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Original research article

Among people and artifacts: Actor-Network Theory and the adoption of solar ice machines in the Brazilian Amazon

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ABSTRACT

Using Actor-Network Theory, this article analyzes the process by which a solar-powered food storage technology was implemented in an isolated floodplain community in the Brazilian Amazon (Amazonas state, Brazil), as part of the *Solar Ice Project* headed by the Mamirauá Institute for Sustainable Development. Our study describes the sociotechnical network that entangles the human and nonhuman actors involved in this initiative and reflects on the complexity of the implementation process. Our discussion seeks to identify elements not generally considered in analyses of Social Technologies used in local development initiatives based on technological innovations. Data on the engineering, use, operation, and adaptation of Solar Ice Machines highlight the need to promote fluid technologies capable of adapting to the different contexts within which they are inserted.

1. Introduction

Non-governmental organizations, foundations, and emerging country governments increasingly use technologies to help the world's most vulnerable peoples meet their basic needs [1,2]. This is especially true in the context of rural and isolated communities. At the same time, professionals dedicated to promoting marginalized peoples' access to basic services have sought alternatives when referring to such technological innovations [3] and have alluded to initiatives that promote socio-economic development guided by the principle of social inclusion.

Beginning in the late 1990's, Brazil adopted the concept of Social Technology [4,5]. Social Technology builds on the notion of Appropriate Technology [6] and has been especially integrated into public institutions and funding agencies. This approach seeks social change through the interaction of scientific and local knowledge and consists of material innovations (machines and artifacts or "hard technology") as well as procedural innovations (methods and practices or "soft technology"). Social Technologies are produced through participatory processes [7] that facilitate the creation of appropriate interventions, i.e. interventions adjusted to the local context, and for these interventions to be appropriated by local actors [8].

The process of engineering, implementing, and sustaining such technologies, which are deemed both inclusive and efficient, is wrought with challenges [3,9–11,2]. Obstacles largely arise due to the disconnect between the idealized technology and its real-life performance. Experimental, pilot, and demonstration projects provide opportunities to verify technologies under conditions that are more realistic than research laboratories [12]. Technological studies, however, rarely pay attention to the artifact and user interface [11], to the technological innovations on a micro-scale.

Sociotechnical approaches in Science, Technology, and Society

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studies (STS) inspire concepts such as Social Technology [13] and stand out as useful frameworks with which to analyze these experiences [14]. Actor-Network Theory (ANT), one such approach, offers conceptual tools that can shed light on the complex network of interacting actors who together define the success or failure of a technological intervention.

Considering ANT's potential to address this gap in Social Technology studies, we use this theory to analyze the implementation of a food storage technology, a central part of the Solar Ice Project (*Projeto Gelo Solar*) carried out in Amazonas state, Brazil.

Access to electricity in the Central Amazonian floodplain communities has long been precarious. Given the region's remoteness and low demographic density, aspects which are not considered when public policies are created, establishing and maintaining electrical infrastructure is a challenge [15,16]. Since many isolated communities are not connected to an energy grid, they also lack the means to power freezers and refrigerators. Instead, residents use salt to preserve fish and meat [17]. They may also limit agricultural activities and the collection of forest products to prevent food from spoiling and minimize production waste.

In addition to salt, some have limited access to refrigerators, up to four hours daily, when gasoline or diesel fuel generators provide energy [18]. Not all communities, however, have access to this technology, and it is environmentally unsustainable and economically inefficient [19]. Families also purchase ice, buying locally from middlemen or traveling to nearby cities to buy directly from small factories [20]. Access depends on the distance between the community and the nearest store. Trips can last hours to days and take place via motorized canoes (*canoa com motor rabeta*), which are the most common fluvial transport in the region [21]. As it is not always available, purchased ice does not meet local ice demand.

With resources obtained from the Google Social Impact Challenge | Brazil 2014, the Solar Ice Project implemented a technology that facilitates food storage in isolated communities (Fig. 1). The technology enables ice production using solar photovoltaic energy. Since this technology does not require batteries, it minimizes environmental and economic externalities [22,23]. Project developers hoped that the food storage technology would strengthen local production systems, and in this way, improve the quality of life for those living in remote areas and not connected to the national electric grid.

The Solar Ice Project was developed by an interdisciplinary team of researchers and practitioners from the Mamirauá Institute for Sustainable Development (*Instituto de Desenvolvimento Sustentável Mamirauá* – IDSM), the Solar Photovoltaic Systems Laboratory of the Institute for Energy and Environment of the University of São Paulo (*Laboratório de Sistemas Fotovoltaicos do Instituto de Energia e Ambiente da Universidade de São Paulo* – LSF-USP), and the engineering company USINAZUL. Formed around the year 2000, the interdisciplinary team has since worked together on projects related to the development and installment of solar powered technologies in isolated communities in the Brazilian Amazon.

The Solar Ice Project was undertaken in collaboration with the floodplain community of Vila Nova do Amanã, located in the Amanã Sustainable Development Reserve (RDSA) in the Brazilian Amazon (Fig. 2). Beginning in the early 1990's, when social mobilization to create the reserve began, the Mamirauá Institute has had an ongoing relationship with the community. After the Amanã Reserve was created, Vila Nova do Amanã was involved in different sustainable development projects, including the testing of in situ photovoltaic energy technology systems. These initiatives began in 2010 and included a water pumping system and a public lighting model adapted to conditions of the Central Amazonian floodplains.

