 2007). Even in OECD countries the informal sector is still substantial, responsible for an estimated 18% of Gross National Income (GNI) (Schneider, 2002) – and growing (Williams, 2013).

The informal economy is especially important for poorer and unskilled people, who have the most limited access to formal jobs. The poorest are also most reliant on natural resources such as agriculture, forestry and other environmental services both for goods and for employment (Haygarth and Ritz, 2009; Ring, 2008). In turn this makes them vulnerable to environmental processes and shocks such as eutrophication and climate change (Barnes et al., 2005; Chambwera et al., 2011).

The close linkages between environmental health, environmental impact, poverty and the informal economy are largely ignored by national and international policy making arenas where until recently the informal economy had a weak voice. The informal economy, with its close links to environmental health, is also marginalised from environmental policy.

One reason for the policy neglect and incoherence is lack of available data on the informal economy. This is not simply due to the lack of government records for it but also due to its complexity.

It is in this dearth of information that this research project makes a contribution. It gathers data using the rice production supply chain as a case study and analyses this information in a novel manner. It fits methods designed to work in the formal sector to the informal economy in order to provide a type and level of analysis that has not been done before. The two key methods to be tested are life cycle assessment (LCA) and supply/value chain analysis (VCA). In this paper we provide a brief overview of each method, followed by an outline of how these methods are integrated to generate a novel model and method in order better to understand how the environmental, economic and labour/social relationships interact along a supply chain.

2. Life cycle assessment

Globally there is increasing awareness that better social and political decisions are needed to regulate the environmental burden of the products we use and the behaviour we practise. Unfortunately even good-will can concentrate efforts in wasteful or even damaging areas (such as the first 20 years of EU agri-environment subsidies or the EU biofuels policy). In order to make informed decisions, the environmental burden of individual products/processes needs measuring using a rigorous methodology which allows for meaningful comparisons. In this research project we are interested, amongst other things, in the environmental product history of rice, and are using Life Cycle Assessment (LCA) for this purpose.

The concept of life cycle assessment is essentially simple – determine all the activities (processes/products) needed to produce the item of interest (in our case a kg of rice) and measure the environmental impacts associated with each activity. The critical advantage of LCA is that it takes full account of a product's life cycle from the raw materials marshalled for its production through to the disposal/recycling of the product when it has ceased to be useful in consumption. This helps avoid an unwanted shifting of the apparent environmental burden from one area to another (for example, i) the use of a high tech insulating material to reduce on-site energy losses which uses more energy in its creation than it saves; or ii) indirect land use change: the conversion to low input agriculture to reduce emissions by country/region A which drives more intensive farming in neighbouring countries/regions to take advantage of the supply-restricted price gains, thereby negating the savings in the first country).

But in order for LCAs to be useful, the process of data gathering has to be carefully controlled. There are already far too many LCAs that, due to not following a standard methodology, cannot be compared to others, and so are of little value. For example if we want to understand the relative environmental costs of a cotton compared to a nylon shirt, but if the two LCAs used unknown or different methodologies, then that comparison cannot be made.

2.1. Methods: ISO 14040 and PAS 2050

The basic tenets of LCA now have an international standard, and are set out in ISO 14040 (ISO, 2006) and carbon foot-printing methods can be found in PAS 2050 (BSI, 2008). A very comprehensive guide based on ISO 14040, published by the Joint Research Centre (JRC), is also heavily relied upon for LCA (European Commission, 2010)

While PAS 2050 and the ISO standards are set out slightly differently and are reported under different headings (see Table 1) the methods and results are essentially the same - PAS 2050 builds upon ISO 14040 – except that PAS 2050 is specifically limited to GHG assessment. It does not cover biodiversity, leaching or other social/economic/ environmental factors. In this project we are specifically interested to research several of these other factors too. Later in this note we will discuss the fusion of LCA and VCA to include economic and social factors in the analysis.

In this research we are looking at limited environmental impacts (GHG emissions, ground water, and energy). A potential problem when an analysis is confined only to certain aspects is that the relative merits of a product or process has to be judged on those criteria alone. If these do not correlate with wider environmental impacts, then negative unintended consequences may occur. This is commonly seen in land-based assessments that restrict analysis to GHG emissions, for example for bioenergy assessments. This can promote activities that cause substantial damage to local and global biodiversity, water quality, landscape value and local economies.

