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A conceptual analysis of gendered energy care work and epistemic injustice through a case study of Zanzibar's Solar Mamas

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Kavya Michael  & Helene Ahlborg 

Energy and climate transitions bear an inherent risk of replicating historically embedded unjust gendered norms in the current energy regimes. Positioning our work within critical feminist scholarship, our study emphasizes the embedded nature of energy technologies within respective socio-economic, institutional and cultural contexts. We use a combined lens of care and epistemic injustice to examine the case study of Solar Mamas in Barefoot College Zanzibar, highlighting the nuanced interplay of power relations in decentralized energy transitions. This approach helps comprehend and value gendered energy care work as involving skilled labour in everyday life. Our findings illustrate the need for energy transitions research, policy and practice to be deeply informed by lived experiences, diverse practices of care within the energy webs and valuing of multiple voices. We argue that interventions prioritizing care and knowledge in decentralized, locally managed energy provisioning have the potential to disrupt established gender relations.

Energy and climate transitions are deeply social and gendered in all contexts where they play out^{1,2}. However, the scholarship on energy transitions remains dominated by techno-economic analyses that fail to recognize or problematize the gendered dimensions of energy policy, production, use and impacts^{3–5}. Research that applies a gender lens to energy studies highlight the problem of women's exclusion from energy services and from influence in decision-making in energy-related matters^{6–8}. The literature also documents women's roles as domestic energy providers and related physical drudgery. The lived reality and experiences of women globally are crucial to document and understand, yet the focus on women's domestic work and family relations has dominated energy studies and rendered other roles that women play in public spheres and private sector less visible. Relatively little work exists on how gender roles shape energy entrepreneurship and who is considered an energy expert^{9,10}. Studies that place emphasis on women's exclusion and suffering without providing sufficient attention to women's agency and contributions to various spheres of society, reproduce problematic assumptions

around women as belonging primarily in the domestic realm and as lacking agency¹¹.

We depart from two interlinked themes that are well grounded in the history of feminist theory: women's knowledge and care work—and how these are (not) valued^{12,13}. Within those, two specific debates have potential to contribute to alternative visions of energy transitions: theorizations of 'care' and 'epistemic injustice'. In this Article, we integrate a unique framing of epistemic injustice with a care lens aiming to explore how power relations shape and get reshaped in processes of decentralized solar electricity provision in Zanzibar. Drawing on a qualitative, interview-based case study of the Barefoot College Zanzibar, undertaken in October 2022, we identify the strategies and actions that enabled a process of empowerment of women enrolled as solar technicians in a patriarchal societal context. This case serves as a distinct approach illustrating the imperative for energy transitions research, policy and practice to be deeply informed by lived experiences, practices of 'care' and valuing of multiple voices and narratives.

Positioning this work within critical feminist scholarship on energy transitions^{14–17}, we argue that a more profound rethinking of the energy–gender nexus is necessary, including attention to intersecting relations of power, heterogeneous contexts and groups, a multiplicity of identities, arenas and norms. The diversity needs recognition without losing from view how gendered norms and institutions effectively impact and delimit people's lives. Given that energy and gender research is dominated by Western theoretical perspectives^{15,18}, there is need for more studies carefully grounded in other cultural contexts. In the feminist theoretical traditions, the dominance of Western perspectives is a point of concern with calls for pluralizing ontology and epistemology^{19,20}. The question of who can speak, who shapes the narrative and whose experience counts as valid²¹ speaks as much to energy sector practice as to scholarly practice.

Critical social science energy research^{22–25} posits 'care' as the missing lens in illuminating the complex web of dependencies, interdependencies and the unequal power dynamics inherent in the unfolding of energy transitions. Our approach draws inspiration from these initial forays into the realm of care. Fisher and Tronto²⁶ define care as 'A species activity that includes everything we do to maintain, continue and repair our world so that we can live in it as well as possible. That world includes our bodies, ourselves and our environment, all of which we seek to interweave in a complex, life-sustaining web'. Drawing on this definition, we introduce the concept of 'energy care work' to signify the daily practices undertaken at a household and community level for provisioning, sustaining, maintaining, repairing and ensuring the availability of energy carriers and services for day-to-day life. This approach to energy care work extends beyond caring for people to also caring for the infrastructures and technology and how these impact the environment. It is rooted in the lived experiences of dependence and relationships within energy webs, acknowledging the intricate connections between individuals, the energy systems and ecosystems that support their daily activities^{23,24,27}. The diversity of energy-related practices and technologies are culturally and spatially embedded in specific ways in different contexts, which means that policy-induced changes play out differently as energy practices in homes and communities are entangled in intersecting power relationships that can be organized around gender, age, class, caste, ethnicity, religion and more. However, feminized practices of care even within the energy sector, especially provisioning for household energy, are often devalued^{7,22}. Scholars have partly attributed this undervaluation of caregiving labour to its link with women, home and domestic responsibilities^{4,28}.

