Emergent and Unexpected Sources of Value from Radio Astronomy Projects

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***Abstract*—Construction projects are under increasing pressure from local communities to deliver Societal Value (SV), defined as integrated social and environmental value. Societal Value delivery requires the co-creation of value outcomes with environmental and community stakeholders, in addition to the functional benefits of the project. The aim of this research is to advance understanding of the conceptualisation and practise of Societal Value in capital projects. This paper will summarise existing research and key concepts in the delivery of Societal Value, applying examples from both existing and planned radio astronomy projects such as the Very Large Array (VLA, USA) and Next-Generation Very Large Array (ngVLA, USA), Square Kilometre Array (SKA, South Africa and Australia), Arecibo (NAIC, Puerto Rico), Ghana Radio Telescope Observatory, and Atacama Large Millimeter / submillimeter Array (ALMA, Chile). Such projects are built in rural areas, bringing services, infrastructure, jobs, education, and astrotourism to surrounding communities. Answering these research questions can lead to the development of a societal value framework for construction projects, including metrics and an audit methodology, for use by organisations and governments in practising project assurance.**

Keywords—societal value, sustainability, radio astronomy, rural communities, assurance, construction

I. Introduction

As science progresses, so too does the discussion about the value and impact of scientific projects. Traditional metrics (such as technical products, benefits to government, new scientific discoveries, science, technology, engineering, and mathematics (STEM) teaching, training, and learning) remain essential. Additional metrics are becoming common, often focusing on societal desirability, value, and ethics [1]. While much of the conversation about science focuses on the merits of intellectual pursuits and investment, attention is now being given to the physical impact of scientific installations (science construction).

This research aims to advance understanding of the conceptualisation and practise of societal value (a principle of sustainability) on construction projects, with the ultimate goal of developing an audit framework for societal value. Societal value expectations pose a dilemma for project managers. In this perspective, beneficial outcomes require an integration of ethics (doing right behaviours), with social (managing enterprises' responsibilities to society) and environmental (managing impact on natural environment) sustainability [2].

Existing frameworks such as Triple Bottom Line and, more recently, Sustainable Development Goals (SDGs) [3] have been adopted in the UK and Europe on construction projects as measurement frameworks, in an attempt to balance the short- and long-term benefits of projects. However, these approaches have been criticised as reductionist methods that implicitly focus on readily quantifiable financial benefits over environmental or social value benefits that are difficult to quantify. The SDGs are viewed as overly complicated, with 196 possible metrics and inherent conflict among the development goals. Adoption of these frameworks on construction projects also provides additional challenges, as the capacity to deliver beneficial outcomes (as defined by Triple Bottom Line or SDG) may be distributed among temporally- and geographically-dispersed participants, with varying and possibly conflicting stakeholder perspectives. Existing frameworks may not adequately represent these inherent complexities and trade-offs in capital projects. Finally, external shocks such as COVID-19 may change project stakeholders' perceptions of their societal role, which may encourage them to take a more broad perspective of societal value, exceeding existing frameworks. There is, therefore, a need to advance understanding of the conceptualisation and practise of societal value in capital projects and come to a consensus regarding the scope of societal value.

Using examples from both existing and planned radio astronomy (RA) major projects, this paper seeks to examine the following research question: What are the challenges in conceptualising and measuring the societal value of construction projects?

II. Background

Since antiquity, astronomers have sought landscapes suited to the viewing of the sky without interference. As the field of astronomy has evolved, so have the location requirements for high-quality astronomical observations. These include atmospheric conditions (cold and dry with a thin atmosphere and good air quality), low light pollution (dark skies preservation) and low electromagnetic interference (radio-quiet zones) which requires increasingly large swaths of land, often with a secured buffer zone. For this reason, telescope and radio astronomy facilities are often sited in remote places, typically distant from major cities. However, this does not mean the regions are unpopulated. In addition to native flora and fauna, such rural territory is often rich in indigenous peoples' history and culture, serving an extant human population.