ISO 14040	PAS 2050
1. The goal and scope definition phase, 2. The inventory analysis phase, 3. The impact assessment phase, 4. The interpretation phase	1. Building a process map 2. Checking boundaries and prioritisation 3. Collecting data 4. Calculating the footprint 5. Checking uncertainty

Table 1. The building blocks of the two major LCA methodologies: ISO 14040 and PAS 2050

3. Creating an LCA

3.1. Goal and scope definition

A clear initial goal is essential to set up the rest of the LCA. The goal should define who the study is for, the intended applications of the final results, reasons for carrying out the study and limitations of the study.

Once this has been established the unit of interest is defined - the functional unit. This should be a meaningful product that is relevant to how it is finally used/ consumed. In this project we are interested in rice, including the post-harvest marketing chain – involving trading, milling, transport and retail. Our project is comprised of numerous smaller projects, so we have three functional units. The first is:

1kg of rice at the point of retail sale

One component of our research examines the agricultural stage of paddy production. In this case rice is not a useful functional unit. Instead the typical product of sale – paddy – is used. Thus we have a second functional unit specifically for this stage:

1 kg of paddy at the farm gate

Some social and economic aspects are best measured on an area basis (for example economic returns, labour requirements). The additional use of an area based unit is also relevant to some environmental parameters. The total availability of ground water is often limited on an area basis, so an additional area based functional unit is also useful for some environmental criteria. This helps address some of the problems identified in Section 5: Problems with LCA. Thus the third functional unit is:

1 hectare of paddy production

There are many potential supply chains for these functional units. We are specifically looking at 4 production systems and 4 distribution systems.[1]

After defining the functional unit, the project boundaries need to be identified. The boundaries consist of what is and is not included within the product life history. There is a trade-off between inclusivity on the one hand and the practicalities of time on the other. This means finding the right

[1] The analysis of distribution is not yet complete as of 2013. To date post-harvest supply chains which might labelled as separate show considerable inter-linkages, so the full number studied may be fewer.

point along the curve of diminishing returns to problem-oriented field-research. It may be useful to work to a larger scale than the functional unit, for example per field of paddy (because farmers account in this fashion), and then calibrate it per kg afterwards so that elements of cost and physical inputs can be gathered in meaningful units for both farmer and analyst. (No farmer for instance will know how much pesticide he applies per kg of paddy, but is likely to know per field/acre).

Defining the boundaries is not a one off stage, because during the empirical development of the model new activities will be discovered, and the importance of different elements will become apparent. Instead it is an iterative process, and made more powerful as a result.

3.2. Checking boundaries and prioritisation

The significance of what is and is not included within the analytical boundaries is further developed in a supplementary paper (Gathorne-Hardy, 2013, 'Baselines and Boundaries'). For the purpose of PAS 2050 the boundaries should comply with rules set out in ISO 14040, and be of an adequate standard to create a Product Category Rule. In essence this means including all sources of emissions responsible for greater than 1% of the total, subject to not more than 5% of total emissions' being ignored. The four key points that PAS 2050 suggests should not be included are:

3.2.1 Immaterial emissions sources (less than 1% of total footprint)

This is a useful guide to determine when to ignore a stage/process/input etc. Clearly information is required before the importance of any stage/process/input can be measured, and this is one area where the iterative practical method of LCAs is relevant. In this instance, if early research shows that the item of interest is far below the 1% threshold it can be safely ignored. If it is near the 1% threshold more work will be needed to determine which side of the threshold it sits. Sometimes processes that are below the threshold will be included if they are of specific interest.

3.2.2. Human inputs in processes

The GHGs directly associated with human beings (i.e. embodied emissions of food, clothing etc) are not included unless they are specifically related to physical work in the sector under investigation (e.g. protective clothing). This is largely because these are deemed implausible to substitute as well as very difficult to measure. This rule comes from PAS 2050, which is only concerned with GHG emissions. But in the current project we are also interested in wider environmental measures including energy, where human energy is sometimes directly substitutable by fossil energy. Thus we include the measurement of non GHG human inputs such as energy.

