INTERNATIONAL DESIGN CONFERENCE – DESIGN 2022
https://doi.org/10.1017/pds.2022.112

Modeling Social Benefits in System Design Optimization of Integrated Natural Resources Conservation and Development (INRCD) Projects: Identification and Quantification of Design Attributes from Extant Literature

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Abstract

Integrated Natural Resource Conservation and Development (INRCD) Projects promote community economic development consistent with natural resource conservation. Such projects are studied analytically as system design optimization problems comprising engineering, economic, and social considerations. Modeling social benefits as objectives or constraints requires proper quantification. From the extant literature, we decompose the social benefits concept into quantifiable INRCD attributes and point to further quantification efforts needed to capture the system design's impact on local communities.

Keywords: sustainability, design optimisation, design methodology

1. Introduction

As part of the Design Society's AFRICA-DESIGN initiative, previous work proposed the umbrella term Integrated Natural Resource Conservation and Development (INRCD) Projects. The term INRCD combines the idea of socio-economic investments in Integration Conservation and Development Projects (ICDPs) introduced by the World Wide Fund for social development and conservation, with the research and development efforts in Integrated Natural Resource Management (INRM) that employ a systems approach for quantitative modelling and optimization.

An example of an Agriculture-Energy INRCD project is shown in Figure. 1. An irrigation system is installed to provide irrigation for the crops and water for household use in a small community. A microgrid using renewable energy sources, such as photovoltaic panels, and possibly a backup generator provides power for irrigation and the households. The system comprises two technology subsystems, irrigation plus crops and microgrid. Each subsystem is a combined design and control optimization problem, since for a fixed design the irrigation schedule is time dependent and generates a power demand that must be met by the scheduler of the microgrid. The system operates under local weather stochastic conditions of rain and sunlight. The overall system objective may be maximum profit with income provided by selling the crops and costs incurred from operations and capital repayments. Such a stochastic coupled system optimization problem is challenging in its own right.

For modelling simplicity and initial quantification, maximum profit is an obvious INRCD system objective function. However, the relevant literature is replete with examples where success of such projects depends highly on the project's value to the local community and its positive impact beyond an immediate financial gain attributed to 'development' (Rajski and Papalambros, op.cit.). We use the term 'social benefits' to capture generically such benefits of the community that may result from INRCD projects. The question then arises how we can quantify such a broad sociological concept so that we can link it with system design decisions.

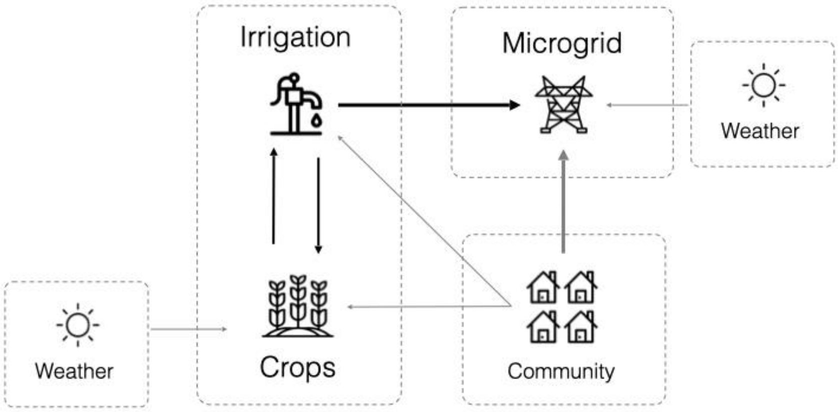

Figure 1. Schematic of an agriculture-energy INRCD project

The objective of this paper is to translate sociological definitions of social benefits and/or impacts into quantifiable metrics suitable for system optimization by itemizing 'benefits' or 'impacts' into social metric categories. In early conceptual design, a key activity is to map the problem statement to design attributes, which are the design properties the user/customer/stakeholder employs to evaluate the design (for example, attractive or easy to use), and then map these attributes to design characteristics, which are the quantified design properties the designer can manipulate (for example, colour or shape or ergonomic dimensions). In decision analysis, attributes are classified as natural, proxy, and constructed (Keeney and Gregory, 2005). In our terminology, this classification corresponds to increasing complexity of the above mapping; for example, the mapping between a natural attribute and a corresponding characteristic is one-on-one. A similar idea is captured in the relationship matrix of classical QFD (Akao, 1990). In this spirit, we look to decompose the concept of social benefits into a mapping hierarchy that ends with quantifiable social metrics. We do this by studying the relevant literature specifically to uncover such mappings which may be indicated explicitly or implicitly in the literature. Covering such a diverse domain makes this review a preliminary effort, yet some key ideas and directions for further investigation emerge.