Recent studies on energy transitions shed light on households as spaces where traditional gender norms intersect with new regulations and advancements in technology. For example, a study from Europe found that whereas activities such as energy renovations at home are often associated with men, most household tasks such as washing, food preparation, cleaning and caregiving are typically carried out by women²⁹. Drawing attention to one unintended outcome, Johnson introduces the concept of 'flexibility woman' to underscore how women as a group are affected by policies introducing 'smart' hour-based energy pricing that incentivize users to engage in time-shifting practices of domestic chores (for example, to do laundry at night), as such activities predominantly are performed by women³⁰. As energy policy increasingly targets domestic energy consumption, practices and responsibilities, it is crucial to understand how these are linked to context and technology-specific gender roles and work division. We argue that attention to energy care work is essential for predicting effectiveness and (unintended) consequences of interventions.

A common pattern across cultural contexts is that gendered norms surrounding care work in general also involve the associated devaluation of women's contributions. The concept of 'epistemic injustice' supports our understanding of the devaluation of women's care work. Defined by Miranda Fricker, it refers to the injustice and exclusion experienced by someone when they are specifically wronged in their

capacity as a knower²¹. Fricker argues that the different social identities that one assumes, including, for example, gender, race and class, play a crucial role in shaping a person's recognition or exclusion as a 'knower'³¹. Given that women are responsible for a lot of energy care work, we may expect epistemic injustice to be replicated as women take on new roles and tasks in new energy systems, also beyond the home.

The case—the Solar Mamas in Barefoot College—is highly relevant for understanding the importance of addressing epistemic injustice in the field of energy technologies as technology and engineering is historically coded as a male sphere and because the College supports the empowerment of rural women with little education by training them into experts and entrepreneurs. The combined lens of care and epistemic injustice provides an entry point to analysing energy transitions as involving skilled work in the everyday as much as in the socio-technical practices.

A conceptual analysis of gendered energy care work and epistemic injustice

Emerging critical literature on energy and climate change have been vocal around gendered norms surrounding care and unequal distribution of care activities^{25,32}. Studies from the African and Asian contexts^{33–37} have evidenced that the care work women perform is not just restricted to direct care responsibilities at the household level. Women are often responsible for provisioning work including subsistence agriculture, household energy supply and water supply. Such care practices often extend beyond the household level to care for the environment and village community spaces. Arora-Jonsson³⁸ introduce the concept of in-between spaces and in-between times to elaborate on women's care work that challenges the boundaries between public work and private care, contributing valuable knowledge and skills. However, the globally skewed division of labour and dominant norms that value women's paid or unpaid work less than men's work, undermine the knowledge and experience possessed by women³⁸.

We build on Miranda Fricker's use of epistemic injustice to make sense of these experiences of exclusion. The concept of epistemic injustice as defined by Miranda Fricker²¹ is linked to 'care' in how norms surrounding care work often brand caring as 'women's work' and by consequence value it less than other kinds of work. Fricker identifies epistemic injustice as taking two shapes: testimonial and hermeneutical injustice²¹. Testimonial injustice signifies being dismissed as a credible and knowledgeable person. In the context of gendered energy care work, women—or for that matter people who do not fit norms about appropriate masculinity—may experience lack of credibility while participating in decision-making processes around matters related to energy programmes due to norms devaluing their experiences and technical competence. Hermeneutical injustice refers to a gap in collective interpretive abilities that disadvantage a socially marginalized group in their ability to make sense of their social experiences and valuing their own knowledge. A gendered manifestation of hermeneutical injustice in the energy space occurs when gendered roles, cultural norms and practices alienate women from technical spaces and/or women themselves restrict their participation in the decision-making process, often unaware of the potential contributions they could make.

Figure 1 illustrates the linkages among care work in general, the gendered nature of energy care work and epistemic injustice leading to women's exclusion in the energy/technology related spaces. The connections depicted in Fig. 1 between the concepts are not suggesting linear causality; instead, they serve to illustrate the mutual shaping of gendered energy care work and epistemic injustice. Care and energy are intricately interwoven in, for example, the responsibilities for provision of domestic and community energy needs and performing manual or mechanized work in homes, public and private spaces. An understanding of energy care work and its gendered dimensions is crucial in the context of emerging energy transitions and movement towards decentralized energy systems and a less energy intensive lifestyle.

