Using energy justice to contextualise existing challenges of wood charcoal against faecal sludge derived briquettes as a future cooking fuel alternative in Dar Es Salaam, Tanzania

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ABSTRACT

Over half of the population in Dar es Salaam (DSM), Tanzania, predominately relies on wood charcoal as a cooking fuel, and this is expected to rise to meet future demands. Drawing on the energy justice framework, this article contextualises the current charcoal supply chain of DSM and discusses the possibility of using faecal sludge-derived briquettes (FS briquettes) as a future alternative. This article demonstrates how current injustices in the charcoal supply chain pose challenges related to availability, reliability, affordability and sustainability and concludes that the future energy system of DSM must become more robust and diversified. This article also concludes that while FS briquettes hold the potential to become a viable and energy just cooking fuel alternative, future adoption may be hindered by limited consumer acceptability, inadequate sanitation management and lack of financial investments and government support.

Introduction

Ensuring access to affordable, reliable, sustainable and modern energy for all is confined in the Sustainable Development Goal 7, yet, achieving this goal requires major changes to energy systems worldwide. Indeed, climate change, growing populations, and increasing urbanisation, tied with economic uncertainties, creates augmented energy demands and thus higher pressure on both human and ecological environments. Firewood and charcoal remain the main source of energy with 2.8 billion people relying on them globally, including 780 million in sub-Saharan Africa (International Energy Agency (IEA) 2019). Yet, in many sub-Saharan countries, growing urbanisation has increased the use of charcoal in comparison to firewood, which is declining in urban households (Doggart et al. 2020). Charcoal usage has several environmental and socio-economic implications (Sola et al. 2017) including deforestation, biodiversity loss (Zulu and Richardson 2013; Mwamlima et al. 2017), and affected health owing to contamination of indoor- and outdoor air (Sola et al. 2017).

While securing sustainable and affordable energy is a particularly pressing concern across urban areas of sub-Saharan Africa, so is meeting SDG 6: Ensuring availability and sustainable management of water and sanitation for all, as people in sub-Saharan African cities often rely on on-site sanitation systems, such as pit latrines and septic tanks for their sanitation needs (Seleman et al. 2020). In the cities’ unplanned settlements, where the majority of these populations reside, these sanitation systems are generally poorly managed and unhygienically desludged (Kasala et al. 2016; Seleman et al. 2020). The associated deaths and diseases caused by inadequate sanitation facilities and unsafe desludging have direct impacts on a country’s economy due to high demands on the medical system, labour losses,
and delayed entry into the labour force due to poor performance during schooling, to name a few (UNICEF/WHO Joint Monitoring Programme 2014). The benefits of transformative innovations in the nexus of SDG 7 and SDG 6, especially in a sub-Saharan African context, thus become apparent, with several potential synergies to sustainable development dimensions including public health, job creation and natural resource savings (Gabrielsson et al. 2019). One example of such an innovation is faecal sludge-derived briquettes (FS Briquettes), which entails recovering and turning human waste into a resource and thereby possibly simultaneously addressing both future energy and sanitation needs and demands (Diener et al. 2014).

With an annual growth rate of 5.6%, the population of Tanzania’s largest city, Dar es Salaam, is expected to surpass 10 million by 2030, a doubling from its current population (NBS National Bureau of Statistics 2012; Rosen 2019). This rapid increase in urbanisation is contributing to a transition away from firewood towards charcoal, and Tanzania is now the fifth-largest charcoal producer in Africa (Doggart et al. 2020). In an effort to overcome the associated implications of charcoal usage, Tanzania’s policy-makers have attempted to infer urban consumers’ dependence on charcoal through national energy policies, assuming that households will climb the ‘energy ladder’ from charcoal to gas and electricity (ibid.). But rather than transitioning away from charcoal, urban households continue to rely on charcoal mixed with additional fuel types, known as ‘fuel stacking’, because charcoal remains the most affordable, available and accepted cooking fuel across Tanzania’s cities (ibid.).

Concurrently, as many as 80% of the population in Dar es Salaam live in unplanned settlements and nearly a quarter of these rely on unhygienic desludging methods, due to poor desludging equipment, high household desludging fees, poor and inadequate toilet design and sanitation infrastructure (Seleman et al. 2021). As a result, there is a persistently high environmental disease burden associated with cholera, malaria, lymphatic filariasis, dysentery and diarrhoea in Dar es Salaam (UNICEF 2017). While the Tanzanian government is improving standards in a range of sanitation areas, these are mostly concentrated on sewage wastewater, which has underprioritized development and management of on-site sanitation systems, despite these being used by the majority of Dar es Salaam residents (GLAAS 2020).