2. Background and Methodology

To frame the mapping question, it is beneficial first to define social impact from a sociological lens. Duncan and Jones (1976) define social impact as the effect, positive or negative, of some event on the well-being of individuals or a community. This definition guides later definitions for assessing social impact: the “identification, analysis, and evaluation of the social impacts resulting from a particular event” (Dietz, 1987). Dietz also emphasizes the fact that impacts have two prongs, objective and subjective, highlighting the importance of gathering data from affected individuals in addition to defining impacts that are perceived by researchers who are outsiders to the afflicted community. There is a potential disconnect between defining a social metric and choosing to either quantify or qualify it in attempts to understand the impacts of an event. Here we aim to define and quantify social metrics related to engineering systems design.

The Human Development Index (HDI), first proposed in the United Nations Development Program’s (UNDP) Human Development Report (1990), is often employed to quantify social impacts. Human development can be defined as the expansion of people’s opportunities and freedoms (United Nations Development Programme, 1990). The UNDP breaks the indicators of human development, or well-being, into three categories: life expectancy, education, and living standards. By these metrics, then, one can quantify the breadth and depth of choices and opportunities available to a population. This

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quantification can be achieved through taking a geometric mean of each of the indicators (United Nations Development Programme, 1994):

$$HDI(l, \varepsilon, y) = \left(\frac{l-20}{83.4-20}\right)^{\frac{1}{3}} \left(\frac{\varepsilon-20}{0.978-0}\right)^{\frac{1}{3}} \left(\frac{\ln y - \ln 100}{\ln 107721 - \ln 100}\right)^{\frac{1}{3}}, \tag{1}$$

where l is an indicator of life expectancy, ε is education, and y is the distribution of income across the population.

Studies of social impact in engineering, design science, and economics have employed an objective function similar to Eq. (1). For example, Engineer and King (2013) maximize the aforementioned three human development indicators by assessing the potential economic outcomes of each one. Similarly, Stevenson et al. (2018) express poverty level (M) as the additive average of health (H), education (E), standard of living (L), employment quality (Q), and security (Y):

$$M = {}^{1}/_{5}\,(H + E + L + Q + Y). \tag{2}$$

They use this relationship as a universal metric for social impact in the engineering of poverty-alleviating products.

These objectives are simple but offer a good early foundation for assessing quantitatively the outcomes of design decisions. Yet a question arises as to the suitability of selected attributes, such as life expectancy, education, or security in the equations above. Keeney and Gregory (2005) offer five desirable attribute properties (unambiguous, comprehensive, direct, operational, and understandable) and describe them in detail. Here we are concerned only with collecting possible attributes suggested from the literature and leave their suitability as a next step.

From studying the literature, we identified seven attributes associated with social benefits, and we categorized the literature accordingly: energy access, human development, environment, economic prosperity, health, security, and education, see Figure. 2. The full list of 46 references examined for this paper can be found in AFRICA-DESIGN@UM (2022). Some references fell into multiple categories and are double counted in Figure. 2. Many of the references were on ecological services which was the attribute easiest to map to quantifiable characteristics. Some references are specific to studies in Africa but when these were not available, we included studies in other parts of the world as a starting point for future studies specific to Africa. We then considered each of the seven attributes as a set and decomposed each attribute to set to elements that we could map to quantifiable characteristics. The resulting decomposition tree has as end points quantifiable metrics that can serve as design variables in a system design optimization formulation, see Fig 3.