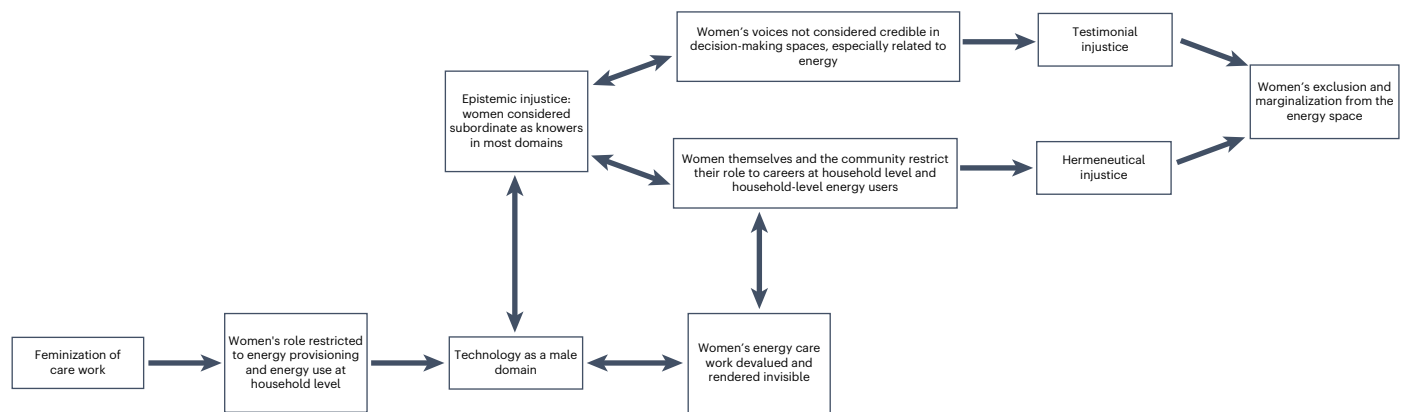


Fig. 1 | Gender, energy care work and epistemic injustice. A conceptual illustration of the linkages among care, gendered energy care work and epistemic injustice.

Table 1 | Different stages of the Solar Mamas programme

Components	Activities	Actors	Desired outcomes
Step 1: pre-training phase	<ul style="list-style-type: none"> Community-level meetings Conscientization initiatives targeting male partners Selection of the women to be trained as Solar Mamas Signing of contracts with Solar Mamas and their male partners 	<ul style="list-style-type: none"> Barefoot College staff members including solar master trainers Recruitment team from the government of Zanzibar Head of villages 	<ul style="list-style-type: none"> Selection of candidates according to the desired criterion Developing community consensus Ensuring support for selected Solar Mamas
Step 2: during the training	<ul style="list-style-type: none"> The Solar Engineer Training Program The ENRICHE module Complementary income generation initiatives such as sewing and beekeeping 	<ul style="list-style-type: none"> Barefoot College staff members including solar master trainers Team from the government of Zanzibar Financial inclusion experts Doctors, advocates and social workers 	<ul style="list-style-type: none"> Demystify technology Unlearn gendered social norms and practices Provide a diversified income basket Financial literacy Legal awareness Entrepreneurship training Awareness about one's own body and reproductive health
Step 3: after training	<ul style="list-style-type: none"> Provisioning of solar panels and other materials necessary for installation Installation, repair and maintenance of solar cells Monitoring and evaluation programmes Follow up and support 	<ul style="list-style-type: none"> Solar Mamas Barefoot College staff members Team from the government of Zanzibar Community members 	<ul style="list-style-type: none"> Electrification of non-electrified villages Implementation of a gender-sensitive strategy for energy supply and use Ensuring sustained income basket for the Solar Mamas Shift in gendered norms and power relations at household and community level Transformation of Solar Mamas from caring at home to caring for the community

Decentralized energy solutions that embed care for technology in the community and domestic routines holds potential for disturbing or reproducing gender–technology conventions^{23,27}. These care practices often sit outside formal markets blurring the lines between public and private and paid and unpaid care practices^{22,27}. Here the ability to care is contingent upon a combination of material resources, time and knowledge^{23,27}. A feminist perspective as employed here challenges the devaluation of gendered energy care work performed by women and their associated knowledge. Instead, it presents the valuation of this work as an open question for those involved to answer instead of viewing people's involvement in care work as a *problem* to be addressed by technological solutions.