In neighbouring Kenya, the social enterprise Sanivation (n.d.) has managed to turn an otherwise taboo-ridden waste product into briquettes and use it as solid fuel for heating and cooking (Gabrielsson et al. 2019; Sanivation n.d.). In the city of Nasivasha, Sanivation currently runs three treatment plants, producing over 1000 tonnes of FS briquettes each month, that serve over 10 000 people with an alternative cooking fuel to charcoal. Thereby providing benefits to both energy security, sanitation improvement and climate mitigation (Gabrielsson et al. 2019; Sanivation 2020).

In this article, we aim to contextualise the current challenges of the charcoal system in Dar es Salaam through the lens of energy justice (Sovacool and Dworkin 2015) and contrast this with the possibilities and limitations of FS briquettes as a future alternative cooking fuel for urban households in unplanned settlement of the city. Guided by the energy justice terminology, we answer the following questions:

1. How available, accessible, reliable, affordable, acceptable, sustainable and well-governed is wood charcoal in Dar es Salaam?
2. What energy justice potential could FS-briquettes have for urban households in unplanned settlements of Dar es Salaam in the future?
3. What are the possible synergies and trade-offs of wood charcoal versus FS-briquettes as seen from an energy justice perspective?

Theoretical framework

To analyse our findings, we draw upon the theoretical underpinnings of energy justice. Emerging from the field of environmental justice, energy justice is relatively new as a field of research (Munro et al. 2017). Environmental justice addresses the proposition that distributions of environmental benefits and harms are interlinked with socio-economic processes (Munro et al. 2017). Energy justice is based on the same philosophy but aims to provide all individuals, across all areas, with safe, affordable and sustainable energy (McCauley et al. 2013). McCauley et al. (2013) argued that three pillars should be applied in order to analyse entire energy systems including distributional, procedural and recognition.

In this article, we draw specifically on Sovacool and Dworkin’s (2015) energy justice framework. This framework stems from the fundamentals of McCauley...
et al. (2013) definition of energy justice and is a conceptual and analytical decision-making tool for energy researchers and planners (Heffron and McCauley 2017). According to the framework aspects of availability, affordability, due process, good governance, sustainability, intergenerational equity, intragenerational equity, and responsibility are essential to a just energy system (Sovacool and Dworkin 2015). The following aspects comprising the framework apply, as seen in Table 1:

It is important to note that Sovacool and Dworkin’s (2015) framework focuses primarily on institutional changes and may thus fall short of realising individuals’ potentials for more participation in social, economic and political life (Lacey-Barnacle et al. 2020). Furthermore, the energy justice framing has Western philosophical underpinnings and assumptions of European institutional settings and can thus overlook the importance of how communities in other regions of the world, like those studied here who reside in predominately unplanned settlements in a large sub-Saharan African city, are structured and governed (ibid). In an attempt to overcome this gap, we have utilised a sustainability science approach that takes into account systems thinking to include and consider individuals involved in each part of the supply chain (Wiek et al. 2011). To further contextualise the use of the theoretical framework, we also add the dimension of acceptability to our analysis. We do this to include the preferences of the end-users and to explore the willingness of end-users to adopt a new and seemingly taboo ridden cooking fuel (Mkude et al. 2021).

Materials and methods

Case study setting

Our choice of Dar es Salaam as the case study site is deliberate because the city’s rapid population growth combined with the absence of urban planning has resulted in around 80% of its residents living in unplanned settlements ([NBS] National Bureau of Statistics Tanzania 2017). These settlements often lack access to infrastructure and services, such as running water and electricity, and the majority of them rely on pit latrines for their sanitary needs (Ramadhani 2007; Seleman et al.). Almost half of all the charcoal produced in Tanzania, 500 000–700 000 tons per year, is used by consumers in Dar Es Salaam (Sanga and Januzzi 2005; [WB] World Bank 2010; Msuya et al. 2011), where 58.9% of the households in Dar es Salaam use charcoal as their main cooking fuel, compared with 60.5% of all urban households in Tanzania ([NBS] National Bureau of Statistics, Tanzania 2019). As many as 96% of the people residing in the city’s unplanned settlements use charcoal as part of their fuel stacking strategy to ensure cooking and heating needs are met (Mkude et al. 2019). Since charcoal is such a predominant cooking source in Dar es Salaam, many people are involved in securing its supply from forest to stoves. Figure 1 illustrates the key actors and linkages between those involved in this charcoal supply chain.

