The Recursively Generative Nature of Complex Agri-Eco-Socio-Technical Systems

A Transdisciplinary Approach to Developing a Low Carbon Footprint Farming System.

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Abstract — **Farming procedures have intensified to the point where they significantly impact on the environment, the social fabric of the communities involved and the political and financial stability of regions. Traditional design procedures do not take the recursive and adaptive nature of these systems fully into account. The author starts from the premise that the feedback loop and recursive causal nature inherent to agri-eco-socio-technical systems make them inherently *wicked*[1]. The design of a low carbon footprint farm takes this into account and uses a transdisciplinary approach to consider the solutions from a broad stakeholder group. An initial solution design is presented that shows how the problem was structured and what factors were considered for a model based approach.**

Keywords—socio-technical; transdisciplinary; dairy; farming; modeling.

I. INTRODUCTION

Farming in developed countries have reached a point where the intensity of effort required to compete in a global market has a large impact on society and the environment. Unless small farmers in small communities are protected by legislation, or unless they decide to only service a small local market, they are pushed out of business by intensified international operations. This has a severe effect on the social fabric in those communities, with jobs lost and social decay almost an inevitable outcome. This adds to the governmental burden on resources like policing, healthcare and welfare support.

The pressure to reduce the carbon footprint of all operations in the light of climate change compounds the problem. The debate at the level of the farm is however not on whether the climate change is manmade or not, but rather on the effects climate change produces and the changes required to cope with it.

On regional levels legislative pressure drives for reduction in nitrogen loads on water resources and curbing of greenhouse gas emissions. And finally society is becoming aware of farming practices and animal welfare.

In general the efforts to address these issues are driven by focused and segmented research based in specific research disciplines. It follows the approach that Descartes and Aristotle proposed and the current system of inquiry is grounded in a logical objectivity and a process of disjunction and reduction to yield understandable and manageable pieces of a bigger problem. This "disciplinary decadence" increases specialization and leaves very little room for cross-disciplinary innovation [1].

Developing a low carbon footprint dairy farming complex could easily proceed along these disciplinary lines, with initial focus on methods to reduce methane production and nitrogen load on the land. In the light of the discussion so far, this would be driven by a singular narrative (on the face of it) of compliance with new regulatory frameworks. The solution space could quickly proceed into bovine genetics and food source management, or soil health and water purification approaches. This would not consider the impact on the small farmers with less than optimal land parcels (limited access to water, poor soil stocked with current herd genetics), or the community that may need to consider expensive off-the-grid approaches. Clearly another narrative that values interconnection, interdependence, co-creation and space for constant change is required [2].

I describe how our transdisciplinary approach expands the solution space by facilitating sharing and solution development by a wider stakeholder group. This is done through the co-development of systems models. The effort moves away from a strict focus on the baselined requirements and know-how of the initial owner of the problem (the farmer). It moves beyond the zero-sum game of reducing environmental impact via legislated management procedures while the farmers try to increase production to remain viable businesses.

II. BACKGROUND – THE MACRO PERSPECTIVE

Extensive targeted effort goes into research in the agricultural space in New Zealand as a result of the reliance on dairy and meat production as primary export industries. It is

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[1] Wicked problems do not have optimal or singular solutions. They can only be resolved (a wise option is found) or dissolved (by declaring them incomprehensible or irrelevant).

safe to say that the research focus is on technology and empirical science to ensure the best possible outcomes in these fields. What is missing is the macro perspective on agriculture within the context of the social contract between the farmers, the industry and civil society in its broader sense. For example, the quality of water and soil is increasingly seen as key to sustaining a successful agriculture driven economy. It is crucial to ensuring the vitality of aquatic life, forests and birds. As well, the quality of water and soil has a direct impact on the New Zealand image as a valuable tourist destination.

The Māori culture and the broader cultural base of New Zealand are linked strongly to the land and the oceans surrounding Aotearoa New Zealand. This is a result of it first being settled by Micronesian ancestors [3] and later similarly being discovered by European sailors. Dependence on the Ecosystem Services (ES) of this land and ocean was entrenched in culture. For example, industriousness (ahuwhenua) relates to activities of agriculture and to the provision of food and sustenance for the family. This is coupled to the fact that Māori traditionally regard themselves as custodians or guardians (kaitiakitanga) of the eco-resources. Vitality and excellence (ihi) are attributes of people, animals and plants and include the physical body, the spritual self and psychological attributes. It is the power of all living things to grow to maturity and excellence [4].