Characteristics of ground-based radio astronomy (RA) observatory facilities typically include long-term community commitments and land use agreements, with the installation of not just research-intensive equipment but also significant civil infrastructure, facilities for research and offices, staff and visiting scientist accommodations, maintenance, fire safety and security, data centres, training facilities, and visitor centres. Some radio astronomy telescope facilities are small; others are on the scale of mega-projects, valued at billions of US dollars. Major facilities are often designed to operate for 20 to 25 years and then be decommissioned, but usually remain in operation decades beyond their planned obsolescence date.

In many countries, RA's growth is nationally transformative and life-changing to the local community in which facilities are established. The construction of radio astronomy observatories has both short- and long-term impacts on the local population, first from building activities over the course of several years and then the physical presence of facilities and infrastructure. Also, such facilities attract both short- and long-term highly educated and sophisticated populations and families that, in turn, themselves have short-term (months to years) and long-term (decades) population booms and ripple effects on the local area and community. Radio astronomy supports an incredible diversity of careers and the golden age of radio astronomy is now, with technology on the cutting edge of capability, facilitating multi-national cooperation and considerable investment. These characteristics make radio astronomy observatories a natural fit for the study of societal value in construction.

III. Literature Review

While the term "value" refers to a preferential judgement by stakeholders of a given project's output, processes or outcomes (e.g., benefits), "values" are the determinants of any social behaviour including attitude, ideology, beliefs, and justifications. They are linked, as the latter can shape perceptions of the former. Early research in project management did not expressly address the concept of value. The later emergence of "modern" project management (that is, the use of dedicated tools and techniques) introduced the idea of delivering financial value from projects. Current research embraces three paradigms: Functional, Perceived and Narrative.

The functional value conceptualisation is captured in the "value for money" (VFM) approach, defined as delivery of cost-effective, reliable, and timely services at agreed prices and to agreed quality, as specified in the contract [4]. This approach attempts to use quantifiable (financial) metrics and the related notion of exchange to capture trade-offs between project value dimensions [5]. Functional value seeks to identify optimal solutions based on a predefined set of quantifiable criteria for domains for a narrow subset of stakeholders, primarily the customer and supplier. Overall, the approach is to minimise uncertainty and reduce to the present the temporal horizon over which value estimation is performed (for example, by calculating Net Present Value (NPV) or Return on Investment (ROI)).

While functional value can be defined using externally verifiable metrics, perceived value is not clearly defined in project management literature and practice. Perceived or perceptual value conceptualisations acknowledge that value is multi-dimensional, and goes beyond a single unitary function, unlike functional value. First, perceived project value is multifaceted as financial, technical, and long-term value can be sought from a single project [6]. Second, individual perceived project value types are evaluated differently by stakeholders. A comprehensive understanding of project value thus must consider different stakeholders' perspectives (i.e., what value is and for whom) and specific contexts (e.g., project types) [7]. The perceived value conceptualisation also acknowledges that contradictory types of value may be obtained by stakeholders [6]. Perceived value is also influenced by temporal and geographic context, enabling or constraining the value creation process. Perceived value is co-created and is emergent from stakeholder interaction [8]. Stakeholder management (as conceptualised and practised) tends to place the project firm or organisation at the core, financially-linked stakeholders closer, and still others at the periphery. In construction projects, this enables considering a range of value types from the perspective of a relational dyad (contractor/client, designer/planner, etc.) since interaction with a smaller subset of closely linked actors shapes value expectations and outcomes. Within this stakeholder network, individual entities, especially those at the periphery, may pursue influence strategies to increase the visibility and salience of their claims. Perceived value incorporates various value metrics which, in addition to financial value, can include relational elements such as quality of relationships, leadership, learning, creativity, knowledge, technology transfer, and trust [8].