The charcoal supply chain is a simplification of the system, as some actors, such as big-scale sellers, play more than one role, while others, such as small-scale sellers, may be bypassed at times. The complexity of the chain in Dar es Salaam is not unique, as the flow of charcoal and actors within are similar to other charcoal supply chain, such as in Kenya (Bailis 2005). To reduce the complexity of the system, this article focuses mainly on the highly visible actors within the chain, namely, producers, big-scale sellers, users, and to some degree, governmental institutions.

Since FS briquettes are currently not manufactured, distributed nor used in Dar es Salaam on a household or community level, we cannot illustrate the supply chain for FS briquettes. Instead, we have relied on our own manufacturing of FS briquettes in the lab of the Water Resources Engineering Department at the University of Dar es Salaam and demonstrated these to possible end users while testing their technical properties and discussing these in relation to their energy justice potential as a hypothetical exercise. We then combine these explorative findings with recent research (Mkude et al. 2019, 2021) on consumer attitudes linked to possible future use of FS briquettes among residents in selected unplanned settlements of Dar es Salaam to be able to discuss all aspects of the energy justice framework. For this reason, the comparison of charcoal vs. FS briquettes is purely a theoretical and hypothetical one. Still, we contend that the scientific value of comparing, contrasting and discussing the future energy justice potential of FS-briquettes with wood charcoal is important if we want to understand barriers to changing the current energy supply chain in Dar es Salaam, or other similar resource and livelihood settings across the world.
**Table 1. Energy Justice Framework.**

| Availability | Availability is the most basic aspect of the Energy Justice Framework, as it encompasses the foundational need of distributing energy services amongst users. This is executed by utilizing a country’s physical resources and a region’s technical abilities (e.g. transport, distribution, storage) (Sovacool and Dworkin 2015). Also implicitly assumed, is that energy resources need to be of high quality (Sovacool and Dworkin 2015). Thus, within availability, resource availability, availability robustness, and quality are applied. |
| Accessibility and reliability | Intragenerational equity is concerned with the right to access energy services fairly (Sovacool and Dworkin 2015). It thereby entails that people have the right to enjoy basic needs and wellbeing such as food, shelter, unpolluted air, and energy (Sovacool and Dworkin 2015). For simplification purposes, this aspect is defined as accessibility and reliability rather than intragenerational equity when applied to the data collection and discussion of the paper. |
| Affordability | Affordability entails stable and equitable prices (Sovacool and Dworkin 2015). Meaning that lower-income households should not have to use a disproportionately large share, or more than 10% of their income on energy services (Sovacool and Dworkin 2015). This definition was applied throughout. |
| Sustainability | Sustainability is the “duty of states of not depleting natural resources too quickly, and not causing undue harm to the environment” (Sovacool and Dworkin 2015, p. 439). It also entails the Brundtland Report’s idea of leaving future generations with the same resources as we have now (Sovacool and Dworkin 2015). Intergenerational equity in the energy justice framework relates to the concept of sustainability in that future generations should enjoy a good life, undisturbed by the damage our energy system will inflict over time (Sovacool and Dworkin 2015). Due to their interrelatedness, these two components are compiled in that paper and named environmental sustainability. |
| Good governance | Finally, the Energy Justice Framework entails three governmental aspects. First, governmental responsibility entails that those nations are responsible for protecting the natural environment and prevent any energy-related social and environmental externalities of the energy system (Sovacool and Dworkin 2015). Second, good governance entails that the energy system is accountable so that it thrives for democratic decision-making and takes measures to reduce corruption (Sovacool and Dworkin 2015). Third, due process is to thrive for transparent processes and to ensure stakeholder involvement in energy policymaking (Sovacool and Dworkin 2015). As all three components are intertwined, they are used in conjunction throughout the discussion under the term good governance. |

**Data collection**

This study is purely qualitative in its research approach, and the focus of the data collection was to gather empirical data that could be used to explore the existing charcoal supply chain from the perspective of the people involved in the supply chain in Dar es Salaam in addition to contrasting these findings with an alternative cooking fuel, here represented by the FS briquettes. Primary data collection took place during different periods between September 2017 and February 2020. Data were collected through focus group discussions (FGDs), semi-structured interviews, participatory observations, participatory workshops, manufacturing of FS briquettes, and expert interviews (Table 2).