3.2.3. Transport of consumers to retail outlets

If someone goes to the shops to buy rice and milk, and is then tempted to also get sweets, how should the transport emissions be allocated between these three products? It is the impossibility of effectively answering this question, together with the difficulty of allocating consumer transport to individual products, that results in the omission of consumer transport.

3.2.4 Animal transport (e.g. farm animals used in agriculture or mining in developing countries)

This is an important issue from the perspective of this project, where animals make an important contribution to GHG emissions at the farm level. We have included livestock based emissions (the enteric methane from bullocks) directly *against* the PAS 2050 guidance, as we have demonstrated that ignoring these emissions significantly alters the final GHG balance (Gathorne-Hardy, 2013c). But in order to allow our results to be comparable with other PAS 2050 LCAs we have also calculated results without these emissions.

3.3. Collecting data

Gathering data requires details on both activity and emission factors. An activity is what occurs, for example transporting a load of rice over 200km may require 50l of fuel. The emission factor is the amount of GHG that is emitted from, in this case, each litre of fuel (including in the production and transport of that fuel). Replicable, meaningful data is required for both the data activity and emission factors – for example our confidence that trucks use 50l of fuel to transport that quantity of rice 200km. Were the data collected from a suitable number or trucks, from a representative region, in a representative time period, etc.? And does the emission factor include the production and transport of the fuel?

As a general rule primary data should be used, as these indicate actual emissions and give a better chance of identifying where emissions can be reduced. There are exceptions though, when it is impractical or unnecessary to collect primary data, for example when there is already adequate data for that object of research. In our case, the emissions associated with fertiliser production are a good example – already data sets exist for embodied GHG of different fertilisers, and, given our resources, it is unfeasible to collect additional raw data.

Additionally there are times when it is useful to use standard data, for example the use of global warming potential (GWP) emission factors. It would be unhelpful if every project tried to establish its own GWP. PAS 2050 also suggests that standard factors should be used for transport and agricultural emissions, but we use primary data here.

Data collection out of official reach is the purpose of our research.

Published secondary data is available from a range of LCA databases. The golden rule is to state why, where and how each data source was used so that readers can understand, compare and judge models. Often good data is not available, in which case what is available must be used, but the analyst has to take care to be transparent and honest about this.

3.4. Calculating the footprint

Some additional complicating factors:

'**Delayed emissions'** How should the interaction emissions and time be considered, for example how should the creation, end use and disposal of a light bulb be calculated – PAS 2050 suggests using the weighted average over the product's life time.

Fixed carbon – If a product is made from organic material, then the carbon in that product can be counted as removed from the atmosphere as long as it: is not food, at least 50% is expect to last longer than a year and it comes from sustainable sources (i.e. a certified sustainable forest rather than wood from recent tropical deforestation). To use these factors, an understanding of the likely lifetime of the products and likely final fate of the products is essential.

Land use change: This must be included if the land was converted to agricultural land on /after 01/01/1990, the emissions are then assumed to be released over 20 yrs. But this does not include changes to soil carbon in existing systems

Energy – all the embodied emissions associated with energy production should be included, such as those involved in mining, distribution and disposal of waste

Capital Goods. PAS 2050 suggests that these should be ignored.

Allocation. PAS 2050 suggests expanding the system boundary, but when this is impractical to use a range of allocation methods.

The next step involves multiplying data activity and emission factors for each stage of the life cycle. It is useful to combine this activity with a mass balance analysis, to check that all material has been accounted for. A mass balance is a sum of all material entering across the boundary, and all material exiting. This is not always possible, for example in the stages of agricultural production, where material is essentially created from unmeasured streams of sunlight, carbon dioxide etc), but it works better in industrial processes.

3.5. Checking uncertainty

The adage "garbage in garbage out" is true for LCA models, as in all models. On top of drawing up a good model and using the best data, it is always useful to carry out uncertainty analysis, so that the importance of each assumption can be evaluated. The most critical assumptions can then be further analysed through simulations of alternatives.