In the narrative paradigm, value is conceptualised as a linguistically-expressed social construct [9]. These narratives and stories express not only value but also the values and beliefs of individuals. The process of value creation occurs via stakeholder discourse involving a wider range of stakeholders, in contrast to the numerical perspective of the functional approach and dyadic co-creation in the perceived perspective [9]. The range of potential value identified goes beyond previous conceptualisations to identify complex societal benefits that include sustainability, societal value, quality of life, and wellbeing. Despite the development of both the perceived and narrative perspectives, there is still an implicit belief in the unidirectional flow of value from organisation to stakeholder. Further, broadening project management goals to incorporate stakeholder concerns sees the emergence of contradictions/tensions in value along with value destruction [10]. Table I provides an illustration of the value created and destroyed. While the emergence of the narrative perspective seeks to explicitly address these issues, little empirical research has been done using this approach.

TABLE I. Value Created and Destroyed

Value Paradigm	Value Created	Value Destroyed
Functional	Financial Self-sustaining economy	Loss of income Loss of revenue (Tax/Business) Loss of services Property damage Productivity reduction
Perceived	Intra-stakeholder relationships	Negative impact on stakeholder routines
Narrative	Quality of life Wellbeing Social value Societal enhancement	Reduced quality of life

(Adapted from [10] and [11])

IV. Research Method

To date, value research in the first two (functional and perceived) paradigms has been conducted with the perspective that entities under examination are fixed with varying attributes [12]. Based on this assumption, a phenomenon is described using a small number of variables (such as financial value, cost, quality, or stakeholder satisfaction). These approaches dominate research in the social sciences, and have particular strengths in comparing entities or relationships among variables. Process approaches, by contrast, assume that both the entities and their attributes are evolving. By directly examining the complex relationships between events and outcomes [13], process approaches explicitly assume that entities are linked.

Developing theoretical understanding from the analysis required a combined narrative and visual mapping strategy [14]. The interview data were coded to identify the various categories of value, which were then compared between and across interviews to identify overarching themes. The team then used themes to create narratives or descriptions of value characteristics. These narratives were analysed to create visual maps [15] in the form of tables and diagrams to identify value conceptualisations.

The research approach combined insights gained from over twenty personal in-depth interviews with professionals working on radio astronomy projects and broader impacts research in the United States, Puerto Rico, United Kingdom, Ghana, South Africa, Australia, and Chile. The interviewees were purposively sampled for their specific responsibilities and expertise in RA projects. The duration of their involvement ranged from four years to several decades. In this research, their identities were kept anonymous, and interviewees are here referred to as "I", followed by their interview number. Interviews were transcribed entirely and coded at the sentence level to identify value conceptualisations and associations among them. This approach provided a diversity of responses that supported the development of an understanding of the activities and associations of value conceptualisations, along with the context in which they were embedded [16].

V. RESULTS

Interviews were conducted with staff at RA observatories in various phases of planning, construction, and operations. For established facilities, some of the identified benefits were already realised. Others were just beginning to exhibit value at the early stage of operations, and still others were planned but not yet realised. Even so, societal value from RA observatories could readily be grouped into several categories, with many similarities.

A. Infrastructure improvements

Modern radio astronomy sites typically include an antenna or group of antennas, and buildings to support the antennas and data, such as offices, data centre, visitor centre, maintenance warehouse, temporary accommodation, and more. Of those observatories participating in this research, sites varied in size, ranging from five acres to 3,500 acres to distribution across entire continents. Some areas included a buffer zone for protection from radio signals. and were often fenced. The radio astronomy observatories in this study were constructed in remote locations which required a considerable number of infrastructure improvements needed at the new facilities sites and also to link the site to the nearest town(s).

These projects catalysed institutional changes to physical and social infrastructure [17] within the surrounding towns. In terms of physical infrastructure, these projects built new roads and improved existing ones, and installed new power and sewer lines, signage, railways, fencing, and high-speed communication fibre, benefiting both the observatory and the local community. These benefits could be conceptualised using a value-for-money (VFM) approach. Long-and short-term visitors and staff necessitated new short- and long-term housing and also influenced physical improvements to schools, libraries, hospitals and urgent care facilities, community centres and other buildings, and transportation. These improvements could be quantified using construction cost and other economic indices.