Few would argue that the earth is not experiencing what seems to be out of the ordinary climatic change. The debate about the drivers of this change will continue. Understanding the effect this change has on sustainable food production is a matter of urgency, given that nearly half of the population of the planet depends directly on agriculture for its livelihood. Four types of functional ecosystem services sustain humans [5]:

1. Supporting (cycling of water and nutrients),
2. Provisioning (production of food and fuel wood),
3. Regulating (control of erosion and water purification) and
4. Cultural (social and spiritual values and aesthetics).

ES functions are found at multiple scales, including climate regulation globally and nutrient cycling locally. ES can be naturally occurring and/or can be engineered by man. A traditional view has man at the center of the services, (Fig. 1) and more often than not the services are "managed" as degenerative and linear complexes.

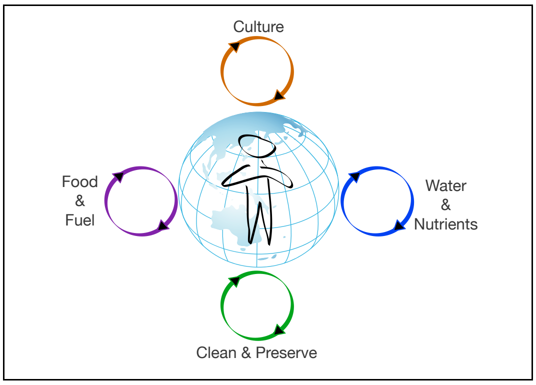

Fig. 1. Man and ecosystem services.

Ecosystems (engineered or natural) are interrelated and provide and consume services. This is an important point that I will return to in section V when I discuss the philosophical and methodological approaches required to make sense of the issues facing us in this space.

As stated earlier, a significant part of humanity relies on engineered ecosystems in the form of agriculture, while an increasing number of people find themselves in urban landscapes - another modified ecosystem. Farmers replace many natural ES with chemical and genetically and otherwise modified biological agents, not surprisingly resulting in a decrease in, and in some cases the destruction of, the natural ES. This trend is recognized as a major threat to food security, as it impacts directly on the supporting, provisioning and regulating clusters of ES.

Understanding how the ES contribute to life is deceptively simple; it is more problematic to apportion (artificial) units of value to the different services. Economists have devised a methodology to assign (monetary) dollar values to the services. The idea is that this will make it simpler for people with diverse backgrounds to understand and compare the relative importance of services. This can cover goods and services traded in a formal way, like paying for fish and timber. Earning loss can be calculated when a resource fails to supply to expectation due to a natural or manmade disaster, for example, loss of milk production during a drought.

Non-market (indirect) values include considering what people have been willing to pay for something, like traveling to a wildlife preserve in Africa, or to own a house with a beach view. It can also include what people would hypothetically be willing to pay for something if a specific situation arises. Suffice to say then that frameworks exist today that take things into account like the value of being able to view pristine wilderness areas or the direct cost of wood for heating in a rural area [6] so that one can apportion value to, and communicate the impact of ES. The question that arises, and one that will not be covered in this short paper, is whether this valuing approach contributes to or hinders a better narrative that places effectiveness over efficiency [2].

Given this broad context of regulatory considerations, farming obstacles and societal perceptions, how would one go about the design of a low carbon footprint dairy farm solution?

III. THEORETICAL AND PRACTICAL CONSIDERATIONS

Buede [7] says that system engineers must be "big picture people". He continues to state that depth of understanding is achieved by *iteration* through the design process (analysis and synthesis) to get to a sufficiently detailed solution specification. Who requires, or acquires this depth of understanding, is an obvious question to be resolved, and this will be addressed later in this paper. This approach is captured in the now well-known systems engineering "Vee" [8], shown in Fig. 2.