4. The LCA Research Context for Indian Rice

As far as the authors are aware, there are no other LCAs based on primary data looking at the Indian rice supply chain. Globally there are few published LCAs of rice, and those that exist are mainly concerned with the potential for energy extraction from rice by-products - from the combustion of husk and straw. Critically, they have treated these co-products as waste, allocating zero embodied pollution to them, therefore allowing the LCAs to ignore them (for example (Mai Thao et al., 2011; Prasara-A and Grant, 2011; Shie et al., 2011)).

Figure 1. A selection of additional factors to consider. A wider range is available from the PAS guidelines

Is this a reflection of how the scientific world also ignores much of the informal economy, except when it clearly interacts with the formal (in this case for power generation)?

Some studies have looked at rice production using primary data-based LCAs (Kasmaprapruet et al., 2009; Wang et al., 2010), but none in India. A discussion of them can be found in Gathorne-Hardy (2013b).

5. Problems with LCA

Life cycle assessment is not a perfect analytical system. Its limitations are split between methodological errors such as poor choice of boundaries, discussed in Gathorne-Hardy (2013a), and fundamental problems which will be discussed here.

5.1 How impacts and products are measured

While the production and use of products/processes are extended in both time and space, in LCA emissions tend to be aggregated across time horizons and summed across space (see Finnveden et al (2009) and Hauschild (2005) for further reading). Additionally, in dividing the total emissions into a functional unit, LCA often gives emissions that are near infinitesimally small.

In real life, the time, location and scale of environmental impacts are critical in the impact of many pollutants, for example the same emission will be far worse if exacerbated by weather/other high emissions, in vulnerable environments, and if the level is above the absorptive capacity of the sink environment. From our project GHGs are an exception in respect to the importance of location as the only GHGs included are long lived enough to mix evenly around the globe. The same applies for ozone depleting gases listed under the Montreal Protocol for LCAs that include impacts on stratospheric ozone.

5.2 Imperfect metric analysis.

In LCAs a 'basket approach' is used to allow comparison between different pollutants. This approach derives from the Montreal Protocol methodology, where different gases are assigned different pollutant factors depending on how damaging they are to stratospheric ozone. It is very useful in allowing comparison between different pollutants, but it also provides answers that are magnifications of the assumptions that went into the calculations - the eternal trade-off between accuracy and usability!

For example GHGs are all placed in a 'single basket'. Through the use of Global Warming Potentials different GHGs are given a value along a single scale, and trade is allowed between gases using this scale (Daniel et al., 2012). The scale compares the amount of infra-red radiation different GHGs absorb to that of carbon dioxide (CO_2). Thus 1kg methane is equivalent to 25kg of carbon dioxide, and 1kg nitrous oxide is equivalent to 298kg of carbon dioxide (Forster et al., 2007).

But the comparison between different GHGs is not perfect, as they absorb different frequencies of infra-red, with different absorptive efficiencies, and have different atmospheric life-spans. For example the atmospheric lifespan of methane is about 11 years. While in the atmosphere it is highly efficient at retaining heat, but once it has degraded to CO_2 (from whence it came - if it originated from flooded paddy or livestock) its efficiency as a GHG is dramatically reduced. GWPs average out the differences over different periods of time, but there are debates in the scientific community about how individual GHGs should be judged. Some call for dramatic action on short-lived climate pollutants (such as CH_4) to provide a big impact quickly (especially as reducing many of them, including methane, black carbon and NOx will bring associated health benefits, see Shindell et al (2012)). In contrast others argue that from the long term climate perspective only long lived gases are most important, so policy makers should be most concerned by atmospheric CO_2 (see Allen et al (2009)).

Similarly when wider factors are looked at, they too are reduced to a single metric, for example eutrophication is reduced to phosphate equivalents, acid rain is reduced to sulphur dioxide equivalents.

5.3 LCA as a 'top down', not 'bottom up', system of analysis

How to approach environmental agricultural sustainability is an issue of longstanding debate since before Malthus. LCA clearly falls into a top-down as opposed to systems-based or consultative/participatory approach to understanding sustainability. The latter would build upon what exists on the ground (from a domestic, catchment, to global scale) so as to understand and optimise production and other practices using the available materials. In contrast, an LCA may suggest that a certain practice is 'sustainable' but, without reference to scale, it may in practice be unsustainable.