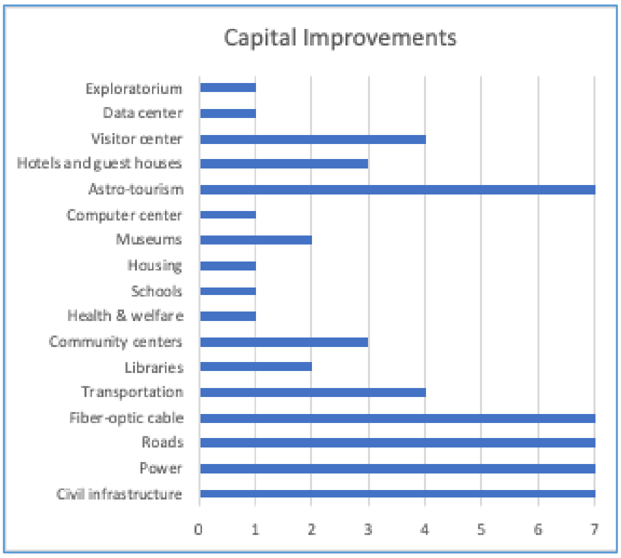

Fig. 1. Infrastructure improvements

On the institutional side, the radio astronomy projects created or expanded support structures that were linked to not only physical infrastructure (such as road and power line maintenance) but also to a broad provision of public goods such as policing, fire and emergency services, food security, and telemedicine, augmenting the standard-of-service provided in these domains. There was also an emergent social infrastructure, linked to opportunities for interaction between the research community and local residents, as well as prospects for collaboration among public and private entities that likely would not have existed without the physical investment.

B. Job and business creation

This perceived value dimension was linked to infrastructure provision, as well as to social and economic developments generally as a result of the overall radio astronomy capital investment. Thousands of jobs have been created through radio astronomy observatories. Some job creation was immediate during the period of construction and available jobs, in turn, created vocational trade-focused training opportunities in carpentry, plumbing, bricklaying, welding, electrical and mechanical. The outcome of this process was the development of a skilled local workforce that then spawned small-business creation and employment in the region. Once regular facilities and research operations began, additional jobs were created, and local workforce and businesses developed, to support on-site operational activity and local growth in the aforementioned vocations plus such necessities as parts and materials supply, materials recycling, food supply, information technology, instrumentation, mechanics, maintenance, tooling/machining, housekeeping, management, and administration. In several instances, the scale of training was such that some surrounding towns became known as centres of excellence for electrical and mechanical trades, and a police academy. Other businesses were also created to support business activity, such as graphic design and conference management; some of these businesses have grown to support more than just the local area. Population growth in towns near radio astronomy observatories resulted in additional job creation and economic growth.

Radio astronomy observatories have a tendency to become beloved iconic structures. Over time, direct and indirect human capital development and job creation occurred, linked to spin-off industries created as a result of the radio astronomy influx but also well suited to the remote nature of the facilities. Astrotourism, ecotourism, and leisure are three such industries, with local growth including but not limited to artisanal crafts, art, hotels, guest houses, restaurants, tour guides, museums, cultural centres, sports/adventure outposts, wild game parks, glamping, and retail. Astrotourism alone has created thousands of jobs, globally. These businesses, and those mentioned previously, provided services not just to the original local community but also to the increasingly sophisticated community that emerged around the radio astronomy facility comprised of imported scientists and support staff (and their families), visitors, and tourists. To support entrepreneurship and business creation, courses in business management, computers, and finance were provided at local schools, libraries, and community centres, and computer centres (cyber labs) were created for public use. Together, these contributed to economic growth and local spending, as shown below (Fig. 2), and could be quantified as the number of jobs and businesses created, and financial value of goods and services imported and exported.