The data collection took place in different areas of Dar es Salaam according to the activities in the current charcoal supply chain. We collected data in the unplanned settlement of Tandale, where many charcoal sellers and users reside. Tandale is one of the biggest unplanned settlements in Dar es Salaam ([NBS] National Bureau of Statistics 2012). Furthermore, data on charcoal producers and on a key informant interview with a forest officer was collected in Pugu forests in Kisorarwe, which is one of the areas producing charcoal to Dar es Salaam (Msuya et al. 2011). Finally, charcoal users at the University of Dar es Salaam partook in participatory workshops in order to discuss the potential future use of FS briquettes. The interview guides can be found in the supplemental material.

**Focus group discussions**

We conducted two focus group discussions with five people in each group. The aim was to explore users’ experiences with charcoal. FGDs can provide large amounts of data on a single phenomenon in a short period of time (Bryman 2012), which was useful as there is limited knowledge on charcoal users (Sola et al. 2017). Two focus group discussions were conducted using the same interview guide in order to ensure both comparable and credible data (Bryman 2012). The interview guide is semi-structured, based on themes from the Energy Justice framework. We chose to make the interview guide semi-structured to ensure insights beyond the analytical framework whilst at the same time addressing themes from the framework (Kvale and Brinkman 2009). Charcoal end-users in Tandale are predominantly female street cooks (cooking for business) and female domestic cooks (cooking at home). One FGD was carried out with six female domestic cooks and one with four female street cooks. The groups were thus kept rather small compared to the standard eight-person size.
Figure 1. Actors and charcoal flow within Dar Es Salaam’s charcoal supply chain (Source Laura MS Floytrup, 2020).

Table 2. Data Collection.

| When          | How                                      | Who                                                                 | Where                      | What                                                                 |
|---------------|------------------------------------------|----------------------------------------------------------------------|----------------------------|----------------------------------------------------------------------|
| Apr. 2019 – Jul. 2019 | FS briquette manufacturing, testing and participatory workshop | Cooks from University of Dar es Salaam, Ardh University and Ubugo | University of Dar es Salaam Canteen Tandale and Kisarawe | To test the quality and availability of the FS briquettes as well as discuss the acceptability of them |
| Jan. 2020 – Feb. 2020  | FGDs, semi-structured interviews and participatory observations | 9 cooks, 3 sellers and 2 producers                                   | To understand the charcoal supply chain in Dar es Salaam as a system |

(Bryman 2012). This was done to allow for a thriving discussion, but at the same time ensure participants felt comfortable speaking (Bryman 2012). During the FGDs, one person spoke at a time to allow for direct translations from Swahili to English, enabling probing and follow-up questions from the author. The FGDs were held at a local restaurant in Tandale.

**Semi-structured interviews**

In order to get a thorough understanding of how sellers and producers in the charcoal supply chain experience the flow of charcoal in Dar es Salaam, we conducted semi-structured interviews with two producers and three sellers. The aim was to obtain an in-depth understanding of sellers’ and producers’ experiences with charcoal. Two semi-structured interview guides were used, one for sellers and one for producers. Similarly, to the FGDs, the interview guides follow aspects of the energy justice framework, with open-ended questions to allow for participants’ insights beyond the themes of the framework (Kvale and Brinkman 2009). Again, the research was translated word-by-word from Swahili to English during the interviews to allow for probing. The sellers and producers were interviewed whilst working, which allowed for observations to be done simultaneously.

**Participatory observations**

The main aim of the observations was to observe how local sellers, users, and producers engage with the charcoal supply chain in their everyday lives. Additionally, the aim was also to engage with even more producers, sellers and end-users. Observations were carried out in Tandale and in Kisarawe. The observations were made whilst being with a local leader or a gatekeeper and were therefore evidently overt (Bryman 2012). During the observations, questions were posed and field notes taken. Taking notes did not seem out of place since the observations were overt. However, the notes were taken discreetly to avoid people from feeling self-conscious (Bryman 2012). Visual ethnography in the form of photographs were also taken to add to ‘what can be seen’ as part of the lived experiences of people (Prosser 2011). Users and sellers were observed in Tandale whilst producers and production processes were observed in Kisarawe.
**Key informant interviews**

We visited the governmental office in the Pwani region and interviewed a forest officer to get insights on how the government approach charcoal in the energy system, specifically linked to administration and legislation of charcoal and the role of big-scale producers. The interview was informal and unstructured and conducted in a mix of Swahili and English.