Care and epistemic justice in decentralized energy solutions

The Solar Mamas programme by Barefoot College showcases how a combination of innovative governance practices, a solar technician training programme embedded within the socio-cultural dynamics of the region and community conscientization initiatives has gradually led to gender inequality being addressed through electrification initiatives in rural Zanzibar. Initiated in 1997 by Barefoot College in the village of Tilonia, Rajasthan, India, the Solar Mamas programme is currently operational in more than 90 countries worldwide. The Solar Mamas—that is the 'solar mothers'—programme in Zanzibar targets

illiterate or semi-literate women who are long-term residents in their respective villages, preferably mothers. Pregnant women and women with young children are not included due to their difficulty to spend extended training periods away from home.

Table 1 describes the different stages of the Solar Mamas programme. Throughout the programme, the recruitment team proactively builds trust in the training process and activities among the community members. The training programme lasts for five months at the Barefoot College campus and comprises three major steps.

Step 1, the pre-training phase of the Solar Mamas programme, as illustrated in Table 1, begins with a community meeting orchestrated by a collaborative effort between representatives from the government of Zanzibar and Barefoot College Zanzibar, facilitated with the assistance of the village head. During this community gathering, the recruitment team solicits volunteers willing to participate in the programme. A critical criterion guiding the selection of candidates for the programme is their immobility. The anticipated long-term presence of the Solar Mamas within their respective villages forms an integral aspect of the programme's expectations, that these trained Mamas should reside permanently in their communities, rendering service to the villagers.

Subsequently, the identification and nomination of women for the training initiative is determined through community consensus established during the meeting. Following the selection, contracts are signed with the selected women and their partners, if they are

married. The initiation date of the training is communicated during this contractual process. Despite the transparent and collective nature of the recruitment process, the team confronts substantial challenges due to the entrenched patriarchal dynamics prevalent within society. Women frequently withdraw from the training programme, influenced by pressure exerted by men, encompassing threats of divorce and other coercive measures. At this juncture, governmental intervention plays a pivotal role in community sensitization. The recruitment team, in parallel, places considerable emphasis on fostering trust in the training process and subsequent activities among the community members.

Step 2, the training phase of the Solar Mamas programme consists of three components that run in parallel. The first component is the Solar Engineer Training Program, where the classes are largely demonstrations and learning-by-doing sessions of assembling, installing, repairing and maintaining solar cells. The second component of the training programme is the ENRICHE module, which places a lot of emphasis on promoting critical thinking and building awareness around injustices encountered by Mamas in their everyday lives. This includes learning about sexual and reproductive health, legal rights and social support structures. Financial literacy is another important topic covered in this module. The women are trained in opening bank accounts, financial management and planning. The third component aims to diversify and strengthen the women's income basket by training them in beekeeping or sewing, ensuring an additional income.

After the training (which corresponds to Step 3 in Table 1), the government supplies the graduated 'Solar Mama Engineers' with the solar panels and equipment for installing these in the villages free of charge. The Solar Mamas, formerly tasked with household energy provision, possess a keen understanding of the challenges faced by community members in energy provisioning. They draw upon their first-hand experiences to persuade the community about the advantages of transitioning to solar energy, emphasizing for example improved health, enhanced education for children and opportunities for shops to stay open late. The training they undergo enhances the credibility of their voices, playing a pivotal role in the electrification process of the villages. Installation, maintenance and repair of solar equipment are conducted exclusively by the Solar Mamas or the assistants they train using their acquired skills.

Customers pay a monthly fee of 6,000 Tanzanian shillings (TSH, approximately US\$2.5) per household to the Mamas as a leasing agreement, thereby also financially valuing the energy care work. This amount is much cheaper than the kerosene typically used for household lighting, which is generally above 9,000 TSH (approximately US\$3.5) per month. The programme implements a monitoring and evaluation plan that includes follow-up sessions with each solar engineer three months post-training and subsequently every six months. At the time of study (October 2022), the programme had led to the lighting of nearly 1,000 homes in 19 villages for at least 7,000 people on the island and mainland. In the sections below we examine the insights from the semi-structured interviews conducted with the stakeholders at Barefoot College Zanzibar. Drawing on the concept of care in conjunction with epistemic injustice, we bring forth a relational understanding of gendered energy care work encompassing socio-cultural aspects and power relations. The paragraphs below elucidate the insights from the semi-structured interviews conducted with the stakeholders at Barefoot College Zanzibar.