The process starts with requirements capture and interpretation of stated needs. When the boundaries of the problem space that differentiate it from the larger environment in which it is contained are clearly articulated, the process

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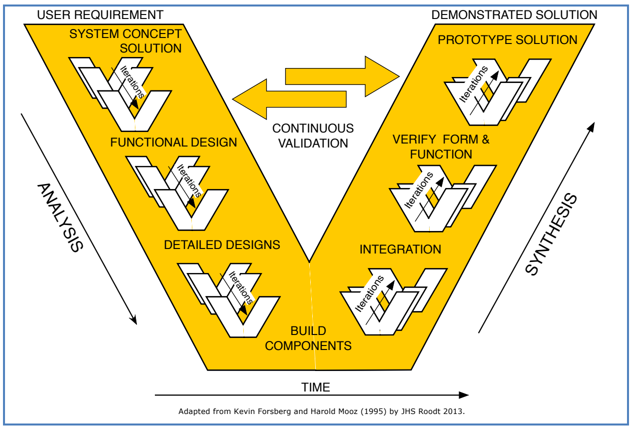
[2] Hes and Du Plessis consider this carefully in [2]: *Designing for Hope: Pathways to regenerative sustainability.*

works well. The requirements can be agreed to and are captured in a logical framework. Ideally the requirements remain stable over time and functional and architectural decomposition is possible.

When the sub-system functions and architectures are subsequently assembled, the behaviour of the synthesised system is expected to be very close to, or exactly as was required. System engineering program managers spend heavily on resources to ensure well-defined problem spaces and subsequent solutions. The principle is to isolate those elements that can be controlled within reason from those that cannot. [9].

What is not apparent in the “Vee” framework is whether a top-down or bottom-up or combination conceptual design approach is to be followed. The requirements are handled as an intrinsic part of the method in a top-down approach and may lead to development of new sub-systems and technologies to realise the solution. In a bottom-up design the exclusive use of existing systems and concepts may yield a solution, but not necessarily one that fulfils all the requirements, often leading to extensive add-on development and cost-overrun. For this reason, most design processes are combinations of these approaches [10].



Adapted from Kevin Forsberg and Harold Mooz (1995) by JHS Roodt 2013.

Fig. 2. The iterative nature of the “Vee” process framework.

Solution designs are judged relative to how well they meet the requirements of the group of stakeholders that expressed the need or problem. Often the requirements are stated very broadly, initially by an individual or small group (a community of farmers, for example) and often escalates into a large group of potential stakeholders when the farmers, government and other agencies become aware of the issue at hand. The solution may be stated in response to a changing environment where the causalities are all but clear. Examining a solution design on paper does not indicate when or if unintended side effects may result from interaction of sub-systems. It is quite possible that several different designs are offered as an answer to the requirement, all seemingly satisfying it. Often complex systems exhibit exactly the characteristics described above [9].

Complex systems exhibit nonlinear behaviour including feedback loop causality and recursive causality. Self-regulating systems have mechanisms that use feedback loops to change behaviour, based on internal and external environmental changes – in some cases responding decisions are made to act on changes. This is the case in social and natural systems: the system may contain a process that is the product of the process that creates it [11]. Or, a system may provide and simultaneously consume services. Predictability that we associate with linear causality disappears, making it difficult to fall back on past experience to develop understanding.

Public policy problems cannot be solved using traditional, structured approaches [12]. These problems are called “wicked” in contrast to the “tame” problems, problems that can be solved using traditional methods. Wicked problems do not have optimal or singular solutions [13]. They can only be resolved (a wise option is found) or dissolved (by declaring them incomprehensible or irrelevant).

Models and descriptions of complex systems do not aid in investigating how systems emerge from their components, or what factors play a role in maintaining them. This is a result of necessary truncation/simplification that removes micro-exploratory processes that drive emergence [14]. Subsequently the model of the system, that is less complex than the system itself, cannot be used to accurately predict the behaviour of the system into the future [15].

However, humans often reduce complex problems by successive truncation and simplification to communicate the essence of the problem. Parts of the problem space resemble patterns seen before, collapsing the big issue into ‘known’ units. Schultz [16] calls this the ‘veneer of simplicity’. When these simplifications are seen as reflective of the real issue and addressed at the level of singular simplifications, a simple answer, that will seemingly do the job, is derived. This may not be a fitting solution, and it may give rise to even more unwanted consequences.

It has also been noted that with complex problem spaces it is better to consider possibility and diversity rather than probability and uniformity [17], to value effectiveness over efficiency [2] and to aim to make wise decisions based on several factors. Such factors include societal perspectives, emerging technologies and natural systems that may be impacted by the system or impact it in turn. To this end a new approach is required that transcends disciplinary research [18] and design, an approach that encourages wide collaboration across disciplines to bring stakeholders with multiple, perhaps conflicting objectives and constraints, to a common understanding of the essence of the problem while allowing a resolution to the problem to emerge iteratively within an acceptable timescale.