C. *Environmental impact*

The telescopes often had a direct impact on the rural environment at and surrounding the installation of physical infrastructure. Since these installations required limited electromagnetic interference, the area around radio astronomy antennas required a relatively pristine environmental state. To protect the environment from human intrusion, some sites installed fencing while others had the area designated as a nature reserve (one particular nature reserve was 130,000 hectares in size). Increasingly large radio astronomy sites enabled university research and land management practices that were beneficial for the environment, such as photovoltaic power, the removal of invasive trees, wildlife introduction, materials recycling and reuse, and bio-control methods such as the rearing of beetles. Radio astronomy technology itself contributed to positive environmental impact; in several instances, satellite / GPS data gathered as part of earth-based research enabled local officers to identify illegal land use, mining, and poachers who targeted rare or valuable animals. In this way, species and natural resources were protected, increasing longevity and ensuring biodiversity.

D. *Research opportunities*

In addition to the formal physical and social infrastructure created by radio astronomy observatories, over the long-term a research and science infrastructure developed that enabled intellectual and scientific contributions, as shown below (Fig. 3). Directly, the radio astronomy facilities housed and built skills in astronomy and astrophysics, mechanical engineering, software development, and systems engineering, and supported citizen science. Complementary research areas also developed, with increasing sophistication over time, specialised to the location. These included engineering skills not just linked to the telescope itself but to the data science and machine learning skills required to manage and interpret the considerable data generated by the radio telescopes. Similarly, technology and science hubs developed in other specialty areas (in addition to the aforementioned environmental research); other fields were supported such as interpreting geographical data (oceanographic and atmospheric data, seismic information, and land surveying) to further research in fishing, agriculture, and climate change. High altitude locations enabled medical research. With the facilities built on rural, often indigenous land, research hubs also developed to specifically support the study of heritage, including indigenous astronomy, paleontology, archaeology, and cultural research.

E. *Education*

Education provided an example of the evolving nature of value derived from radio astronomy projects. Initial impacts were immediately visible within the area of science (STEM) education, at the K-12 level and in community programming and adult learning, part of the radio astronomy projects' strategic plan for education outreach. Over time, local high school students proceeded to university and, as the number of local science graduates increased, these individuals went on to further study at the masters and doctoral levels. In several instances, the surge in graduate students exceeded the number of available PhD supervisors and teaching assistants. Some of the university graduates ultimately returned home and became local educators in their own right, creating a decades-long cycle of STEM education in the local community. This could be measured in terms of number of publications, targeted interactions, students participating and graduated, grants

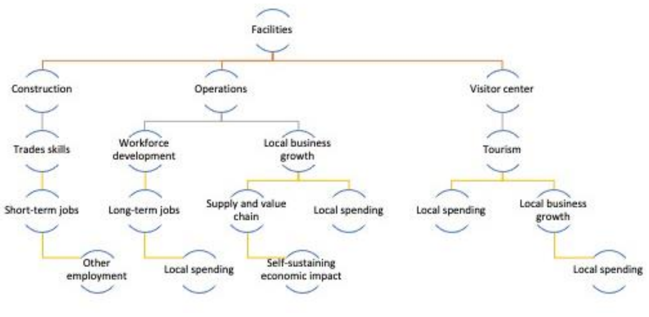

Fig. 2. Job creation at radio astronomy observatories

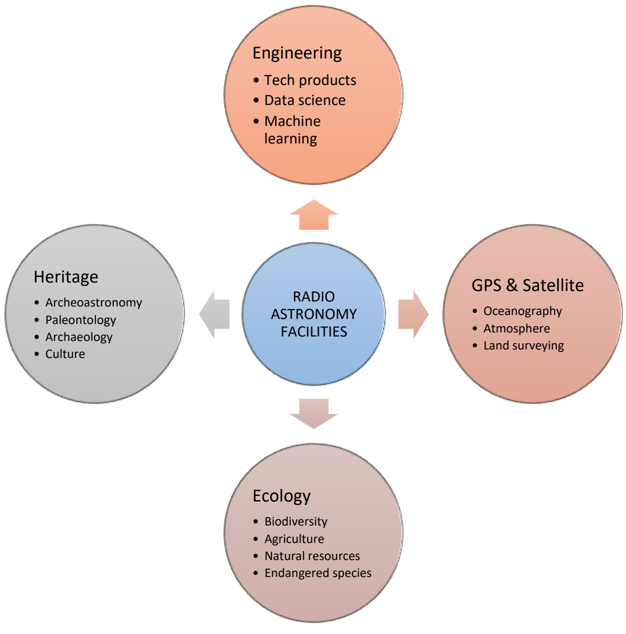

Fig. 3. Research opportunities created by radio astronomy observatories

given, public attendance, teachers funded, students funded for university, and test score improvements. Globally, thousands more students are currently progressing through this global K-12 to higher education to career pipeline.