In the context of decentralized electricity systems, practices of care, including installation, monitoring and maintenance of technologies, are crucial for ensuring their sustained functioning²⁷. These are also common challenges that have caused the failure of many small electricity systems in rural areas²³. To invest in women who are likely to stay in the village rather than move to town after training is a proven concept^{39,40}. In this context where the domestic reproductive labour is often taken for granted, the college works to make the value of women's traditional care work visible to the women and the community. In addition,

the ENRICHE module supports the integration of the Solar Mamas' lived experiences with their newly acquired knowledge and technical expertise, demonstrating the tangible impact of acknowledging and leveraging women's traditional care work in community development.

The programme makes an intervention in rural non-electrified villages and homes across the islands by offering affordable electricity access, altering the everyday lived experiences of the women who get training and changing community perceptions of solar technology. The Solar Mamas transition from provisioning for household energy through fuel wood and kerosene to becoming solar engineers and providers of electricity to households and businesses. As providers of and carers for electricity, the Solar Mamas enable further services that benefit all village households, including electricity at the school and health care centre, thus becoming providers of critical care-related infrastructure⁴¹. As shown by previous studies^{42,43}, electrification leads to changes in daily work practices and use of public spaces. In Zanzibar, shops started to stay open late, and women occupied public spaces after 6 pm, slowly creating a shift in gendered norms and power relations around who belongs in what space and when.

However, the programme does not merely follow an individualistic approach to training women as solar engineers. Their role is imagined as embedded within the communities they come from, and the college staff are cognizant of the power relations and gendered norms surrounding work and knowledge. The Solar Mamas' ability to care for their communities were dependent on their social connections within the community, their knowledge, skills and status. This makes the support from the college and government vital, through all stages.

The college sees community involvement and sensitization as a crucial element for the success of the programme. Norms and attitudes are collectively held and changed, so male relatives and community members are involved directly or indirectly. These include gendered norms around women as sole providers of care in the household, men as breadwinners and decision-makers and electricity as a masculine domain. The pre-training phase's community meetings are important in manifesting the support from male leaders in government and for explaining the programme's transformative potential. But also, the programme is set apart from many short-term projects by the care the government and college display for the women *after* training.

Some of the trained Solar Mamas still experience major challenges in certain villages when households default on monthly payments. Collective revenue from or imposing sanctions on neighbours is a well-known social challenge⁴⁴. Even with government support for removing panels from households that have defaulted on payments three times, this is often difficult for the women in practice.

Sometimes the batteries are kept inside their bedrooms, and it is not easy to access them and uninstall when the men are present.
Interview with Solar Mama

The college staff also notes that the problem is larger in villages where village leaders, always men, are less supportive or even opposed to the programme.

When the village leader is not supportive of the programme, the whole community tends to be resistant. Interview with Barefoot College staff member

Instances such as these lead to gaps between those giving (the Solar Mamas) and those receiving care (the community, which fails to care for the Solar Mamas in return)²⁷, emphasizing the interdependence of actors in the decentralized energy web. The college and the Zanzibar government are currently exploring alternative business models to overcome this problem, such as a one-off payment at the time of installation and giving ownership of the solar panels to the households as such, but that would undermine the affordability of service.

Challenging traditional attitudes around knowledge and expertise, the Solar Mamas training programme questioned widespread assumptions around who could be a skilled technician.

The class is practically oriented. People who have gone to school for years are amazed at how we do this with no educational background and a training of just five months. Interview with Solar Mama

By specifically engaging women with limited formal education, the college confronts gendered norms associating technological expertise with masculinity and boosts the women's self-esteem in addition to altering community perceptions. In addition to the technical knowledge the women acquire, the ENRICHE module provides a safe space for addressing motherhood, family and gender relations and jointly reimagining and unlearning a set of regressive gendered norms surrounding work division in the households and domestic relations. Taking women's knowledge and lived experiences, their social and cultural contexts as starting point, the facilitators ask women to voice their experience, knowledge and fears developing a sense of stronger agency, belonging and community.

The government of Zanzibar, in line with its stated mission⁴⁵ of addressing 'harmful social and cultural norms and practices', plays a key role in enabling socially innovative practices and transforming gendered norms, also providing trust and credibility for the programme.

When Mamas agree to join the training for five months, their husbands must sign an agreement saying they are letting their wives go for training. So, when there is a sudden change of mind, with the help of the village leader, we have dialogues with the husband or other men in the family and try to educate them about the benefits of the programme for the family. Interview with recruitment team member from Zanzibar government

Despite resistance, the political support and clearly positive benefits resulted in a slow transformation of attitudes and generated support from male partners, leading to programme expansion and sustainability. The credibility attained by the women as 'knowers' is an outcome of addressing the devaluation they experienced as caregivers at the household level.