Fig. 3 illustrates the phases of the Solar Ice Project and the associated research described in this article. Research results were incorporated into project management and, a year after implementation, served as data points with which to evaluate the technology. Integrating research and extension allowed the team to understand the implementation process and provide feedback for further technological development.

This study investigates the micro-scale relationships between the actors involved in the implementation of a Social Technology and takes into account both the human and nonhuman actors that interact in this sociotechnical network. Research is based on the understanding that the work involved in creating Social Technologies is not limited to the laboratory but rather continues when equipment is installed and when technological support is provided. Understanding the relationships woven in the implementation phase is essential to achieving the sustainability of such initiatives, and insights from the case presented here may help promote a better use of the material and human resources invested in similar enterprises worldwide.

Following this introduction, we describe the study's methods; then we outline the theoretical contributions of ANT to analyses of Social Technologies. Next, we present the research results and discuss them in five sections. The first discussion section deals with the actor-network character of the technology and identifies the numerous agents that entangle with the artifact's idealization and materialization. Subsequent sections discuss how community members use ice, the collective operation of the technology, and adaptations made by the technical team based on the first-year of experience of the project.

2. Methods

This study analyzed the implementation phase of the Solar Ice Project, specifically focusing on the first year of the operation of three solar powered ice machines (SIM or SIMs, in plural). In August 2015, the machines were installed in the community of Vila Nova do Amanã (Maraã county, Amazonas state). To reflect on the process of implementing Social Technologies and the challenges that may arise, our research design considered the network of actors entangled in the conception, material production, implementation and operation of these machines. Field research was conducted between August 2015 and September 2016. Table 1 shows the four different research methods used during this study.

Fieldwork was undertaken by the first author. At the time of the SIM installment, a community meeting was held. During this community meeting, the first author met, for the first time, with the community residents. After this initial meeting, the researcher made visits to the eight households that compose the community (a total of 57 residents) to explain research objectives and the ethical principles of the process – for instance, that participation was voluntary, and participants could withdraw at any time. All families agreed to participate and signed consent forms.

After this initial contact, household interviews were conducted to register how residents use ice and their perceptions of machine performance, particularly as related to ice production and distribution among households. The researcher also engaged in participant observation. During participant observation visits, families volunteered to host the first author who stayed for a period of two to eight days. During these visits, the researcher observed the daily operation of the SIMs taking particular note of both their productivity and users' engagement with the technology.

The researcher also participated in host families' daily routines, engaging in different activities, such as domestic chores. The researcher conversed informally with all community members, observed training workshops conducted by the IDSM team, and attended community events where ice was used.

Observations during home stays were recorded in field notebooks. These notes included descriptions of actors and their relations to one another. Recording such observations was an effort to describe, as Latour [24] suggests, all actors as networks – i.e. that they all have agency in dynamic relations, which are traceable, but not tangible.