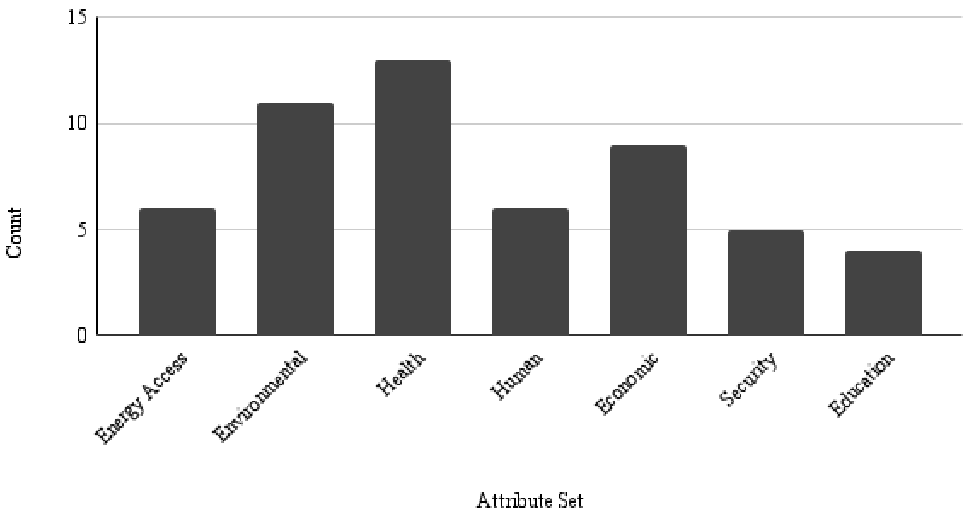

Figure 2. Categorization of paper types by attribute sets

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Notably, we observe some overlapping among attributes and associated characteristics. For example, both energy access and ecology relate to human health, and the associated linking variables are metrics for air quality. The presence of linking variables in an indicator of system complexity as might be expected. In the next section we describe these findings in more detail.

3. Attribute Sets and Mapping to Characteristics

The attribute sets above match well the literature on success or failure of INRCDs in Africa (Rajski and Papalambros, op. cit.). Furthermore, they also line up well with the UN Sustainable Development Goals. In this context, a system design model that incorporates these attributes should provide some deeper insights on the design trade-offs for the value of INRCDs to the local communities.

Each attribute set was decomposed to elements mapped to characteristics that can be quantified in an optimization model. Figure 3 depicts the hierarchical mapping of each attribute to its characteristics and the linking variables within the sets. We describe this decomposition and mapping below. Note that this early effort is likely to be modified with further study; it provides a starting point for the modelling effort.

3.1. Energy Access Attribute

Energy poverty refers to access to reliable and affordable energy (MacCarty and Bryden, 2017). Energy is linked to climate change, poverty, inequality, food security, health, and education (Nussbaumer et al., 2012). The energy access attribute set is broken into three different categories: health risks, lighting systems, and allocation of time. Health risks are mapped into the types of stoves used in the community and are quantified by measuring exposure to air pollution. Traditional cookstoves lead to 1.6 million deaths each year (Allen et al., 2017). Newly designed cookstoves have been replacing traditional ones to counteract health risks from increased particulate matter and carbon monoxide emissions (Roden et al., 2009). Furthermore, modern stoves, such as LPG stoves, decrease the amount of time needed to collect fuel which relates to the characteristic of energy access - allocation of time (MacCarty and Bryden, 2017). With more access to modern technology, individuals in communities will have more time to spend on educational, income generating, and social activities. Lastly, access to energy allows for better lighting systems to be implemented leading to activities occurring after sunset and decreased incidents of violence. Indoor lighting means social and educational activities do not only have to occur in the day and increase opportunities for individuals in rural communities. We can also distinguish benefits from renewable vs. non-renewable energy. Solar lighting reduces health risks by 15% and climate change risks by 10% compared to kerosene/acetylene lighting (MacCarty and Bryden, 2017). Increased lighting in streets decreases incidents of violence; for example, in Edmonton, North London, violent incidents decreased by 80% (Painter, 1996).

3.2. Human Development Attribute

For the human development attribute set, we focused only on women and their rights. Time poverty is a major contributor to limited opportunities for women and refers to the limited amount of time women have due to being overburdened with childcare and household responsibilities (Hyde et al., 2020). In a case study done in the East Africa Dairy Development in Uganda women complained about having to juggle household and reproductive responsibilities with dairy production (Bain et al., 2018). Men were often found to have significantly more leisure time than women. Increasing time demands for women may decrease quality of care for children, food, and nutrition. In addition, time poverty can decrease the opportunities for other income generating sources, impede women’s ability to expand individual growth through engaging in activities such as education, skills development, social groups, or collective actions. The human development attribute is mapped to the different methods of calculating trade-offs between incomes earned from different sources if more time could be allocated towards it. This attribute is linked to education through increased educational opportunities for women and freedom to make choices and to economic prosperity through increased income opportunities (see, e.g., Ross and Van Willigen 1997).