I am more respected now—they see me as a solar engineer. Interview with Solar Mama.

This includes the credibility the Solar Mamas have gained in the society and their voices being heard—addressing testimonial injustice—and a shift in the community's perception around women's capabilities, which improves the collective interpretive resources of the community—addressing hermeneutical injustice. It also shows slow shift in attitudes of the male partners with the women's voices being heard and valued more.

My husband has changed. My power in decision-making regarding our family has increased—we communicate well, and we discuss issues together, and when I tell him of something, he doesn't disagree much. Interview with Solar Mama.

The community, especially men, are amazed at how a job that was predominantly done by men is done by us! Interview with Solar Mama

The training modules and increased economic independence improved the level of confidence and sense of agency for Solar Mamas, who became more assertive and demanded a place at various decision-making arenas. The communities in turn increasingly recognized them as solar engineers and people supporting the community.

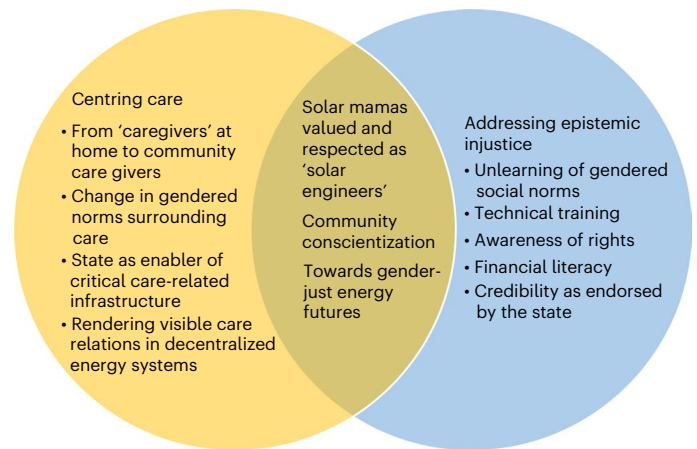


Fig. 2 | Exploring the concepts of care, epistemic injustice and their intersections. Illustration of the combined lens of care and epistemic injustice in the Solar Mamas programme of Barefoot College Zanzibar.

The care–epistemic justice interface

The synergistic lens of care and epistemic injustice aids in articulating a feminist vision of energy transitions. Figure 2 illustrates the link between the concept of care and epistemic injustice in the Solar Mamas case study. The case shows the effectiveness of addressing the norm of men as superior knowers of technological matters through an approach that involves not just training of women to possess new skills but also collective community conscientization around the value of women's pre-existing knowledge and capabilities.

For the Solar Mamas, the economic and social shift in status changed their relations with the community. Their ability to care for the technology and their communities, brought a sense of pride, joy and power. By leveraging the concept of 'in-between spaces and in-between times', as proposed by Arora-Jonsson, we contend that the work undertaken by the Solar Mamas in their communities erases the boundary between public (work) and private (care), between paid or unpaid work³⁸.

The existence of an innovative partnership between the college and the government of Zanzibar plays a key role in the operationalization and success of the programme. Supported by both the college and the government of Zanzibar, the Solar Mamas dedicate their lives to electrifying villages and maintaining technology. In doing so, they mobilize valuable knowledge and skills from their lived experiences and technical training, offering insights essential for the care and maintenance required in decentralized energy transitions⁴⁴. The case study also emphasizes the crucial role played by cross-scalar support networks involving, for instance, the collaboration between the state and development organizations/non-governmental organisations in facilitating gender-just energy futures.

Conclusion

The emphasis on techno-economic aspects of energy transitions neglects strategies for fostering positive change through social relations, local resources, innovative organizational methods and political mobilization^{46,47}. The Solar Mamas programme serves as an illustrative example of a comprehensively designed Solar Engineer Training Program, which is embedded within the communities they come from cognizant of the gendered norms and power relations that exist. The programme addresses contextual barriers in the shape of attitudes and norms underestimating illiterate women's capacities in addition to the technical training provided. This involves the unlearning of gendered social norms and unjust practices by the women themselves, their male partners and the wider community. In the process, the knowledge that these women already possess as caregivers, including as providers of

household-level energy, also becomes valued. The transformative impacts are achieved by primarily targeting the society's devaluation of women's domestic care work and making visible the care for community that was already practiced but now extends to a new shape involving a desired technology³².