The increasing volume and sophistication of human capital resulted in the further growth of science-based businesses and an increasing number of highly educated individuals, as shown below (Fig. 4), sometimes to the point where they exceeded the local absorptive capacity of jobs within the field of education. This then led to partnerships with industry, forging local relationships and creating local, national, and international internships, jobs, and career paths in such fields as big data, aeronautics, deep space, telecommunications, power, renewable energy, infrastructure, and medical imaging.

F. Emergency response

Staff at radio astronomy facilities were typically embedded in the local community and behaved as part of that community, often highly valued. During times of strife, their contributions did not go unnoticed, with science, project management, and engineering expertise transferable to solving immediate problems. During 2020's COVID-19 pandemic, contributions from the radio astronomy community at the local and national level included the development of contact tracing apps, biological data analytics, telemedicine, and the production of ventilators.

VI. Discussion

Radio astronomy observatories are an unusual combination of capital-, land-, and knowledge-intensive projects. Therefore, they generate a wide variety of value types, both directly and indirectly, and the interaction of these value components creates ever more complex evolving outcomes that exhibit tensions and paradoxes. While the value for money (VFM) conceptualisation can easily measure causality or benefits, other value types are more complex and direct measurement is difficult. Indeed, the cause-effect mechanism is sometimes not direct, with many variables, and thus can be difficult to measure. Perceived value dimensions, such as changes in the local labour market, advancing the field of science, and economic impacts, are not necessarily reducible to parts, making causation difficult to validate.

There is limited training in the area of impact assessment where the focus was on delivering VFM dimensions. Since these installations are in place for long time, a number of emergent impacts have occurred which were not necessarily predictable from the conceptualisation of the project. These are difficult to measure by their very nature, and since there was a lack of longitudinal studies it is fairly difficult to formally quantify these impacts at this time. The adoption of a narrative approach, based on the analysis of interviews in this study, suggests that value emergence follows a particular pattern, from the immediate value of rural services and infrastructure installed during facilities construction, to immediate to long-term value achieved during facilities operations, to value realised within the community in the future (longitudinal, measured in decades), as shown below (Fig. 5).

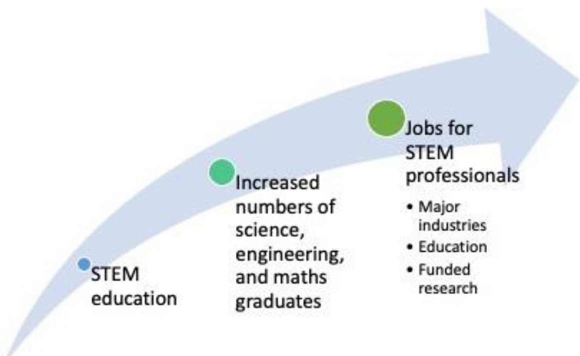

Fig. 4. STEM impact by radio astronomy observatories

In addition to identification, the societal expectations of value can be expected to change over time as the observatory and the host community co-evolve. For example, the initial installation attracted radio astronomy researchers, staff, and tourists. Over time, some communities developed additional attractions based on the preservation of the biosphere, building a more complex astrotourism product that incorporates such elements as technology, agriculture, sports, and ecotourism.

A. Tensions and Paradoxes: STEM

As discussed earlier in more detail, while significant value was provided through education, over the course of a decade or more the local education market could not support all the new university graduates, and industry relationships were not yet created that could absorb these individuals at the rate at which they graduated. This improved over time, as relationships with industry were created and strengthened.