To document SIM operation, the researcher attended daily

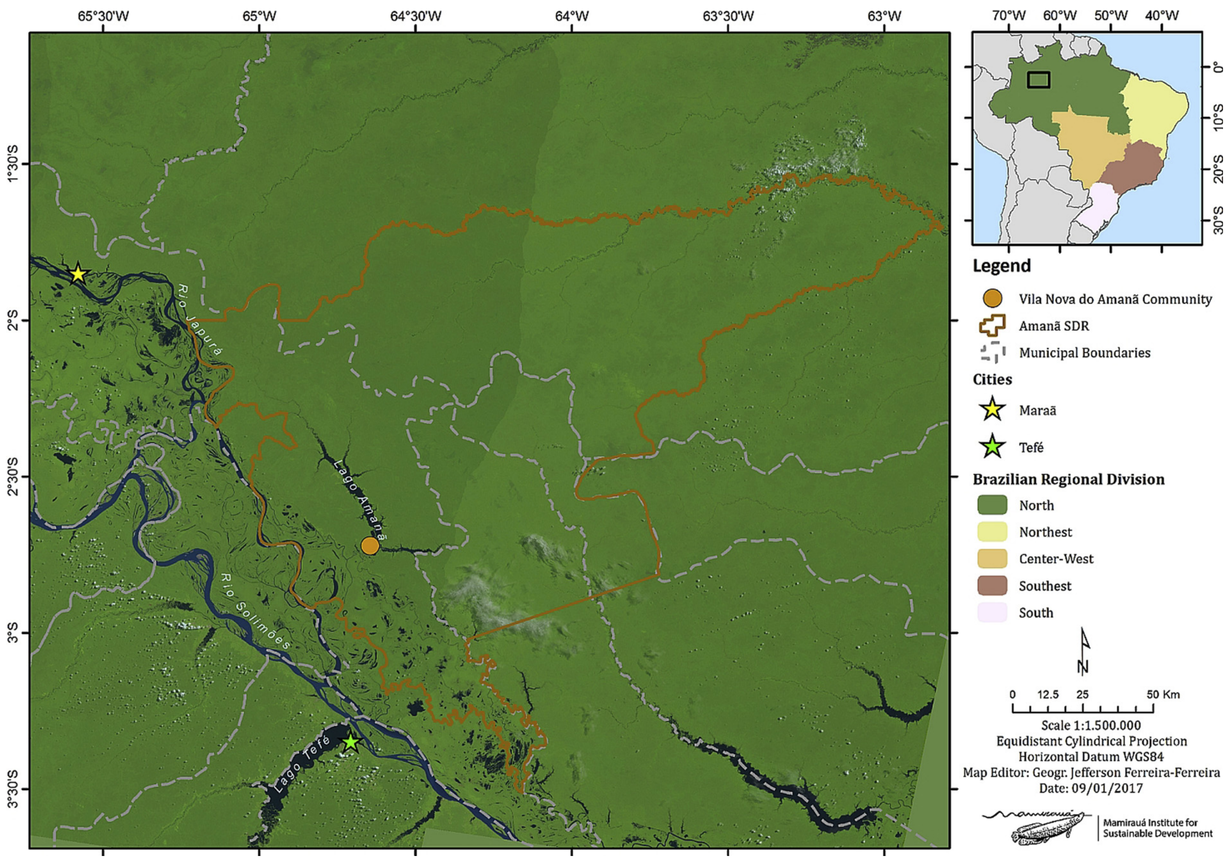

Fig. 1. A woman filling recipients of a solar ice machine with water. On the paperboard in the right of the photo, is a list of the teams who operate the machine on a weekly basis. Teams are composed of and organized by community members.

Fig. 2. Study site map showing location of the Vila Nova do Amanã community within Brazil and Amazonia.

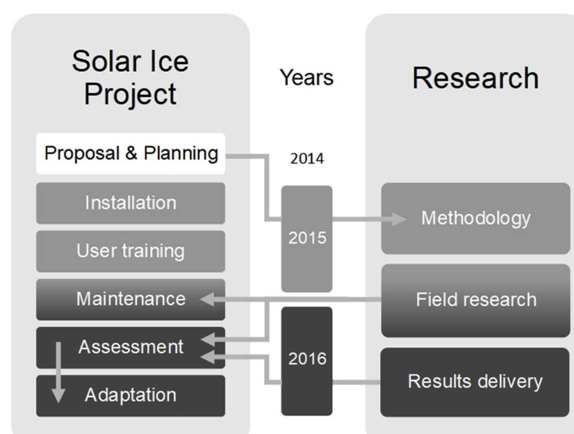

Fig. 3. Phases of the Solar Ice Project and associated research.

gatherings where ice was distributed. The researcher measured machines' productivity (kg of ice produced) and recorded days when machines did not produce ice and the reasons for lack of production.

To better understand these operational problems and document residents' reactions to them, the researcher also analyzed a technical report developed by the IDSM team. The IDSM report documents maintenance activities conducted during the first year of machines' operation.

3. Theory

Social Technology initiatives [5,6], just as those of Appropriate Technology [4], are concerned with improving the quality of life of local peoples and promoting environmental sustainability. In addition, Social Technology initiatives reflect upon the production of technical-scientific knowledge and its role in society. To do so, these initiatives incorporate contributions from sociotechnical approaches in STS [3,13,14] and pay special attentions to criticisms of the neutrality and technical-scientific determinism embodied in conventional technologies.

Meanwhile, Actor-Network Theory (ANT), a sociotechnical approach in STS, allows for the analysis of actors' relations at the micro-

Table 1
Research methods employed in the current study of Solar powered Ice Machines implementation.

	Method	Source	Frequency (period)	Data
1	Household interviews	Heads of household	10 visits over 13 months (August 2015 to August 2016)	Uses of ice produced by the SIMs Users' evaluations of machine operation
2	Participant Observation	SIMs and their users	55 days total in 11 visits (August 2015 to September 2016)	Ice use and its distribution Collective organization for SIM operation
3	Documentation of SIM operation		22 non-consecutive days over 10 months (October 2015 to August 2016)	Kg of ice produced Reasons for lack of ice production
4	Document review	IDSM technical report	Document based on 11 months of work (October 2015 to August 2016)	Technical explanations for machine malfunctions Actions taken to address lack of ice production

scale of project implementation. Actor-Network Theory assumes, as one of its premises, that society cannot exist without the technology upon which it is based [25,26]. ANT, therefore, rejects the notion of the social purity of society, understanding that materials – such as artifacts that sustain our daily lives – play a fundamental role in the structure and function of social networks [27]. Artifacts may play a political [28] or moral [9] role to achieve more than a *stricto sensu* technological performance [29].

In this way, instead of social networks, it is more adequate to speak of sociotechnical networks, designating a set of interactions in the world, where agency is not only a human attribute, but also extended to collectives, institutions, and even artifacts [28]. In the field of Social Technology, recognizing the existence of nonhuman actors [30] allows us to understand technological artifacts not simply as inert material that enable human activity, but also as actors with their own agency capable of influencing the complex processes that drive the sustainability of technological interventions.

If we approach technological development in a linear fashion, technological artifacts are viewed as predictable and unchanging units [31]. Described as products disconnected from social relations, technologies are turned into black boxes [25] – entities whose construction processes need no explanation and are only known for their utilities. As with other actors in a sociotechnical network, however, technological artifacts not only integrate into networks but also are themselves a network woven by multiple influences.