The Solar Mamas programme reflects a nuanced understanding of gendered energy care work, addressing the devaluation experienced by participants and overcoming epistemic injustice by fostering confidence, agency and a transformative shift in gender norms within their communities. The evidence suggests that interventions that centre care and knowledge in the transition from centralized electricity supply towards decentralized and locally managed provision holds potential to disrupt established gender relations and develop a new functional energy order²⁷. The case illustrates the cross-scale networks and importance of alliances that help overcome or diminish resistance, and the ongoing adjustments that are necessary for viable initiatives^{48,49}. The findings from the case study also underscore the need for further work in energy studies, which is cognizant of the care practices, gendered norms, lived realities and diverse knowledge of the communities in the Global South. This exploration is vital for comprehending the everyday experiences of individuals experiencing energy transitions.

Methods

The study of the Solar Mamas programme of Barefoot College Zanzibar was conducted in Zanzibar during October 2022. The study was informed by previous studies conducted at the Barefoot College campus in Tilonia, Rajasthan, India^{40,41}. The case selection was preceded by online interviews with the communication team of Barefoot College International and the former chief executive officer of Barefoot College International. These interviews aided in the process of case selection. In addition, our research has also been informed by previous studies on decentralized energy systems in East Africa, which have particularly examined the gender–energy/electricity nexus^{36,43,44,50,51}.

Zanzibar, a semi-autonomous province that consists of an archipelago with two main islands, has been part of the United Republic of Tanzania since 1964. It is a cultural meeting place shaped by trade and colonization, with Swahili culture emerging from African Indian Ocean encounters, and later western colonization of the African East Coast. Tourism and spice production dominate the economy. Culturally, Zanzibar distinguishes itself from the Tanzania mainland with Sunni Islam—not Christianity—as the dominant religion. Traditional gender roles as understood in Sunni Islam define women as care providers and men as breadwinners. Winther's^{36,51} anthropological account of Zanzibar's energy sector shows the gendered division of energy work, with firewood, charcoal and kerosene as dominant domestic energy sources, the provision of which is largely women's responsibility. Despite this provisioning role, Tanzanian energy policy portrays women as 'users', and the supply chains and infrastructure for electricity, gas and diesel are male dominated. Winther articulates that the Islam religion as practiced in Zanzibar is of a pragmatic nature despite conforming to traditional gendered roles. She argues that despite women's roles being defined as homemakers and care providers, the precarious living conditions in rural Zanzibar often led to reliance on women's labour outside the home for survival. Islamic rules apply to marriage and inheritance, allowing women very limited rights of ownership, and women rarely own land or houses.

In 2015, the Barefoot College Zanzibar was established through a memorandum of understanding between the Zanzibar's 'Ministry of Empowerment, Social Welfare, Youth, Women and Children' and 'Barefoot College International'. The collaboration began in 2011, when 13 rural women from Zanzibari villages were trained as 'solar engineers' at Barefoot College, Tilonia, in India^{40,41}. These women returned to Zanzibar and electrified more than 200 homes in rural Zanzibar. The former president of Zanzibar, Ali Mohamed Shein, visited Barefoot College in India in 2014. Impressed with the transformation happening there, he aimed to replicate the Indian model in Zanzibar and supported

the establishment of Barefoot College Zanzibar in 2015. He appointed the 13 Zanzibari Solar Mamas trained in India as *Solar Master Trainers* in Zanzibar, who played a key role in designing the training. Set within the socio-cultural context of Zanzibar, the case is an example of how gender relations can be centred as a leverage point in the energy transitions process within traditional patriarchal orders and technology-oriented programmes that are typically 'masculine spaces'.

The data for the case study were collected through semi-structured interviews. A total of 16 interviews were conducted, including interviews with four solar master trainers, three government representatives, three Barefoot College staff members and six Solar Mamas with the help of an interpreter. While acknowledging the limited sample size in this qualitative study, it is important to emphasize that the focus on depth over breadth enabled a thorough exploration of participants' experiences, contributing to the richness of the data collected. Furthermore, it's important to highlight that the inclusion of diverse stakeholders in the interviews aimed to capture a diverse range of perspectives, enriching the study despite the inherent limitation of a small sample size. Our engagements with stakeholders are guided by internationally recognized ethical principles. We approach communities transparently, clearly articulating our intentions, expectations and data-handling procedures. Before interviews or questionnaire administration, participants are briefed on data usage, storage practices and their rights under General Data Protection Regulation regulations. Consent agreements are obtained, affirming participants' understanding and agreement to data-use protocols. Personal data collection is minimized. Data management adheres to university guidelines on data security and privacy. Additionally, we uphold responsibility by sharing preliminary findings with key informants, seeking input, feedback and clarifications to mitigate misunderstandings or misinterpretations. This iterative process ensures ethical conduct throughout the research endeavour.