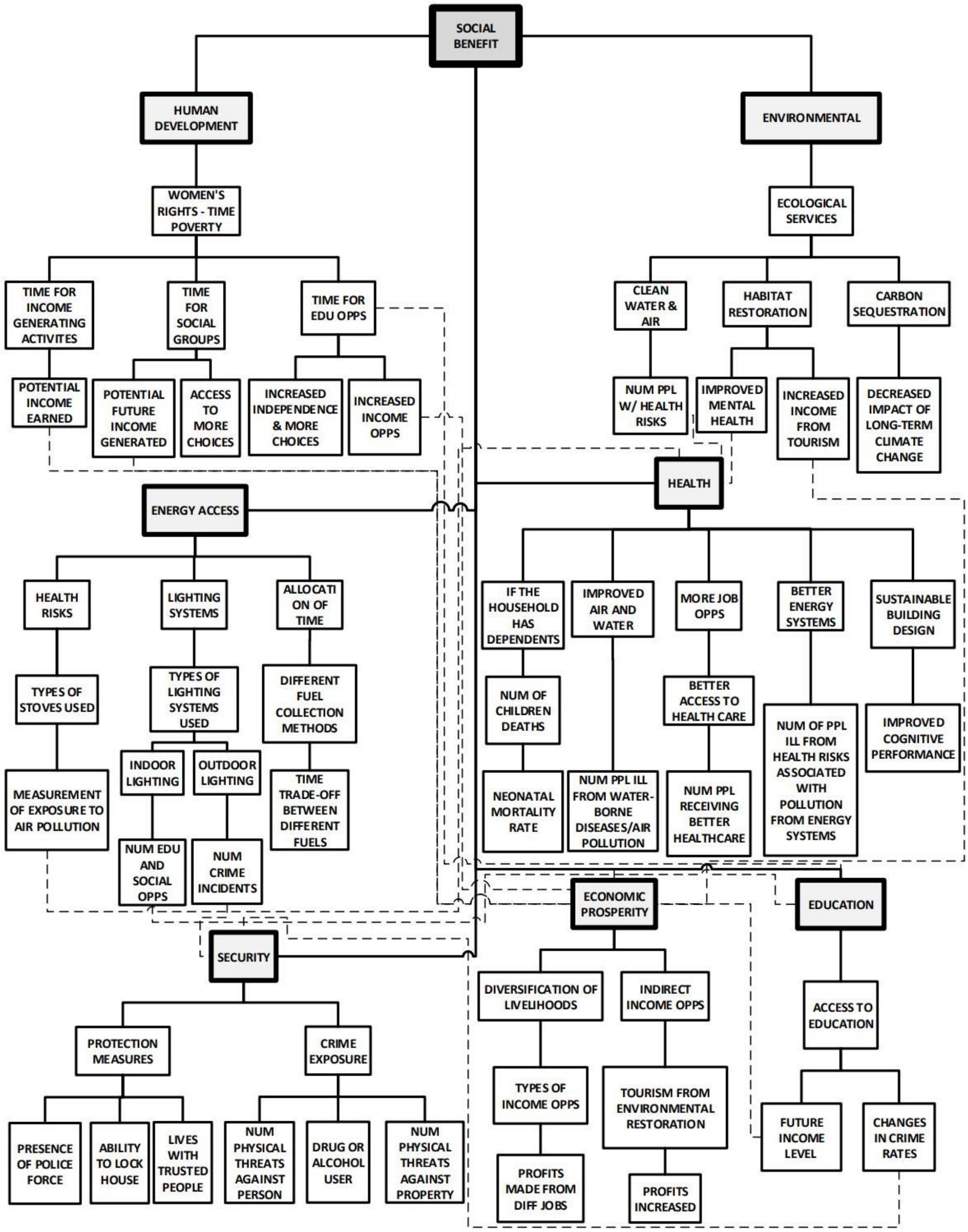

Figure 3. Hierarchical breakdown of attribute sets

3.3. Environment Attribute

The environment attribute set focuses on the human benefits from ecological services, which are decomposed here into clean water and air, habitat restoration, and carbon sequestration, although there are more ecological services that offer benefits. A case study in the Lower Atchafalaya River looked at dredging for increased carbon sequestration (Foran et al., 2018). No clear method for quantifying