This assertion builds on arguments of the social construction of technology [32,33], which argue that technological artifacts, as well as scientific facts, are not generated through neutral and inexorable processes but are the result of a combination of interests and conditions. They are processes that give way to new technologies – from their conception, manufacture, and subsequent operation by users – and involve a series of decisions made by relevant social groups. Hence, innovation is not solely based on technical elements.

Technologies are thus actors-networks, simultaneously producers and products of social relations [27]. This implies that technologies can deviate from the operating scripts that developers seek to impose [9]. Technologies not only respond to the rational of initial planning, but also are influenced by interactions with other actors-networks, humans, and nonhumans. The mutual production of actors is continuous and articulates in a network that is more like a verb than a noun [28]–networks are not given structures in the order of things, but rather are precarious processes in constant transformation [34].

Some of the concepts presented here are the basis for theoretical discussions on Social Technology [3,13]. This framework, however, is rarely applied to analyze the relationships between actors during technological implementation, yet it is these relationships, which may determine the overall success of such interventions. With this in mind, we use an ANT perspective to shed light on the challenges of engineering, implementing, and sustaining of technologies geared toward local development.

4. Results and discussion

4.1. Engineering of the solar ice machine artifact

The Solar Ice Machine model emerged out of a post-doctoral project in 2009 in the LSF-USP, and was financed by FAPESP, a Brazilian funding agency supporting scientific research and technological development. An ice machine using alternating current, already on the market, was the inspiration for the SIM design. This model was adapted through the placement of an electrical control board to receive energy generated from an arrangement of 20 photovoltaic modules of 55 Wp each [23]. The selected equipment had the smallest motor-compressor set on the market at the time and, thus, was compatible with the financial resources available for the study – a choice that then guided the technological development process.

This technology was originally developed in university laboratories in Southeast Brazil. Yet, to increase the scale of its impact, it needed to be field-tested in other regions of the country, in places that met the minimum solar radiation requirements. Afterward, it could be further adapted to accommodate the climatic and socioeconomic particularities of the regions where it would be installed. The technology was brought to new regions through partnerships with other universities, such as the Federal University of Pará (UFPA) and the Federal University of Santa Catarina (UFSC). Collaboration between researchers of these universities resulted in the installation of five SIMs in the Northern and Southern regions of Brazil (Fig. 2).

In the interest of testing the SIM technology in isolated Amazonian communities, a network of actors mobilized around a call for projects based on technologies for social change, the Google Social Impact Challenge | Brazil 2014. The Solar Ice Project was submitted and became one of the 10 finalists that received financial and technical support, which in this case enabled ongoing technological development and installment of SIMs in a floodplain community in Amazonas state.

The relationships that allowed the Solar Ice Project to unfold demonstrate the actor-network character of this technology. The machine resulted from dynamic articulations and contingencies, such as securing financing for research and implementation. The technology, however, was not simply born through local resource and knowledge exchanges between the community, developers, consultants, implementing agents, and funders. Its materiality also results from a much larger network of interactions since parts of the machine were produced in distinct locations. For instance, a refrigeration company from Southern Brazil produced the cooling chamber and the motor-compressor set. The electric control board was designed by the LSF-USP team but mounted by specialists in solar energy technologies who also supplied the photovoltaic modules. In this way, the technological artifact is part of an extensive chain of interactions between actors, including humans and nonhumans [25,26]. When communication or logistic complications arise, misalignments in these chains could potentially hinder the technological performance.

Moreover, in the case of Solar Ice Machines it is impossible to identify a single developer. On the contrary, the technology is the result of a collaborative process that involved different members of the LSF-

USP team (researchers, technicians, and students) over several years. The development process began with a post-doctoral research project, which was expanded upon with further testing at the university. As further adjustments were made in situ, the process also extended to the implementation phase. This occurred particularly when the machine did not perform according to expectations, demanding additional interventions to re-establish its operation. First, the actors designed, constructed and tested the idealized technology. Then, they put the technology into operation, further testing and adapting it. As described in the case of the Zimbabwe Bush Pump [35], a single leader did not set the network into action. Instead, multiple human actors produced (and produce) the SIM.

In their consideration of the Zimbabwe Bush Pump as a nonhuman actor-network, Marianne de Laet and Annemarie Mol [36] deconstruct the human heroism that permeates the notion of a lead designer who guides all actions. Instead, they illustrate the distribution of power across actors within the network. From this perspective, the success of a technology depends upon a humble developer who allows the technology to follow its own course through the networks through which it circulates through a design process that creates technological openness to adaptation. We can refer to this technological openness as *fluidity*. Hence, a firm technology, one that is rigorously bounded and imposes itself, can be more fragile than those that are adaptive, flexible, and responsive – or rather, a technology that is entangled in the social realm, capable of dealing with the unpredictability of the reality in which it is inserted.