IV. A Transdisciplinary Approach

Transdisciplinarity can be defined by the following requirements [19]:

1. To grasp the complexity of the problem and focus on components and the interactions between them,
2. To account for diverse scientific and societal views of the problem,
3. To link abstract and case specific knowledge,
4. To synthesize knowledge focused on the problem to be solved, and
5. To be perceived to be for the common good.

Transdisciplinarity is inquiry driven, not discipline driven. It recognises the value of discipline specific knowledge in the development of knowledge "pertinent to the inquiry for the purposes of action in the world" [20]. It includes knowledge creation by the researcher that is reflective and self-critical (acknowledging the subjective role of the inquirer). As the requirements evolve and the structuring continues, a synthesis of possible (re)solutions is developed. Documentation of the recursive process is crucial to the co-development and evolution of a result that is accepted as being for the good of all. The process is explained in the recursive process diagram (Fig. 3), redrawn by the author from [19].

This method can scale to mega-system projects that include cultural and societal complexity. Prof Julie Thompson Klein [18], Fellow in the Office For Teaching and Learning at Wayne State University, USA, put it this way: "One of the transgressive purposes of the new discourse of transdisciplinarity is to renounce the logic of instrumental reason by creating a more democratic discourse involving participation."

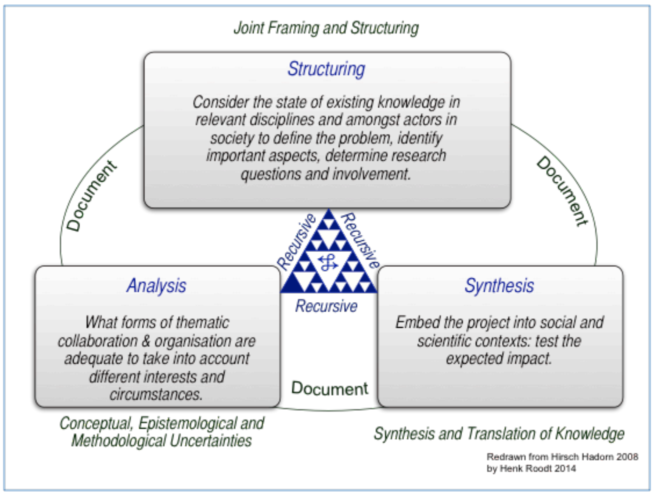


Fig. 3. The recursive process of transdisciplinarity.

The use of appropriate problem structuring and pattern discovery methods allows the system design engineers and stakeholders to share and communicate understanding of the problem and to identify aspects that are important to all [17, 21]. The understanding of the problem space is increased during this process, without undue simplification or trivialisation. It allows engineers to work with more traditional methods to develop partial solutions, all contributing to the bigger resolution of the problem or the shifting of the problem to where it becomes accessible. It also helps the stakeholders to make informed decisions.

To conclude this discussion of the underlying procedural methodology, it is important to consider how this approach differs from the standard system engineering approaches we are accustomed to [22]. One could argue that the core of systems engineering is similar or identical to that of the transdisciplinary process. One could consider more recent versions of the extended "Vee" framework, which includes several nested "Vee"s, which allows for much of the iterative nature of the proposed approach. However, the transdisciplinary approach is recursive, and iterative. The requirements are diverse and they evolve as the understanding of the problem domain improves – the baseline effectively shifts. The boundaries of the problem space move. The structuring and analysis proceed along a different process and the process of structure-analyse-synthesise occurs concurrently, building at each step on one another.

The transdisciplinary approach expands the solution space by facilitating knowledge sharing and solution co-development by a wider stakeholder set, rather than focusing on the requirements of the initial owner of the problem and acquired know-how of, perhaps, an interdisciplinary team. The relationships and uncertainties within the framework can continuously be analysed in a collaborative manner to account for multi-stakeholder interests.

Diverse candidate strategies can be synthesized and embedded into the social and knowledge-building contexts. The expected impact of these strategies can be simulated by the systems tools developed in the analysis phase while aiding continuous structuring of the domain. For instance, agent-based models can be used to determine whether influences from Iwi (traditional cultural entities in New Zealand) leadership will tip community behaviour towards total rejection or acceptance. Bayesian networks would be helpful in assessing the likelihood of these various systems-wide outcomes. When the strategies are actually implemented, data collected after implementation can be used to update the Bayesian networks, which would result in changes in the likelihoods of various outcomes. If there are significant changes in the likelihoods, then the solution strategy can be adapted accordingly.