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these long-term benefits was identified. Studies on large-scale forest restoration depicted the diversification of livelihoods and off-farm employment opportunities such as forest management and eco-tourism that provide income generation opportunities outside farming and increased access to timber for fuel from restoration projects (Adams et al., 2016). Increase in biodiversity through forest restoration leads to healthier soil and more diverse crops and helps biomedicine and public health. Ecological services have additional health benefits such as purifying air and water through increased vegetation; for example, urban trees remove 711,000 metric tons of pollutants in the USA annually estimated to save 3.8 billion dollars (Coutts et al., 2015). Certain vegetation and trees also capture gaseous and particulate airborne pollutants. Finally, increased greenery helps improve mental health (Coutts et al., 2015). Studies demonstrated individuals can recover from stressors faster when they are in a green environment rather than a man-made one (Brown et al., 2013). Through this attribute the quantifiable characteristics include the number of people in a community that are affected by water and air pollution related diseases and the increased income from ecotourism and other income opportunities. A method for quantifying the decreased impact on climate change and mental health improvements has not been identified.

3.4. Economic Prosperity Attribute

The economic prosperity attribute set is broken down into diversification of livelihoods and indirect income opportunities. Proper INRCD project implementation can lead to more income-generating opportunities. For example, studies indicate renewable energy systems can meet the demand of African countries in the near- and long-term future (Sanoh et al., 2014). The implementation of these new energy systems would create job opportunities in construction and maintenance, providing individuals with different income options. As mentioned in the environment attribute, forest restoration projects also contribute to the diversification of livelihoods. Furthermore, a study investigating the impacts of Farmer Managed Natural Regeneration (FMNR) and Modified Taungya System (MTS) in Niger and Ghana found that there were possibilities of receiving payments through the creation of carbon emission offset markets (Adams et al., 2016). Creation of such markets is an indirect income opportunity from these resource management projects. Nguyen et al. (2017) used a system dynamics approach to perform a cost-benefit analysis on transport infrastructure projects, accounting for impacts on unemployment rate, gross domestic product, and taxes gained by the sectors in question — all of which are indicators of both individual and community economic prosperity. The model is based on a case study in Vietnam, but it can be modified for smaller-scale infrastructure projects in Africa.

3.5. Health Attribute

The health attribute is an obvious stand-alone social benefit attribute which has been studied extensively in Operations Research (see e.g., Zeckhauser and Shepard 1976; Bordley 1990, 1994; Weinstein et al. 2009), but its mapping paths relate directly to other attributes. The attribute set is decomposed into improved air and water from environmental restoration, more job opportunities, better energy systems, and sustainable building design. The quantifiable characteristics identified are neonatal mortality rates, number of people affected by water-borne and air pollution related illnesses (Coutts et al., 2015), number of people who have access to better healthcare (Mphande, 2016), number of people who are affected by air pollution from energy systems (Roden et al., 2009), and improved cognitive performance (Heerwagen, 2006). The health attribute has the most linking variables to other attributes, except for the neonatal mortality rate which was derived from the Product Impact Metric (Stevenson et al., 2018). Access to health care is an important factor in preventing disease outbreaks within a community. A study using Markov chains, simulation, and optimization depicted having three nurses available for four hours a day, five days a week, decreased the spread of pertussis cases by 26 cases compared to having one nurse work one hour, one day a week (Yaylali et al., 2014) in a simulation with 500 replications. The health attribute, specifically referring to global health, has a broad scope and further research is required to determine further aspects to quantify.

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3.6. Security Attribute

The security attribute set is broken down into protection and exposure (Stevenson et al., 2018). These attributes are then mapped into the following characteristics: presence of police force, ability to lock doors, lives with trusted people, drug and alcohol users, number of physical threats against person, and number of physical threats against property. The security attribute is included because it directly links to people's freedom and their ability to live safely and securely (Diprose, 2007). Violence sustains poverty traps within communities, and individuals in extreme poverty are often the most vulnerable (Diprose, 2007). The security attribute, like the health attribute, is interlinked with many of the other attributes. Unemployment, lack of education, and income inequality all contribute to increased crime rates (Jonathan et al., 2021). Therefore, security has a significant impact on socio-economic development and social benefits in communities.

3.7. Education Attribute

The education attribute (Stevenson et al., 2018) is broken down into increase in future income opportunities and changes in crime rates within the community. A study in rural China indicated that stronger educational policies and increased educational opportunities led to significant decreases in crime rates (Eryong and Xiuping, 2018). The educational policies were implemented to combat crime rates and violence; however, they simultaneously helped poverty alleviation. Increased educational opportunities led to more income opportunities which helped combat overall poverty rates in the community.