**FS briquette manufacturing, testing and participatory workshop**

Since the availability and use of FS briquettes are still in their infancy stage in Tanzania, i.e. it is not yet used by communities, we had to manufacture FS briquettes in the lab of the Water Resources Engineering Department at University of Dar es Salaam in order for them to be compared with charcoal. Building on previous research by one of the co-authors (Mwamlima et al. 2017) and adapted to our study, a total of seven one-litre bottle samples of treated FS from the Vungunuti Waste Stabilisation Pond in Dar es Salaam were collected. The FS was then dried on sand beds and mixed with the binding materials waste paper slurry or cassava starch in different ratios until optimal texture was reached. The mixture was pressed into FS briquettes using a Peyam Screw cold press, invented by one of the co-authors (see Figure 2).

The physical characteristics of the FS briquettes were then tested to assess moisture content (smoke), smell, combustion quality, and carbon emissions along with calculations of investment costs (see the supplemental material for more details on the technical aspects of these tests). Testing for smoke and smell was included in order to assess user acceptability, and the combustion quality was used to analyse the potential availability and accessibility of the briquettes, whereas the analysis of emissions was used to assess the sustainability of the briquettes and finally investment costs were calculated to inform our discussion on affordability.

We also conducted a participatory workshop with professional cooks from the student and staff canteens at the University of Dar es Salaam and Ardhi University to explore user knowledge and attitudes towards using FS briquettes as an alternative cooking fuel to charcoal. During the workshop, the process of manufacturing FS briquettes was demonstrated to participants and their perceptions of the physical characteristics of the FS briquettes compared to charcoal were explored, in addition to identifying their preference criteria for a good-quality cooking fuel. The workshop was conducted in a mix of Swahili and English. The key purpose of the workshop was to supplement the technical data with empirical data from the perspective of potential future end-users. (See the supplemental material for details on the content of the participatory workshop).

**Data analysis**

The data analysis was done drawing on Kvale and Brinkman’s (2009) steps: organising the data through translation and transcribing, and then conducting thematic coding. The translations and transcriptions were done by the third author in a word-by-word manner in order to allow for thorough reading and a comprehensive view of the interviews (Kvale and Brinkman 2009). The second step was done through thematic coding (Bryman 2012) with elements of theoretical reading (Kvale and Brinkman 2009) utilising the data management program NVivo. The codes are based theoretically on the Energy Justice framework: accountability; accessibility; affordability; quality; sustainability; good governance; as well as the added dimension of acceptability. To allow for aspects beyond the theoretical framework, thematic sub-codes were generated based on the lived experiences of the informants. The sub-codes came about based on repetition to identify patterns (Bryman 2012). The sub-codes were as follows: seasonality, deforestation, replanting; tree types, hardwood, softwood, flooding, expenses, and profit. The interviews were revisited several times during the process to encapsulate everything relevant (Bryman 2012).

**Ethical considerations**

A written research permit to be able to carry out the study was requested from and granted by the Directorate of Research at the University of Dar es Salaam. Moreover, each respondent was asked for individual consent before participating, and no personal identifiers were recorded to ensure anonymity.

**Results**

The results section introduces the synergies and trade-offs between charcoal and FS briquettes, which we have analysed based on our empirical findings. An energy justice perspective is utilised throughout the Results section, meaning that the aspects of the framework are utilised to guide the results according to availability, accessibility, reliability, affordability, acceptability, sustainability and good governance.
Resource availability and accessibility

Charcoal
From an energy justice perspective, a country’s resource endowment is a necessity to provide and sustain energy services (Sovacool and Dworkin 2015). Charcoal is abundant both within Dar es Salaam and alongside roads coming from charcoal production areas, as one charcoal seller (31 January 2020) explains: during the dry season charcoal is easily accessible as it is available almost everywhere’. Thus, indicating that tree availability is not yet hindering charcoal production. However, the forest cover in coastal forests surrounding Dar es Salaam is changing ([GFW] Global Forest Watch 2020). In the 2000s, 80% of charcoal for Dar es Salaam was produced within a 20 km radius from the city; in 2013 that radius had expanded to 200 km due to loss of forests (Burgess et al. 2013). As a result, producers and sellers must travel further to access trees, as described by one seller ‘we used to go to Morogoro as well but the trees are finished there. Then we came to Kisarawe … we produced a lot there, but the trees are finished in all the places where we used to harvest’ (Seller 31 January 2020).

The quality of charcoal is also essential for availability in the energy justice framework as energy services should be not only available but also of a minimum standard (Sovacool and Dworkin 2015).