The actor-network character of the SIMs is also revealed by its inscriptions [2], also referred to as scripts [12]. An inscription is a way to translate an idea, interest, or worldview into a material form. It is a technological choice based on the inventor's assumptions about the social, economic, political, and/or physical universe within which the technology comes to be inserted. These assumptions can act as limiting forces or influence actors' behaviors. This means that they may shape the technology's materiality, defining components, measures, or mobility. But they may also imply a mode of societal organization around the artifact, regarding forms of use (individual or collective, time-bound or continuous) or the knowledge required for user operation, with a tacit or explicit intention of producing certain user behavior [36,12]. Assumptions regarding the place where technologies are implemented, as well as regarding users' values and needs, can often represent reasonable design criterion. Yet, if they are inaccurate, technologies may be doomed to failure.

The case of the transfer of lighting kits from France to African countries is a good example of this relationship [9]. On the one hand, kit developers assumed that people wanted lights in their homes and did not consider lighting demands for collective spaces. The assumption of household-level demand was inscribed in the immobility of kit components. Developers also chose nonstandard plugs and watertight batteries, not available through local suppliers. This curtailed users' attempts to fix faulty kits. With these inscriptions, developers sought to ensure that maintenance problems would not limit the life of the systems, but, ultimately, they restricted technological appropriation by users, who then gave up using the kits because they did not meet their needs.

In the case of the SIMs, developers' assumptions were related to: the availability of solar radiation in Amazonia, floodplain communities demand for ice, and the communities' organizational capacity. Assumptions regarding solar radiation in Amazonia directly materialized in the technology, determining the number and potency of solar modules, which in turn, determined the machines' freezing capacity. Developers also assumed that locally-produced ice was needed to support rural production activities – giving less priority to other potential uses of ice. Furthermore, the assumed demand was quantified, determining the number of households that would benefit from each machine.

The assumption regarding the organizational capacity of local communities was expressed by the absence of electrochemical accumulators, such as automotive batteries, commonly used to store solar energy in isolated systems. Compared to the rest of the components, these batteries have a shorter life span and imply higher replacement costs. The absence of batteries from the design was justified on the grounds of sustainability, including both environmental (waste disposal) and economic (high replacement costs) concerns. But it was also based on the presumption that the communities do not have the organizational capacity to meet the financial and logistical demands required to replace batteries – an assumption based on LSF-USP's previous experience with solar electrification projects in isolated communities throughout Brazil. Opting to mold the artifact to this presumed scenario, technology operation was restricted to daytime hours, limiting ice production.

In the case of the Solar Ice Project, identified inscriptions were not obstacles to users' appropriation of the technology. Nevertheless, they illustrate how developers' assumptions materialize within the technology, ultimately determining the machines' productive capacity and affecting project planning and sizing.

The inscriptions described here illustrate how the technology is a product of social relations. This also becomes evident when we observe how the technology operates in daily life. The following section discusses these relationships through an analysis of the SIM production trends.

4.2. Operation as a network

Considering the nominal capacity of ice production at 90 kg/day when operating 24 h/day (when connected to a continuous source of energy), in minimal conditions of solar radiation (5.5 kW h/m^2), the average production per SIM was expected to be around 27 kg/day [23]. However, total production was registered to be equivalent to 35% of the potential of the three machines. In addition, when production was being registered, solar ice machines were reported active only 40% of the time – with no record of the three machines all operating at the same time.

Lack of ice production was mostly attributed to technical problems (in 50% of the reported cases). Some of the registered problems include: gas leaks, errors in the frequency inverter, and burnout of the DC power source. There were also user-related issues (9%) including: users not turning on the machines, not supplying them with water, or not extracting ice from recipients.

Many actors come together in SIM operation, as illustrated in the heterogeneous network woven for their maintenance. The IDSM team resolved the aforementioned technical problems with remote support from LSF-USP and USINAZUL teams – interactions that depended on internet connections, trips by airplane, and the availability of team members. In addition, to undertake maintenance activities, the IDSM team purchased parts from suppliers in Amazonas state or from other regions in Brazil. They also hired local refrigeration and electronics service personnel.

As this case illustrates, technological operation not only depends on human actors, physically close or distant to the machines (from developers to service personnel), but also on nonhumans, which act as intermediaries (such as computers, internet, airplanes, and boats) or as central actors (such as machine parts or refrigeration gas). This scenario contrasts with the typical heroism of modernity, which tends to highlight a single human inventor and suppress other actors in the sociotechnical network [28,36].

Another characteristic of sociotechnical networks depicted in technology operation is its precariousness [28,35]; in other words, the instability derived from its constant transformation. This characteristic is illustrated by the response time needed to provide solutions to the aforementioned technical problems. Response time depended on the logistics of machine access (necessarily fluvial) tempered with the team's other work commitments, delivery time of parts coming from outside the county or state, the availability and specialization of local service personnel, and opportunities to communicate with the LSF-USP and USINAZUL teams. These factors prohibited all three SIMs from functioning for five months during the implementation phase. Hence, the multiple actors that needed to come together to make the technology work compose a complex network prone to misalignment. Yet, actors-networks do not always need a stable identity to preserve their agency; amid bursts and unexpected responses, the technology continues to have effects. The following section will discuss these effects by describing how community residents used ice locally.

4.3. Potential and real uses

Machine productivity, when reduced to kilograms of ice fabricated per day, may appear as an exclusively technical and precise data point. Productivity data is, however, much more complex than it appears. After all, how did the SIMs come to produce the registered amounts of ice per day? What was possible to do with this amount of ice? These questions resonate with the understanding of productivity as part of a sociotechnical network, both a product and a producer of social relations.