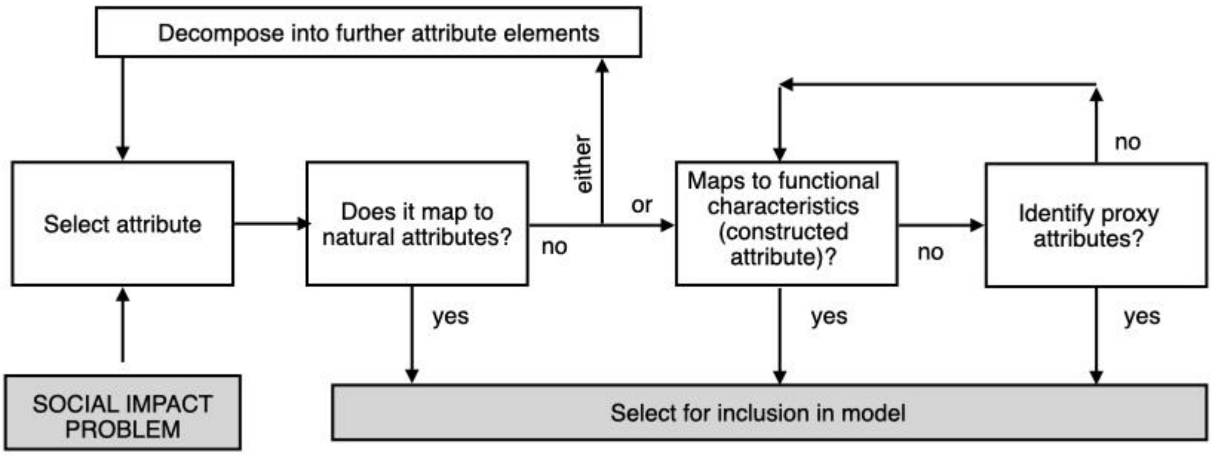

Figure 4. Attribute selection chart

4. Discussion

System design optimization for INRCD projects can account for social benefits in a model of the form {max f(**a**(**x**)), subject to **h**(**a**(**x**)) = **0** and **g**(**a**(**x**)) ≤ **0**}, where **x** is the vector of project design decisions, **a**(**x**) is the vector of project attributes, and *f*, **h**, **g** are the objective function, equality, and inequality constraints, respectively. The attribute vector can include functional (or 'simple' in marketing jargon) attributes, such as those derived from engineering analysis, perceptual attributes (or 'complex' in marketing jargon), such as those derived from surveys and marketing studies including machine learning models, and social benefit (again 'complex') attributes quantified as discussed above.

INRCD projects have naturally multiobjective optimization models with an **f** vector of objectives. Still, the objective function can be a simple additive scalar function *f* like in the models mentioned in Section 2. A more sophisticated model can be built using approaches such as MAXDIFF or conjoint analysis weights derived from data specific to the region of the project, for example, through local surveys, see, e.g., Sawtooth (2021). The constraint functions are derived from setting upper or lower bounds on

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relevant attributes for technical feasibility as well as for certain social impacts, for example, lower bounds for social benefits and upper bounds for negative impacts.

The multidisciplinary, multiobjective nature of this system optimization problem can be addressed in several ways of increased complexity: (1) Select the 'most important' objective as the system objective and set bounds on the other competing objectives using the so-called upper bound formulation to generate an approximation of the Pareto set, see e.g., Papalambros and Wilde 2017. (2) Create a social benefits utility function as the scalar substitute objective that combines the multiple objectives. For example, the relatively straightforward maximum profit objective can be used along with specific constraints on health or environment improvement goals. (3) Use the Analytical Target Cascading (ATC) Process (Papalambros and Wilde op cit.) to coordinate desirable targets for different attributes, see e.g., Michalek et al. 2006 and Kang et al. 2019.

The attributes/characteristics in Figure. 3 must be evaluated as to suitability for inclusion in a decision model. To this end we can use the attribute selection flowchart adapted from Keeney and Gregory (2005), see Figure. 4. A natural attribute maps to a measurable functional characteristic one-on-one and can be selected directly. If not, we can create the mapping with a more sophisticated model (constructed attribute) and select it. If that is not possible or realistic, we will look for a proxy or 'sentinel' attribute (MacDonald et al., 2010) that people may use anyway if the desired attribute is elusive to quantify.