The quality of charcoal in Dar es Salaam is affected by the availability of specific tree varieties and in Tandale, charcoal users prefer hardwood trees, such as Dalbergia melanoxylon (Mpingo), because it burns longer than softwood trees (All in FGD 26 January 2020). However, Mpingo trees are now scarce, due to charcoal production and additional activities, such as agriculture and furniture production (Field notes 28 January 2020). Hardwood trees, like Mpingo, have little other value to producers than charcoal production and are therefore slowly being replaced by the producers with fruit trees, which can be used both for farming and charcoal production (Producer 28 January 2020). As a consequence hardwood trees are often logged using the roots of the trees, whereas fruit trees are only harvested for fruit and charcoal rather than logged completely (Producer 28 January 2020). Users in Tandale often only have the option to buy low-quality charcoal from fruit trees amend it burns out faster (FGD 26 January 2020; Field notes 31 January 2020). This means that there is a low incentive for producers to plant new hardwood trees. As one producer explains it:

The natural trees, that was brought by God himself, are almost finished … there are some kinds that we don’t remove because they are needed, like Mango trees, the rest that are not useful, we cut them … These useless trees are useful for the government, but for us they are
useless because they don’t produce fruits or anything… The government says they produce quality air, but even Mango trees can do that and give fruits as well (Producer 28 January 2020). The remaining and replanted Mpingo is mostly found on reserved lands, inaccessible to most producers (Producer 28 January 2020), and users thus experience the quality of charcoal going down. In turn, this means that more charcoal, and hence wood, is needed to compensate for the quick burning of low-quality charcoal, which creates a vicious circle of increased demand for wood.

**FS briquettes**

Faecal sludge, the main resource needed for manufacturing of FS briquettes, is already available in abundance inside millions of on-site sanitation facilities across Dar es Salaam as more than 2221 m³ faecal sludge is generated daily (Mkude et al. 2019). However, desludging is currently ridden with a multitude of challenges including; pit latrine design, vehicle access, desludging costs and a persistent practice of flooding out FS during heavy rains (Jenkins et al. 2015; Seleman et al. 2020). In fact, about 37% of Dar es Salaam’s on-site sanitation systems are not emptied and only 27% of the emptied FS goes to treatment plants (Brandes et al. 2015). Presently, this means that although available in abundance, the majority of FS produced remains largely inaccessible for FS briquette production. This may change drastically, however, if the Tanzanian government heeds the calls made by local sanitation research (Seleman et al. 2020; Mkude et al. 2021) on the importance of improving sanitation infrastructure in unplanned settlements of Dar es Salaam.

**Reliability**

**Charcoal**

Reliability, is an energy system’s ability to withstand disruptions and guarantee reliable energy services at all times (Sovacool and Dworkin 2015). In Tandale, and its surrounding production areas, infrastructure and technology for production, transport, and distribution and storage of charcoal are vulnerable to disruptions, specifically from heavy rainfall. Charcoal is produced using traditional earth kilns, which is a wood and soil construction that is used to slowly burn the wood into charcoal (Figure 3).

Rainfall can negatively affect the traditional earth kilns: ‘the kiln might turn off if you don’t inspect it frequently, because the soil is wet, or, the kiln might be destroyed by rainwater’ (Producer 28 January 2020).

Furthermore, an overwhelming majority of sellers interviewed confirm that charcoal is not only more difficult to obtain during the rainy season but also more difficult to transport. Flooding of roads from forest areas to Dar es Salaam combined with inadequate infrastructure results in trucks frequently getting stuck in mud (Anande and Luhunga 2019; Seller 31 January 2020). This unreliability deters small-scale sellers from using charcoal as a livelihood during the rainy season (Seller 31 January 2020; Field notes 2020). These combined factors increase the production cost for one sack of charcoal during the rainy season to about 4.3 USD as compared to 3–3.5 USD in the dry season (Producer 31 January 2020). Consequently, the price of charcoal also increases for the end-user during the rainy season. Besides lower affordability when it rains, end-users also face challenges of the flooding itself ‘The rainfall of two days ago, no one cooked, because water entered inside the houses and they flooded’ (Domestic cook, FGD-Tandale 26 January 2020) (Figure 4):

When flooding disables the use of charcoal many are forced to purchase cooked street food instead of cooking themselves, adding to their household expenditures (FGD-Tandale 2020). To street cooks this means increased earnings during the rainy season, which they use to stock up on charcoal by storing sacks under the house ceiling, away from rain, to ensure livelihood security (FGD-Tandale 26 January 2020). Domestic cooks on the other hand cannot afford larger sacks but are instead forced to buy smaller amounts of charcoal at a higher price or refrain from cooking during the rainy season. With the rainy season expected to increase but become shorter and more severe in the future (Burch and Harris 2014), especially affecting urban areas, it is likely that charcoal unreliability will persist.