Developers involved in the Solar Ice Project were interested in improving food conservation, particularly of products designated for commercial sale, possibly increasing earnings from fish and fruit pulp sales. Our data, however, pointed toward different trends. The eight families who received ice in the first year of the project said they used ice to cool drinking water (98%) and to preserve fish (45%), other meats (7%) and *açaí* (5%) for their own consumption (n = 64). In addition to these domestic uses, ice was also used to chill drinking water for collective consumption and to cool beverages sold in the community.

As predicted, families earned extra income as a result of the machines' implementation; however, earnings came from selling ice to residents of neighboring communities. As documented by Akrich, where residents used cotton crop residue as fuel in Nicaragua [37], visitors' spontaneous demand stimulated the sale of part of the production. In the case of the Solar Ice Project, attending to a neighbor's demand is both an interest in the immediate financial return and a characteristic of the reciprocity typical of Amazonian peasant societies [21].

Nevertheless, ice was primarily used to chill drinking water, consumed at home or during collective work gatherings, community parties, and soccer tournaments. Residents also reported using ice to chill water during group fishing expeditions made with residents from other communities. Collective use indicates that the availability of ice water plays an important role in social relations.

In the region, residents generally cooled drinking water by storing it in large clay pots [37]. This practice has to some degree been replaced using freezers [21]. In Vila Nova do Amanã, all households had at least one functional freezer at the time of research, with the oldest refrigerator being acquired 10 years ago. The community generator, which powers freezers for a few hours a day, was experiencing technical problems and was unstable from August to December 2015. Therefore, families' only alternative was to use ice to chill drinking water, which was either acquired in the city or produced locally. Thus, we can understand the choice to use ice to cool drinking water as related to not having stable access to electricity.

Users' temporary demand for cool drinking water affected the way in which they evaluated SIM performance. In days of low productivity, often ice did not totally solidify and resulted in a large volume of cold water. For users, this characterized the initiative as a success, even though it did not correspond to implementers' expectations.

The divergence between what was valued locally and what was prescribed by project implementers was also observed in the transfer of ultrasound machines from Holland to Tanzania [8]. In the latter case, locals were encouraged to use the technology in a specific way (i.e. for pre-natal exams to determine gestational age), while locally there was demand for another use (post-natal exams to determine fetal or placental matter retention). In both cases, technological efficiency assumed a different meaning for each actor.

Differences in how technology is used and valued by each actor is not necessarily a problem if spontaneous and unforeseen uses are respected, or put another way, if the *fluidity* [36] of the technology is embraced by the project. For this to occur, developers often need to put aside their original assumptions. Many may want to make the artifact more rigid, so that it is more resistant, ostensibly turning it into a stable product [9]. However, as previously mentioned, the stability of a technological innovation is no guarantee of its survival [36]. To promote long-term use, it is necessary to foster users' appropriation of the technology, allowing users' participation through the domestication of the technology [12].

Users' appropriation of the technology is expressed both in the form in which they decide to use it and in how they operate and incorporate it into their daily lives – thereby aligning the scenario inscribed in the artifact to the context within which it is inserted. To better understand the appropriation process, the next section discusses how residents of Vila Nova do Amanã operated the SIMs.

4.4. Collective operation of technology

To keep the SIMs operating, residents established a management protocol during a Community Association meeting. Members organized themselves into seven operation teams, each consisting of four to five members. Teams were responsible for carrying out activities, such as extracting ice and distributing it among residents and supplying machines with fresh water.

These activities demanded a collective (re-)organization, changing residents' routines and leading residents to become both technology users and operators. In this way, the technology presents itself as an agent, since it promotes user transformation, not only through the benefits it generates, but also by stimulating new forms of social organization by sharing responsibilities.

One of the SIM's scripts is that it demands a human operator. Different from other inscriptions in this technology, the prescription of a user-operator, who is available daily, has implications for its operation – since this interaction can alter the efficiency of the technology. This is illustrated by the days in which SIMs did not function due to users' lack of interest in obtaining ice on a given day, difficulties accessing adequate water to supply machines, and perceptions of insufficient solar radiation.

Another example of how users' interactions alter the efficiency of the technology is related to the volume of water placed into the machines. Controlled experiments in the LSF-USP facilities determined that to achieve the greatest productivity, each machine should receive 27 liters of water per day [22]. However, SIM recipients used in the Solar Ice Project can be filled with more than this ideal volume, which leaves room for users to alter the machines' operation.

This is not a technological failure, but rather a SIM characteristic that affects interactions between other actors of the network. This is also true for implementer-user interactions, which may take place during planning meetings with the community, when the technology is implemented with community participation or during training workshops and maintenance visits.

During training sessions offered by IDSM, the team would teach users how the machine should ideally be operated. Training included tangible instructions, such as how much water to put into recipients (volume); but also, abstract prescriptions related to implicit assumptions that may also induce specific behaviors. One example is the notion of collective use and management, where all residents were to be equally responsible for the machines and benefit equally from them.

The assumption of equal benefits was implied in the way that residents decided to distribute ice. Distribution was based on demand,

Table 2
Proposals for technology adaptation.