5.4 Simplification.

Finally, from the policy perspective, there is a danger in the results of LCA - as there is in all complex models – because it can provide apparently simple numerical findings. LCA will provide answers to the questions that are asked of it, but this should not be mistaken for judgements on the relative sustainability of each functional unit. A product better from the GHG perspective is not automatically more sustainable when a wider range of factors are introduced.

6. Supply/Value Chain Analysis (VCA)

The LCA helps us understand the contribution of the rice supply chain to GHG emissions. Economic activities are carried out based on considerations of income security and financial gain. The social and economic outcomes of these activities are determined indirectly by the technology regime and by the nature of explicit and implicit contracts governing the chain's activities. Thus, a shift in the technology regime to lower GHG emissions would result in a new set of social and economic arrangements and outcomes. To evaluate the merits and disadvantages of potential shifts in the technology regime across multiple dimensions (of sequences and combinations of extraction, production, processing, trading, transport, storage and for differently endowed economic agents), a good disaggregated evidence-base for the economic costs and value addition is needed. Value chain analysis helps develop this knowledge base.

One of the ways in which the outcomes of any economic activity can be measured is by its 'value addition'. Technically, value addition is defined as the difference between the 'value' (price) of the output of the economic activity and the 'cost' of all the intermediate inputs used in the activity. This value addition is essentially the sum of (a) income derived by all the labour inputs into that activity (b) returns earned by all the capital (including land) employed in that activity and (c) profits earned by the entrepreneur(s) involved in that activity (although these three may be indistinguishable in self-employment, the commonest form of production in in India). A supply or value chain consists of stages or links defined by transactions and/or activity combinations. In paddy-rice we can identify all the tasks comprising production, transport, post-harvest sales and a series of combinations of activity involving storage, processing, transport and trade/arbitrage ending with retailing.[2]

Value chain analysis becomes particularly important, when 'non-market' forces govern the intra-link or the inter-link activities of the chain. If the activities are regulated purely by the price mechanism then we consider them to be governed by market forces (Hema, 2013). Where the state procures and distributes, these links are governed administratively or politically. However, in order to minimise the transaction costs arising from information asymmetry or from assets specific to the transaction or in order to secure economic rent (windfall economic gains), other contractual arrangements may exist which govern some or all of the activity in the chain. Hence, if the quantitative knowledge base of the economic costs and value additions at the disaggregate level is combined with an understanding of the type of formal or informal contractual relations at various stages of the chain, a better understanding of the pathways through which the social and economic outcomes in the system are determined will follow.

The value chain analysis is the ***only existing framework*** from social science with which to understand, at a first cut, the implications of an existing commodity system's shift towards lower carbon production. This can be complemented with i) behavioural analysis - to estimate the likely magnitudes of changes (elasticities) - and ii) welfare analysis to judge the social welfare implications of existing and proposed low carbon systems.

However the value chain for rice, though it is short in comparison with, say, a global chain for computer hardware, gains in complexity since it weaves in and out of the state-regulated formal and socially regulated informal economy. to this we turn.

7.1 Informal Economies, Sustainable Development and Value Chain Analysis

Informality: Agriculture and related activities in India (and in many other developing countries) are largely part of the larger fraction of the economy that is unregistered and 'informal'. Informality poses a new set of questions for VCA.

First, there is *insufficient and deteriorating data* available from existing secondary sources which can capture the rich tapestry of inter-linkages between technology, organizational and governance

[2] For reasons of tractability, we have excluded the preparation and consumption of rice as food and of its byeproducts.

structures, jobs, market power, government policies, taxes and subsidies, social relations and all their environmental and climate impacts. There is no alternative to primary data collection.

Second, the informal economy is *not directly regulated by formal policy processes*. Its markets consist of firms which are unregulated or selectively regulated (Prakash, 2015). There is no alternative to empirical enquiry into the manner in which markets and firms are incorporated into the ambit of regulation and policy. This enquiry must examine the alternative institutions of regulation to those of the state (Prakash, 2015).