**FS briquettes**

Faecal sludge is visibly available throughout the year, regardless of the season; however, similar to charcoal, limitations exist to production and use of FS briquettes both generally and during the rainy season (Mwamlima et al. 2017). From producing and testing the FS briquettes for our participatory workshop, we
found that rain is directly affecting the energy quantity of faecal sludge by diluting it. During the rainy season the faecal sludge had a slightly lower higher heating value (11 MJ/kg) than the faecal sludge sampled during the dry season (12 MJ/kg), which means slightly higher energy can be recovered during the dry season. This is due to an increase in %TS that leads to an increase in %Cfix, resulting in that a larger volume of FS is required in the rainy season to obtain the same value of energy that would be obtained during the dry season.

Hence, the collected faecal sludge from pit latrines, the most commonly used lavatory in Dar es Salaam (Mkude et al. 2019), is more diluted during the rainy season than during the dry season (Seleman et al. 2020). Septic tanks, on the other hand, are lined inside and are therefore less likely to have water entering compared to pit latrines (Seleman et al. 2020). Adding to this, high groundwater tables, common in low-lying unplanned settlements like Tandale, combined with many people sharing one toilet accelerates the filling rate of toilets (Seleman et al. 2020). The end result is that larger faecal sludge volumes are required to obtain the same value of energy during the rainy season as compared to the dry season, and thus, these factors all pose a challenge to ensure FS briquette production during the rainy season.

**Affordability**

**Charcoal**

The collected data indicates that charcoal is the cheapest cooking fuel option available, when users buy it on a day-to-day basis. Buying LPG is more affordable than Charcoal on the long-term (Malanga 2021) but people in unplanned settlements, like Tandale, are unable to invest the initial cost of LPG and the stoves associated with it (FGD-Tandale 26 January 2020). Hence, they find it necessary to buy charcoal which is cheap on a day-to-day basis, but end up costing more for the end-consumer.
“Gas is expensive”, “you can’t use gas, especially for us, the cost is high” “If the gas runs out and you don’t have money, it means that you won’t eat”, “I also use charcoal because… I make profit by using charcoal, but I would make loss if I use gas” (FGD 26 January 2020).

Even though charcoal is cheaper than other cooking fuels in Dar es Salaam, purchases generally constitute 40% of users’ household expenses (up to 26 USD) each month, compared to rent, electricity and water (see Table 3), a conclusion found also by Sanga and Januzzi (2005).

Street cooks similarly use a disproportionate large part of their business expenses on charcoal: ‘probably even more than half of my profit is on charcoal’ (FGD-Tandale 26 January 2020). Our focus group discussions (26 January 2020) indicated that all of the cooks interviewed earned approximately 4.3 USD a day and spent approximately 2 USD of that on charcoal. In a country where the GDP per capita is only 1 080 USD (Serajuddin and Hamadeh 2020) Tanzanians ultimately spend a high proportion of their income on charcoal. In addition, the price of a sack of charcoal has increased rapidly in the last ten years, from 16 USD ([WB] World Bank 2010), to between 30 and 50 USD depending on the season (Fieldnotes, 2020).

Furthermore, prices and volume of charcoal fluctuate depending on the season (Figure 5), thus going against the notion that energy services should be equitably priced with minimal volatility (Sovacool and Dworkin 2015).

### FS briquettes

Since FS briquettes are yet to be sold on the market, we have calculated an estimate of the initial investment price of producing the briquettes, based on our own production costs at the participatory workshop. Our calculations show that the investment costs would be at minimum 1 388 USD for 12 kg including transportation, dry faecal sludge, water binder material (saw dust and waste paper), pyrolysis reactor and the Payam Screw could press. While this is significantly higher than for charcoal, which can be produced for an initial investment cost around 2.39 USD (for a permit, sacks and rope) given that the producer has access to trees (Producers 26 January 2020), numbers from Sanivation (2020) show prospects of FS briquettes becoming an affordable alternative to charcoal. Sanivation (n.d.) collaborates directly with the local government and revenue from the FS briquettes is used to cover both the operational cost of desludging, FS treatment and ensuring safe management of FS throughout the entire sanitation supply chain. Sanivation (2020) estimates that there is a 38–84% cost saving for the end-user when switching from firewood or LPG (gas) to their FS briquettes.