As per the Swedish Ethical Review Authority and the provisions of the Act Concerning the Ethical Review of Research Involving Humans, this research falls outside the scope of projects requiring formal ethical approval. The project team at Chalmers for the User Centred Energy Systems (UsersTCP) Gender and Energy Task comprises researchers with a wealth of experience in ethical research practices. They meticulously reviewed the research design, methodology and interview questionnaires, granting approval for the study to proceed. Furthermore, ethical approval was obtained from a team at Barefoot College Zanzibar, including its director and team members, who played a pivotal role in facilitating interviews with diverse stakeholders. Supplementary Table 1 provides general information about the interviewees.

Building on previous literature and feminist theory, an interview guide was prepared, and the scope included the programme history, the set-up (pre-training period, the training process) and the programme impacts. Audio recordings from the interviews have been transcribed and translated with the help of the interview assistant. The interview material was coded with the qualitative analysis software Nvivo. We adhered to an abductive content analysis approach that iterated between pre-defined themes and concepts (deductive codes) and those emerging from the interview data (inductive codes)⁵². The analytical framework that combines the lens of care and epistemic justice emerged through this abductive process where epistemic injustice and care work were among the themes identified ahead of the study, but their intersection and interplay was informed by the analysis and empirical findings. Beyond the application of pre-defined deductive codes, an additional layer of analysis involved a comprehensive examination of the data to formulate inductive codes. For instance, the deductive codes under the theme care captured relationships between care and power, care and knowledge and energy care work. However, the analysis revealed emergent inductive codes related to care as social infrastructure and the concept of community/collaborative care. This was identified in interviews with the Solar Mamas, who highlighted the community's perception of the services they rendered as a crucial

support infrastructure. This support, in turn, facilitated extended business hours and supported school-going children in their education. Supplementary Table 2 enumerates key themes and associated codes relevant to the analysis undertaken in this study, following the structure adapted from Johnson et al.⁵³.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data that support the findings of this study are included in the article.

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Author contributions

K.M. conceived the idea for the manuscript, designed the study and formulated the overarching research goals and aims with input from H.A. K.M. conducted fieldwork in Zanzibar, collected and analysed the data and developed the theoretical framework, which H.A. helped refine. H.A. provided inputs and revisions throughout the process. K.M. wrote the first draft of the paper, which H.A. commented on and revised. Both K.M. and H.A. discussed the results and implications and collaborated on rewriting, editing and revising subsequent drafts of the paper.

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Competing interests

The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to Kavya Michael.

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Ethics oversight

The Project team at Chalmers for the Users TCP Gender and Energy Task comprises researchers with a wealth of experience in ethical research practices. They meticulously reviewed the research design, methodology, and interview questionnaires, granting approval for the study to proceed. Furthermore, ethical approval was obtained from a team at Barefoot College Zanzibar, including its director and team members, who played a pivotal role in facilitating interviews with diverse stakeholders.

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Study description

The study of the Solar Mamas Program of Barefoot College, Zanzibar was conducted in Zanzibar during October 2022 . The study was designed as a qualitative study where the data was collected using semi structured interviews. We also report the assistance of an interpreter to conduct the interviews in Swahili.

Research sample

The 16 interviewees (research sample) included the Solar Mamas or the Solar Engineers, Solar Master Trainers, the staff of Barefoot College Zanzibar and representatives from the Government of Zanzibar. These stakeholders were selected to garner the varied perspectives pertaining to the program. A detailed table containing information of the respondents are included in the methods section

Sampling strategy

The interviewees were selected based on purposive convenience sampling with the assistance of Barefoot College, Zanzibar. Data saturation was considered in terms of redundancy of themes, depth of understanding and when no new keywords, patterns, codes or themes emerged.

Data collection

The data was collected through semi structured interviewees. The interviews with the Solar Mamas were conducted in Swahili with the assistance of an interpreter. The interviews were recorded and was later transcribed and translated.

Timing

October to November 2022

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No data was excluded from the analysis

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No participants dropped out

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Randomisation is not applicable as this is a qualitative study that adopted purposive sampling techniques

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Diffusion MRI	<input type="checkbox"/> Used <input type="checkbox"/> Not used

Preprocessing

Preprocessing software	<i>Provide detail on software version and revision number and on specific parameters (model/functions, brain extraction, segmentation, smoothing kernel size, etc.).</i>
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