Third, VCA has been developed for *multi-sited sourcing* and for systems of production and distribution in *multiple national jurisdictions* whereas the value chains for an agricultural commodity like rice are not yet governed by the demand of international destinations, even if national prices are now affected by the world market for rice. This enquiry approaches the adaptation of VCA to local conditions in several ways. It examines the equivalent to the national jurisdiction in a global VC inside India and takes sites in several states with their different policy environments. Instead of variation in national regulative jurisdictions it also examines variation in the effects of agro-ecology (Gathorne-Hardy, 2013; Mishra, 2015; Reddy and Venkatanaranaya 2013). It further sets out to examine the governance relations in the new scale of (supermarket) business which sources rice from multiple sites (Mani, Mody and Sukumar, 2013)

Fourth, while in global value chain analysis the concept of the *governance structure* has been developed for vertical integration and for the terms and conditions of outsourcing contracts, in the informal economy the existence of equivalent relations of governance must be established. Relations of authority governing transactions in the informal economy are known to be rooted in social institutions and business associations (Harriss-White, 2003). Debt, advance payment and delayed repayments are widely used to control the quantity and quality of supplies (Harriss-White, 2013).

Fifth, production-marketing systems in the informal economy are known to be *complex*, while the value chain is stylised. As in the establishment of boundaries for Life Cycle Assessment so here there is a mismatch between the comprehensive prior knowledge needed to establish the relevance of the stylised value chain to the *complexity* of informal supply chain structures and relationships in the informal economy. This problem is often addressed by iteration: in particular by the choice of regions and technologies for which there is a prior literature, and of field researchers with familiarity drawn from prior experience.

Sixth, in the informal economy the '*entrepreneur'* is a small family firm, self-employed or employing a small labour force, not a vertically integrated or flexibly specialised, multi-sited or out-sourcing international firm. Since family labour is not paid wages, the small family firm does not take profit, it takes a residual claim that is divided between investment and consumption and between family members according to social norms. This is sometimes addressed by imputing family labour and simulating accounting conditions of value-addition and profit.

Sustainable Development: As indicated earlier, there is an urgent need to move away from the currently dominant agricultural technologies and farming practices in India to maintain food security, to increase financial viability and 'decent' livelihood opportunities while also addressing the problems of environmental degradation and climate change. A quantum shift in technologies and practices will be needed. The choice of the policy regimes to address this will determine technological outcomes and the institutional arrangements. These in turn will influence the way agricultural and related activities get organized and governed, the magnitude of value creation and the share of different economic agents and interests in it, the nature of labour relations and the social, political and economic outcomes. Once there is a major shift towards environmental sustainability, technology regimes and institutions could get locked in for a long period of time. In a low carbon transition, value chain analysis should be a 'valuable' tool both for analysis in market and social prices, and to develop the accounting framework that will be needed for planning both production and welfare.

7.2 Social aspects of the rice production supply system

One of the most important aspects of welfare is ***work.*** As discussed in other working papers, notably Gathorne-Hardy and Harriss-White (2013) and in Mani, Mody and Sukumar (2013), both the quality and quantity of work is critically important in determining the quality of life for those producing goods and services in the informal economy. Evaluating the quality of labour is a fraught with complexities; and integrating qualitative and quantitate techniques ((ILO, 1999; Lorano, 2005)) is a time-consuming process. This poses an intractable barrier to its inclusion in life cycle assessment, so a reductionist alternative, confined to income and to the economic value of benefits in kind has been developed as a compatible substitute. While missing the holistic aspiration of Decent Work as an analytical tool, this has the benefits of political meaningfulness to labour organisations[3], practical collectability in the field and analytical scalability so that it can be compared and contrasted across different fields (Gathorne-Hardy and Harriss-White, 2013).