The discussion so far focussed on the three processes in the transdisciplinary approach namely structuring, analysis and synthesis. The recursion that occurs, rather than iteration, ties these elements together. This "call back" or "run back" nature of the process is unique. Documenting the process becomes critical to ensuring that new understanding is shared and that the process can be terminated once the growth in understanding tapers off and the problem domain can be classed as resolved, or remains unresolved. In essence the process aims to be diverse at one level and integrative at another.

As hinted at in the previous paragraph, a recursive process needs a stopping flag! As the problem domain is understood better and a variety of decisions lead to implementation of (re)solutions, the problem may shift into a new paradigm. This may be seen as a stopping criterion for the process. Setting up and documenting flags to ensure that a return of the problem can be signalled, or that a systemic change has occurred, may be seen as the last actions of such a project package.

In the next section core elements of the process will be demonstrated briefly by discussing the initial phases of developing a systems model response to the development of a low carbon footprint dairy farm.

V. FIRST RECURSIVE DESIGN AND MODELING

An initial discussion took place with a farmer willing to turn his current dairy farm into the hub for a system that could potentially consist of several farms in a cooperative venture. The farm is situated in a region of New Zealand with specific issues around seasonal flooding, reduced ability of the environment to cope with intensified pastoral farming techniques, social issues as a result of land claim settlements, changes in other agricultural operations and limited access to highly developed infrastructure like roads and train services.

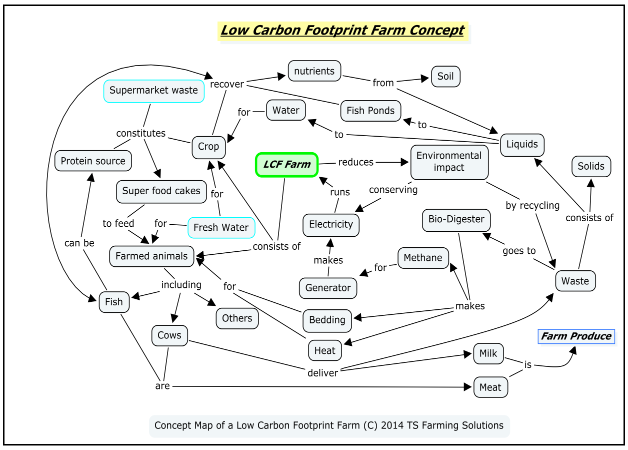


Fig. 4. Capture of early discussions with stakeholders.

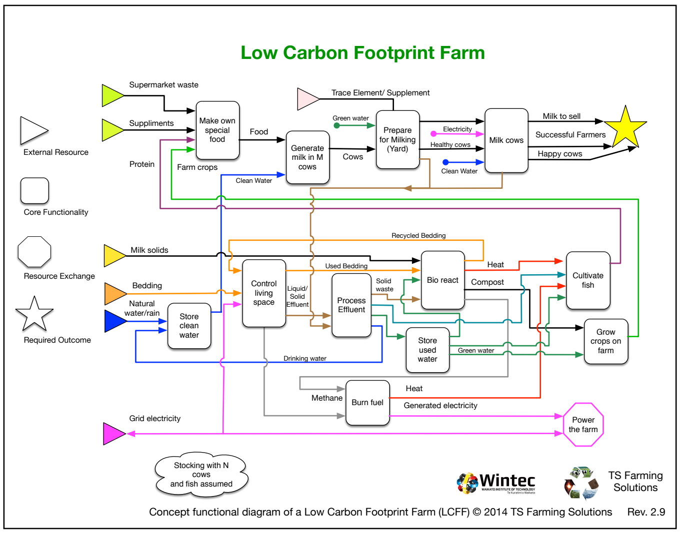
As was expected, the discussion focused on specifics of dairy farming, like optimizing feeds and dairy output while minimizing the impact on the environment (Fig. 4). Later discussion extended the space to include regulatory bodies in the region, the investment of trusts and the political frame of reference. Using the notes from the discussions and a visit to the farm, several experts from different disciplines were asked to contribute initial bits of information to develop IDEF0[3] diagrams of key functional elements. These elements were pulled together through process inputs and outputs, shown in Fig. 5.