5. Conclusion

Social benefits can be quantified for inclusion in system design optimization studies through mapping to associated attributes and quantifiable design characteristics. While a generic model structure can be adopted, the specific quantification models will depend on local data which is a challenging task. However, even with incomplete data, the expanded system models can capture the trade-offs between technical, economic, and social decisions and how their trends change as assumptions change. Understanding the true impact of INRCD projects is a 'wicked problem' with many externalities that influence project outcomes. The systems optimization approach is still a highly useful tool in the design and execution of such projects informing the potential outcomes of design decisions under given assumptions.

Acknowledgement

This work has been partially supported by the Donald C Graham Endowed Chair at the University of Michigan. Special thanks to Prof. R.F. Bordley for his insightful advice.

References

Adams, C., Rodrigues, S.T., Calmon, M. and Kumar, C. (2016). "Impacts of large-scale forest restoration on socioeconomic status and local livelihoods: what we know and do not know", *Biotropica*, Vol. 48 No. 6, pp.731–744.

AFRICA - DESIGN (2022). List of examined references available at the following URL: https://drive.google.com/file/d/1T5l03vnVfYfYqbAmKYCt1XxkjY_6T4rv/view?usp=sharing

Akao, Y. (1990). *Quality Function Deployment: Integrating Customer Requirements into Product Design*, Productivity Press, Portland, OR.

Allen, J.D., Mattson, C.A., Thacker, K.S. and Ferguson, S.M. (2017). "Design for excess capability to handle uncertain product requirements in a developing world setting", *Research in Engineering Design*, Vol. 28 No. 4, pp.511–527. https://doi.org/10.1007/s00163-017-0253-8

Bain, C., Ransom, E. and Halimatusa'diyah, I. (2018). "'Weak winners' of Women's empowerment: The gendered effects of dairy livestock assets on time poverty in Uganda". *Journal of Rural Studies*, Vol. 61, pp.100–109.

Bordley, R. (1990). "Measuring Risk Reduction Benefits with Discounted Longevity," Operations Research, Vol. 38, No. 5, pp. 815-819.

Bordley, R. (1994). "Making Social Tradeoffs among Lives, Disability and Cost," J. of Risk and Uncertainty, Vol. 9, No. 2, pp. 135-150.

Brown, D.K., Barton, J.L. and Gladwell, V.F. (2013). "Viewing Nature Scenes Positively Affects Recovery of Autonomic Function Following Acute-Mental Stress", *Environmental Science & Technology*, Vol. 47 No. 11, pp.5562–5569.

https://doi.org/10.1017/pds.2022.112 Published online by Cambridge University Press