As discussed above, the quality of labour has been reduced from its real-world complexities to key indicators compatible with the modelling aspect of this project. Assessing the quantity of labour required is immediately quantifiable, but when calibrated against a kg of rice it loses much of its conventional meaning. While the provision of labour is important for poverty reduction and development (Chambwera et al., 2011; Gathorne-Hardy and Harriss-White, 2013), what is the meaning of 3 minute (or 10 hours) of work per kilogram of rice to a village of 800 people? This is an example of where the lack of dimension to LCA style results restricts their meaning and social relevance. For this reason, when discussing quality and quantity of work, we gave measures in area based units too: the quantity of work/hectare.

8 Linking LCA to social and economic data

It is perfectly possible to fuse VCA conceptually with LCA. By this we mean that the entire life cycle can be included as appropriate; what is and is not included within the value chain life cycle boundary can be clearly identified; and allocation between end products will be as accurate as possible. But the practical aim of this project is not to fuse the two types of model into a single output, due the difficulties of putting prices on all inputs and outputs in a semi subsistence system dominated by family enterprise. Instead we intend to build a model that allows the two processes to work in parallel. They share the same functional units, and (where possible/applicable) the same boundaries. Thus for each functional unit we will have an understanding of the energy, water, and labour going into it and the GHGs, economic and social values it generates. Figuring out how and why these

[3] The choice was developed in a dialogue with the Centre for Workers' Management and the New Trade Union Initiative.

correlate (positively, negatively or not at all), for different functional units and at different points in the supply chain, is a key aim of our collective research.

While a parallel LCA VCA model is relatively simple from a theoretical perspective, there are several complicating factors which have been summarised in a tabulated form in Table 2 .

Table 2. Problems and solutions for combining LCA and VCA into a single model

Problem	Solution
LCA suggests straight line amortisation, while financial analysis may discount and write off products over a far shorter time and economic analysis would require annuitized opportunity costs.	We have used straight line amortization for both systems
In industrial systems daily running emissions tend to be high relative to the daily fraction of the embodied emissions (Frischknecht et al., 2007) and subsequently PAS 2050 suggests ignoring embodied emissions - something that certainly cannot be ignored in economics.	We have included embodied emissions for all major items (mills, shops, tractors) in parallel to accounting emissions.
Resolution. LCA has a finer resolution, measuring the impact of every process individually, which is often not possible for VCA. In a farming example, LCA measures the GHG emissions from each task (e.g. cultivation, weeding, harvesting) separately, while VCA cannot do this, as until the final product is sold, there is no additional value. And when it is sold the returns are per unit area or per enterprise. This mismatch also applies to the post-harvest system.	We have matched the systems as closely as possible, but a perfect match was not possible
The interaction of the firm and the product. LCA approaches products/services through a narrow perspective using economic, weight or energy allocation to separate the product of interest from other products produced and distributed in the same firms. In contrast 'the firm' is an essential aspect of economic analysis. Actual firms have had a history of diversifying, creating complexity and uniqueness of function. Marketing systems are modelled horizontally (i.e. the structure and competitive conduct of a set of individual organisations at a given point in a set of transactions) or vertically (the series of transactions constituting a ladder or chain). In reality however a marketing system should be modelled as a set of complicated organisations with multiple interactions with other equally complicated organisations.	Our solution has been to simplify the concept of the firm so that it is only dealing in rice based products, and when other products are included to allocate emissions/costs and labour to these using economic allocation methods.
Invisible inputs. Some aspects are invisible to one but not to the other assessment methodology, for example VCA includes the use of human labour, while LCA is blind to the GHG emissions directly released from human beings.	From the analysis perspective this has been ignored, for example while the sum of GHG emissions from paddy production will include soil derived GHGs (methane and nitrous oxide) these cost nothing to the farmer. Similarly, interest on loans are important costs, but generate zero emissions from the GHG perspective.

9 Conclusions

The informal economy has environmental impacts, yet is widely ignored in environmental policy. Our research provides new data on the informal economy, using the case of a supply/value chain for rice production and distribution. In addition it develops a novel analytical tool to improve understanding of the interactions and synergies between the environmental, economic and social development goals. To do this it fuses life cycle assessment and value chain analysis, together with gendered measures of both work quality and quantity. Such a model has not been generated before, and inevitably its multi-disciplinary origins have required the modification of certain concepts and measures. These have been discussed in this and our other working papers.

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