	Modifications proposed	Objective	Inputs
1	Improvement of cooling chambers	Increase cold retention capacity, minimizing energy loss with door opening	Documentation of SIMs' operation, participant observation. and technology assessment
2	Improvement of the refrigeration circuit	Reach greater motor-compressor efficiency	Documentation of SIMs' operation and technology assessment
3	Simplification of the electric control board	Prevent constant breakdowns	Documentation of SIMs' operation and technology assessment
4	Use of hybrid energy system	Using community generators, increase the hours of machine operation	Documentation of SIMs' operation, participant observation, and technology assessment
5	Use of recipients made from stainless steel	Use a material more suitable for holding liquids designated for direct consumption	Household interviews and participant observation

where interested residents collected ice in their own recipients (buckets, containers, pots, thermoses, or Styrofoam boxes). Based on household size, families with more members received more ice than others. Furthermore, as the thickness of the ice bar varied daily, and no measuring instrument was used, no precise unit guided distribution.

Distributing ice in this way was well intentioned since it aimed for equitable benefit sharing. However, it did not consider that the quantity of ice received daily per family would also determine how it could be used. Fishers from Vila Nova do Amanã reported that they need to purchase approximately 90 kg of ice in nearby cities for fishing. This amount of ice is needed to withstand the trip from the city to the community, guarantee a few days of fishing, and preserve the fish for the trip back to the city to sell it.

Ice is purchased from urban vendors sporadically and in larger quantities, contrasting with the small daily quantities produced by the SIMs. Aiming to obtain a reasonable quantity of ice to support fishing, and diverging from the usual form of ice distribution, one resident reported an attempt to reserve all the ice produced during one day for himself. Even though this did not occur (due to technical and climatic factors), this is an example of a resident's attempt to reorganize ice distribution to meet productive demands, and, therefore, how efficiency is also produced by choices made within the realm of community management.

In relation to assumptions of collective management, we observed that for the most part, residents did not stick to the original SIM management protocol. On average, half of the team members participated in daily activities. Members of the responsible team were often engaged in other activities, such as agriculture, fishing, hunting, work in schools, studies, domestic chores, or trips to the city – illustrating that technological management was entangled with other spheres of community life.

The initial management model established by user-operators was upheld for the first four months of the project. After the five-month interval without SIM operation, however, community management followed a different routine. Over the last three months, one resident was responsible for tasks related to ice production; she worked with the immediate support of relatives and sometimes with the help of her neighbors. This scenario shows that models of collective organization are not inert, but alive and dynamic, responding to the daily interaction between humans and artifacts.

4.5. Technology under construction

Highlighting accounts in which users act upon technology operation could lead to accusations, especially when operation does not correspond to expectations [38]. This, however, would be a superficial approach to the question at hand. First, because it concentrates the driving power among users, disregarding the performance of the other actors within the network – human and nonhuman. Second, because it fails to recognize the feedback relationship between productivity and uses – between technology and users. It reinforces a unidirectional notion of the influence of society on technology or vice-versa, following the tendency to adopt a *sociologism* or *technologism* in the analysis of interventions [39]. As such, it becomes necessary to overcome the a priori division between the technical and the social to note that innovation successes are linked to the ability to move between these two registers [9].

One aspect of such success is technology's capacity for adaptation, which has been stated as its *fluidity* [36]. Users' contributions to adaptations can be seen in their active role in aligning the scenario inscribed in the artifact to its real operation over the course of the Solar Ice Project. This also occurred in the case of transferring an energy generating technology from Sweden to Nicaragua [37]. In both instances, technologies were conceived within the context of realities different from those where they were implemented. As a result, users needed to recognize – and describe for developers – the qualities of the artifact and its products in the new environment in which it was placed. They also had to develop operation routines based on practical knowledge and structure rules for sharing production with outsiders. Such contributions point to a symmetry between users and implementers, where both groups collaborated in technological development. Thus, development is no longer restricted to the laboratory.

Moreover, the feedback loops between research and action foreseen in the Solar Ice Project design (Fig. 3) sought to generate insights to improve the technology. The team of implementers hoped to improve technological quality and identify relevant sociotechnical adaptations based on the experience of collective use. The research described in this article yielded information on the interaction between users and technology, which then enriched the SIM evaluation conducted by IDSM, LSF-USP, and USINAZUL. This research was, therefore, an important intermediate step in the continuous process of technological development. Modifications identified as relevant after the first year of operation of the SIMs in the Solar Ice Project are presented in Table 2.

Since the end of 2016, LSF-USP and USINAZUL have been discussing and testing modifications to the SIM model, seeking to improve the cooling chambers and the refrigeration circuit and to simplify the electric control board (modifications 1–3). In addition to increasing SIM efficiency, these three alterations have the potential to decrease SIMs' production costs. Moreover, the use of updated components should minimize the need to call upon specialized personnel for maintenance, and, due to accessibility issues, reduce operation costs and prevent long periods of inactivity.

The relevance of these alterations came to light during the technology assessment conducted by LSF-USP and USINAZUL. It was further supported by documentation of SIMs' operation, including productivity data and reoccurring technical problems inhibiting ice production (i.e. errors in the frequency inverter and burn out of the DC power source). In the case of improving the cooling chambers, the following factors were also considered: the hot and humid Amazonian climate, chamber efficiency, and the observation that users constantly open and close machine doors, especially during parties, soccer tournaments, or community work days.