Note that for commercial reasons some aspects are not shown here. However, the construct is populated adequately for discussion purposes.

It was decided early on to use model based design approaches. The reason for this is that models can capture and clarify common understanding; they can be used to effectively document and explain the recursive nature of the process being followed (as each model must stand alone as an artifact during each structure-analyze-synthesize effort). As the models increase in complexity and domain reach, it is possible to start with what-if analysis to support investment and technical decision making.

The choice of the model framework was based on the level of the work required. Initially the knowledge and understanding would be at the level of systems interaction, simple high level process logic and systems dynamics. In time adaptive elements would need to be introduced in the form of software based agent constructs. This would allow for the non-linearity of the system to be reflected properly. It is recognized that circular and recursive causality would occur in the system. We must be able to model a system that supply services and consume services that it generated. A mixed-model approach is thus called for. AnyLogic[4] was chosen for the modeling as it is a commercial package that can cope with this type of complexity and allows for webcasting of developed models to stakeholders and co-creators.

A first iteration simulation model was built in AnyLogic to reflect the information available during the initial structure-analyze-synthesize cycle. Each of the elements (in Fig. 5) requires the focus of specific disciplines and experts to populate the model. During the phase discussed in this paper some of the teams were already operational, and while not all stakeholders have been finalized, the initial models are useful already to enable discussion and knowledge sharing. It also allows for effective financial estimation and discussion with investors.



Concept functional diagram of a Low Carbon Footprint Farm (LCFF) © 2014 TS Farming Solutions Rev. 2.9

Fig. 5. Conceptual functional diagram for discussion.

VI. THE NEXT PHASE

The approach being followed is novel in the New Zealand context. This research project is fully externally driven with the requirement that it will deliver a working artifact at each stage of development. It is fair to expect that the client(s) will have an expectation of a valuable deliverable, something that is considered important (it has a value proposition) and that they are willing to pay for. In the case of transdisciplinarity, it is a challenge to decide up-front what will satisfy and delight the client, as the problem identification and structuring is part and parcel of the methodology. "The client" is also a larger collective (stakeholders) that includes society in many cases. However, as was shown, the agency requesting the inquiry becomes part of the iterative process towards co-development of the deliverable. This implies that part of the role of the research manager will be to ensure the client and key stakeholders remain satisfied and have significant buy-in at every stage of the research project.

As part of the next phase of the project Lean Principles will be introduced. Considering Lean Principles as embodied in engineering of large systems of systems may be beneficial and it is currently proposed that Lean Principles are adopted and adapted for the purpose of TransDisciplinary Research (TDR).

In short, the adoption of Lean Principles implies the following (derived from the requirements and goals of TDR):

- Capture value through the rigorous documentation of the creative, iterative (recursive) process of deliverables. TDR insists that the method, the road to discovery and the discovery are all equally important aspects of the action delivered in the real world.

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[3] *Icam DEFinition for Function Modeling (IDEF)*

[4] http://www.anylogic.com

- Map the value stream in research project plans commensurate with the level of complexity of the research task.
- Follow the iterative flow of the TDR process and streamline the processes required for interaction and communication by utilizing tried and tested methodologies like Design Thinking [23] and other appropriate process to ensure rigorous verification and validation of synthesis against analysis.
- The lean principle of customer pull is embodied in the requirement to ensure appropriate diversity of scientific and societal views of the problem.
- Given the complexity of the type of problems under consideration, the pursuit of perfection is reflected in the quality of the creative and reflective aspects of the TDR approach and how innovative approaches are woven (and documented) into the TDR process.
- Finally, respect for people is part of the understanding that the knowledge embodied in the individuals and their networks can only be harvested towards the real world (re)solution if the team operates at all times to the highest ethical standards, so that the outcome can be for the common good.

VII. FINAL REMARKS

The shifting nature of the agri-eco-socio-technical system of farming today requires a wider approach to the development of solutions for the space. The design of a low carbon footprint farming complex needs such an approach to prevent discipline specific solutions that cannot be harmonized with holistic systemic requirements. This paper showed how the initial phase of such a project was approached. It showed how and why the current process is different from the traditional system engineering methods, and acknowledges the value of those methods when applied at the right level and phase of the structure-analyze-synthesize loop. It is clear that a problem of this magnitude requires mixed model methods for simulation. This brings with it new challenges in model verification and validation techniques, especially during early stages of projects.

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