Coutts, C. and Hahn, M. (2015). "Green Infrastructure, Ecosystem Services, and Human Health", *International Journal of Environmental Research and Public Health*, Vol. 12 No. 8, pp.9768–9798.
Dietz, T. (1987). "Theory and Method in Social Impact Assessment", *Sociological Inquiry*, Vol. 57 No. 1, pp.54–69.
Diprose, R. (2007). "Physical Safety and Security: A Proposal for Internationally Comparable Indicators of Violence", *Oxford Development Studies*, Vol. 35 No. 4, pp.431–458.
Duncan O. and Jones, A. (1976). Methodology and Guidelines for Assessing the Social Impacts of Development, Duncan and Jones, Inc., Berkeley, California.
Engineer, M. and King, I. (2013). "Maximizing human development", *Canadian Journal of Economics*, Vol. 46 No. 2, pp.497–525.
Eryong, X. and Xiuping, Z. (2018). "Education and anti-poverty: Policy theory and strategy of poverty alleviation through education in China", *Educational Philosophy and Theory*, Vol. 50 No. 12, pp.1101–1112.
Foran, C.M., Burks-Copes, K.A., Berkowitz, J., Corbino, J. and Suedel, B.C. (2018). "Quantifying Wildlife and Navigation Benefits of a Dredging Beneficial-Use Project in the Lower Atchafalaya River: A Demonstration of Engineering with Nature®", *Integrated Environmental Assessment and Management*, Vol. 14 No. 6, pp.759–768.
Heerwagen, J. (2006). "Investing in People: The social benefits of sustainable design", *Rethinking Sustainable Construction*.
Hyde, E., Greene, M.E. and Darmstadt, G.L. (2020). "Time poverty: Obstacle to women's human rights, health and sustainable development", *Journal of Global Health*, Vol. 10 No. 2.
Jonathan, O.E., Olusola, A.J., Bernadin, T.C.A. and Inoussa, T.M. (2021). "Impacts of Crime on Socio-Economic Development", *Mediterranean Journal of Social Sciences*, Vol. 12 No. 5, p.71.
Kang, N., Feinberg, F., and Papalambros, P. (2019). "Designing Profitable Joint Product–Service Channels: Case Study on Tablet and eBook Markets."Design Science, 5, E12. https://dx.doi.org/10.1017/dsj.2019.11
Keeney, R.L. and Gregory, R.S. (2005). "Selecting Attributes to Measure the Achievement of Objectives", *Operations Research*, Vol. 53 No. 1, pp.1–11.
MacCarty, N.A. and Bryden, K.M. (2017). "Costs and impacts of potential energy strategies for rural households in developing communities", *Energy*, Vol. 138, pp.1157–1174.
MacDonald, E. F., Gonzalez, R., and Papalambros, P. Y. (2010). "The Construction of Preferences for Crux and Sentinel Product Attributes", *Journal of Engineering Design*, Vol. 2 No. 6, pp.609-626. https://dx.doi.org/10.1080/09544820802132428.
Michalek, J. J., Ceryan, O., Papalambros, P. Y., and Koren, Y. (2006). "Balancing marketing and manufacturing objectives in product line design",Journal of Mechanical Design, Transactions of the ASME, Vol. 128, No. 6, 2006, pp. 1196-1204.
Mphande, F. A. (2017). *Infectious diseases and rural livelihood in developing countries*, Springer, Singapore.
Nguyen, T., Cook, S. and Ireland, V. (2017). "Application of System Dynamics to Evaluate the Social and Economic Benefits of Infrastructure Projects", *Systems*, Vol. 5 No. 2, p.29.
Nussbaumer, P., Bazilian, M. and Modi, V. (2012). "Measuring energy poverty: Focusing on what matters", *Renewable and Sustainable Energy Reviews*, Vol. 16 No. 1, pp.231–243.
Painter, K. (1996). "The influence of street lighting improvements on crime, fear and pedestrian street use, after dark", *Landscape and Urban Planning*, Vol. 35 No.2-3, pp.193–201.
Papalambros, P.Y., and D.J. Wilde (2017). Principles of Optimal Design: Modeling and Computation, Third Edition, Cambridge University Press, New York.
Roden, C.A., Bond, T.C., Conway, S., Osorto Pinel, A.B., MacCarty, N. and Still, D. (2009). "Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves", *Atmospheric Environment*, Vol. 43 No. 6, pp.1170–1181.
Ross, C.E., and Van Willigen, M. (1997). "Education and the Subjective Quality of Life," Journal of Health and Social Behavior Vol. 38, No. 3, pp. 275-297
Sanoh, A., Kocaman, A.S., Kocal, S., Sherpa, S. and Modi, V. (2014). "The economics of clean energy resource development and grid interconnection in Africa", *Renewable Energy*, Vol. 62, pp.598–609.
Sawtooth (2021). Sawtooth Software https://sawtoothsoftware.com. Accessed 11 Nov. 2021.
Stevenson, P.D., Mattson, C.A., Bryden, K.M. and MacCarty, N.A. (2018). "Toward a Universal Social Impact Metric for Engineered Products That Alleviate Poverty", *Journal of Mechanical Design*, Vol. 140 No. 4.
UNDP.org. (2019). *About Human Development: Human Development Reports*. [online] Available at: http://hdr.undp.org/en/humandev.
United Nations Development Programme (1990). Human Development Report, 1990. Oxford University Press, New York, New York.
United Nations Development Programme (1994). Human Development Report 1994. Oxford University Press, New York, New York.

Weinstein, M. C., Torrance, G., McGuire, A. (2009). "QALYs: The Basics", Value in Health, Vol. 12, Supp. 1
Yaylali, E., Ivy, J.S. and Taheri, J. (2014). "Systems Engineering Methods for Enhancing the Value Stream in Public Health Preparedness: The Role of Markov Models, Simulation, and Optimization", Public Health Reports, Vol. 129 No. 6, pp.145–153.
Zeckhauser, R., and Shepard, D. (1976). "Where Now for Saving Lives?", Law and Contemporary Problems.Vol. 40, No. 4, pp. 5–45.