The use of a hybrid energy system (modification 4) consists of alternating between solar energy and thermoelectric power, increasing the machines' working hours. Taking advantage of the community generators already in use, this adaptation could increase productivity without burdening users. This suggestion was made by the IDSM team based on productivity data and on informal conversations with residents during participant observation.

Finally, the adoption of stainless-steel recipients in place of the original zinc recipients (modification 5) was proposed by IDSM team members based on ice use data obtained during household interviews, which showed that residents use ice to cool drinking water. Embracing this unforeseen use, IDSM team changed all recipients by the end of 2016, buying the new materials from a supplier outside the county.

Lessons emerging from user-technology interactions were then integrated into proposals to materially reconfigure the SIM model. This openness to adaptation – even after one year of the technology's operation – is a common characteristic of technological innovations where inventors and users are interconnected [9], and it is especially true for processes that value the role(s) of users-innovators [40] or that hope to foster project ownership by technology users [11].

In the Solar Ice Project, users' interests were translated [24] through associated research; a similar process occurred in a pilot project for photovoltaic electrification in Norway [12]. Aiming to recruit participants, the Norwegian project used an application form to generate information on technical criteria related to energy production. The responses of potential users, however, went beyond the role prescribed to them, with comments that inspired implementers to broaden their view on project planning.

Similarly, the IDSM team translates users' interests through monitoring implemented technologies. This activity has been practiced since 2013 in other solar energy projects led by IDSM and continued with the Solar Ice Project in 2017. Monitoring applies household interviews and direct observation to periodically assess how the technology is being used and its physical condition. These activities are inspired by the concept of Social Technologies, aiming to incorporate users' participation in project management to promote both technological efficiency and project ownership.

5. Conclusion

When technologies stop working as expected, their heterogeneous compositions, resulting from multiple interactions between an infinity of actors, are revealed [25]. Thus, the implementation processes of technological innovations are particularly fertile grounds through which to analyze the actor-network character of a technology. Such processes are conducive to a mismatch between the real artifact (what it does), that is immersed in a network of relations, and its idealized operation in the lab (what is should do). This moment of controversy [9,25] is commonly hidden in reports on interventions, where a harmonious scenario is most often portrayed. Looking closely at these mismatches can bring about contributions to help improve these processes.

As Laet and Mol [36] affirm, and as research results from this study show, rarely is there a simple solution to the question of the success or failure of interventions such as the implementation of Social Technologies. The ballistic metaphor of impact is superficial because it reduces the possible effects of technological insertion to a linear and unidirectional movement (moving from the promoter of the intervention to the beneficiary group), disregarding the heterogeneity and agency of the context where the technology becomes inserted. By describing the interactions between actors on the micro-social scale of the Solar Ice Project, we hope to have reinforced the idea that intervention evaluation processes should broaden their vantage point and consider nonconventional aspects. This expansion is a strategy to understand the relevance of the impact and origins of challenges for their sustainability within a local context.

Discussing the sustainability of technological initiatives requires recognizing the interactions that make them viable – from their idealization to their operation. In the case presented here, a series of articulations were needed to make the transposition of a technology from one context (university, technical-scientific research, Southeastern Brazil) to another (rural community, development project, Northern Brazil) viable and guarantee its operation. The technology needed a network to ensure its implementation and will continue to depend on these interactions to maintain itself. The technology, therefore, is not a finished product, but rather is under continuous construction.

This open ended, unfinished condition is due to the dynamism of the implementation processes of Social Technologies, or rather, the precariousness of these networks [35,37]. This occurs because networks encompass more than the technology-user binomial and include service providers, differential access to components, resource availability, and community organization, among others. As a result, sporadic investments in demonstration projects will not guarantee that initially generated benefits will be continuous; instead, maintaining them requires continual efforts of multiple actors within the network.

On the other hand, moving away from a hierarchical model of technology transfer changes the concept of failure itself, such that failure can be understood as momentary and part of a larger process of developing solutions. In this case, the fact that the technology did not operate as hoped is not due to a constitutive fault; rather, it indicates the need to adapt to the local reality – such as adjusting for questions of access, to parameters of social organization for collective use, or to meet other local demands.

Speaking ironically, Akrich [37] states that developers who manage to transpose a technology from one context to another without adaptations must have divine powers. It is not possible to account a priori for all that one encounters in the field, and adaptations to the local context are always necessary. This is true because technology use depends on the sociotechnical network that was already alive before artifact insertion.

Exploratory research with an emphasis on actors can identify dynamics that until now have not been considered by outside actors. This allows us to re-design interventions to be more efficient. To produce substantial and long-lasting results, it is necessary to leave room for actors' contributions. This openness to adaptations – a process of design that continues outside the inventor's laboratory – can (and should) take place throughout the entire course of a Social Technology: from its idealization or planning, through its engineering and implementation, through its use and management.

Nevertheless, incorporating the fluidity of the technology into project management is not an easy task. It requires reconciling technological rationality with that of the actors involved in the project, overcoming the division between technology and society. This entails a continuous effort on the part of implementing agents to deconstruct dichotomous visions and build a practice that is truly sociotechnical in nature.

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