Since these facilities operate in a number of institutional contexts, there were domains in which science may not necessarily have been seen as a public good, but as a politicised tool to achieve particular economic and social outcomes. Various funding institutions supported the agenda of providing support to marginalised groups in the community, specifically in Africa with support of black economic empowerment initiatives which provided training and preferential business access to particular communities. Again, given the multilevel conceptualisation of value and conflict among stakeholders, these preferential schemes may have created some tension.

B. Tensions and Paradoxes: Value Destruction and Re-creation

Sometimes, immediate impact was not positive; construction of the facilities came with consequences. Conflict over land acquisition was not uncommon, as were

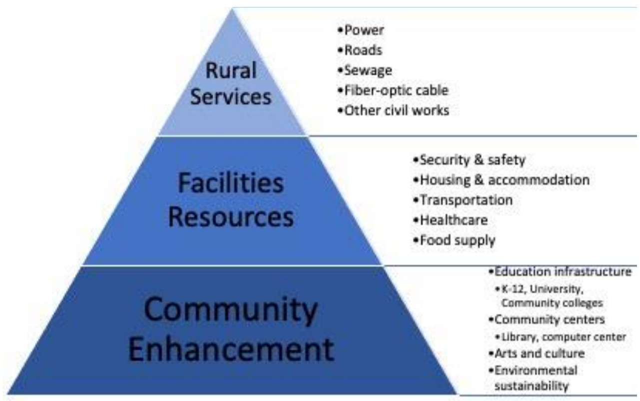

Fig. 5. Categories of infrastructure impacted by radio astronomy observatories

concerns about historic and culturally significant sites. In one particular instance, the radio quiet zone required for radio astronomy necessitated reducing the local community's wireless (cellphone, WiFi, and radio) signal pollution; voice and data connectivity was restored by installing an area-wide low frequency communications network. Ultimately, this resulted in reliable communication technology provided to traditionally rural and underserved communities and improved emergency-service communications. In another instance, protection of the antennas required limiting sheep grazing in the area, affecting the agricultural community. Although value destruction did occur in these instances and more, it was often offset by an order of magnitude in value created in the same category. For example, where sheep grazing was restricted and local farm jobs lost, local businesses were created to provide centralised feed lots, with training provided in agriculture, trades, and business management, and jobs, businesses, and career paths created.

VII. Conclusion and Next Steps

Radio astronomy science provides a portfolio of societal value to the local community: commercial products, scientific products, and national image. One challenge in conceptualisation and evaluating societal value of facilities construction and operations is the longitudinal nature of value. Impacts are both short- and long-term, and the time frame for value capture often does not occur immediately. Indeed, measurable and demonstratable value might not appear for several years, or even decades [18]. While radio astronomy antennas are often designed for a 25-year useful life, they tend to well exceed that timeframe, often remaining useable 35 to 55 years after construction. This means organisations that wish to measure the value of long-term facilities, and the changing dynamics of that value, need to plan to conduct periodic retrospective assessments and require funding for multi-decade studies. This process could be supported by computational text analysis of project documentation to enable the identification of insights from stakeholder discussions.

Perceived value of capital projects can vary depending on the perspective of the stakeholder conducting the evaluation. A narrative perspective extends this further as multiple stakeholders both co-create and co-assess value. The value types identified here for radio astronomy observatories should be studied for other major capital project types. There is a need to define value criteria to be measured, specifically for construction projects, creating a uniform consistent global language for comparison across contexts; practices in some countries may be advanced, whereas other countries are at differing levels of practice for societal value assessment. These new approaches need to explicitly capture tensions and paradoxes which may be missed in approaches that seek to simply measure associations among variables. Future strategies should recognise value destruction, as it enables stakeholders to develop trust by presenting a complete picture of costs and benefits.

Further, examination of RA-specific dimensions (such as Astrotourism) may require additional study as a distinct value type. In addition to individual regional benefits, Astrotourism (like other tourism experiences) is a networked phenomenon incorporating multiple locations. Societal value assessment approaches will need to explicitly recognise this value network and encourage the adoption of communication, knowledge exchange, and value co-creation strategies that integrate the input of multiple sites.

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