### Acceptability

#### Charcoal

While the other aspects of the energy justice framework are important, without acceptance from the end-users no innovation will ever be adopted, and this is particularly significant if it is a taboo ridden energy source. Since charcoal is the cheapest available cooking fuel on a day-to-day basis for the end-users in Dar es Salaam it is also highly accepted (All FGD-Tandale 26 January 2020). Yet, while affordability is one key aspect for people’s acceptance the specific technological characteristics of charcoal also align well with people’s cooking norms and habits (Mkude et al. 2021). As expressed in the FGDs (26 January 2020), many users cook with charcoal.

#### Table 3. Monthly Household Expenses.

| Expense type | Rent | Electricity | Water | Charcoal |
|--------------|------|-------------|-------|----------|
| Expense in USD | 11–17 USD | 4.3–9 USD | 13 USD | 26 USD |

Figure 5. Charcoal buckets in Tandale, Dar Es Salaam, Tanzania illustrating differences in volume depending on the season. Left: green bucket filled during the rainy season vs. right, orange bucket filled during the dry season (photo by Amidu Mtalii, 16 February 2020).
because it is slow burning and thereby allow them to easily cook traditional food such as beans and chapati:

For charcoal you can reduce the heat underneath by placing the charcoal on top of the pan, then you will get matandu [a hard-top layer of rice], which has a nice taste (end-user FGD-Tandale 26 January 2020).

As indicated by the end-user, charcoal is deeply ingrained in Tanzanian cooking traditions, as it is in most sub-Saharan countries (Sola et al. 2017). But while charcoal is preferred for its cooking versatility, it is similarly disliked for the smoke that it produces. Smoke can affect both human health and the environment negatively (ibid.). Yet, charcoal users in Tandale feel dependent on charcoal as long as they do not have alternatives which are as cheap:

Even for us, it is not as if we like using charcoal, if we get an alternative, which is as cheap as charcoal, we will dump charcoal (FGD-Tandale 26 January 2020).

Currently, charcoal is therefore not necessarily a preferred cooking fuel, but it is the only one the end-users can afford, thus indicating that end-users are also open to alternative cooking fuel.

**FS briquettes**

Acceptability of FS briquettes is highly dependent on local norms and taboos, as expressed by an end-user during our workshop ‘People perceive faeces as the dirtiest material of all waste’ (Workshop 18 May 2019) and another cook adds ‘The perception of the customer might change, which might affect the business’ (Workshop 18 May 2019). Adoption of FS briquettes is therefore contingent on overcoming these taboos. As other studies in Tanzania show, persistent faecophobic attitudes towards the use of human waste derived end-products that are ingested (Mkude et al. 2021). Adding to this, cooking with our manufactured FS briquettes during the participatory workshop revealed a lot of smoke in the beginning of burning, which the cooks were not happy with (Workshop 18 May 2019). The smoke is caused by the relatively high moisture content of the sun-dried FS briquettes, meaning that the initial burning is used to completely dry the briquettes. Our manufacturing showed that the initial smoke can be eliminated by combining sun drying with solar dryers to attain full removal of the moisture content in the briquettes. One other thing to consider is the ratio of binder to faecal sludge as our manufacturing showed that increasing of the binder reduces the higher heating value but increases the longevity during burning. Thus, the binder content and amount affect the quality of the FS briquettes.

Yet, a huge benefit of FS briquettes is that they can be utilised with existing charcoal cooking utilities. **Figure 6** illustrates how FS briquettes resembles charcoal both in appearance and application which appeals to users and increases acceptability (Workshop 18 May 2019).

Furthermore, our workshop participants reacted positively to the FS briquettes when they realised that the briquettes have no smell and they also ranked price and reliability as the most important features of cooking fuels (Workshop 18 May 2019).

**Sustainability**

**Charcoal**

The aspect of sustainability in the energy justice framework (Sovacool and Dworkin 2015) argues for maintaining resources in a way that can sustain future energy demands. Calculation of deforestation from charcoal production is dependent on several factors, for example, land use change, consumption rates, population growth rates of, kiln efficiencies, and wood type (Msuya et al. 2011). It is therefore also questioned how much charcoal production attribute to deforestation. In line with this, [SDC & TFCG] Swiss Agency for Development and Cooporation & Tanzania Forest Conservations Group (2017) argue that charcoal production is far from the biggest contributor to deforestation, and that it should rather be attributed to clearing land for agriculture ([SDC & TFCG] Swiss Agency for Development and Cooporation & Tanzania Forest Conservations Group 2017). However, our interview with the producers indicates that charcoal and agriculture function as a livelihood in conjunction, or that agriculture is a side-income to charcoal production:

‘I need charcoal money to run my life and agriculture as well’; ‘… during the dry season, the agricultural works are not available, so all the people engage in charcoal production’ (sellers 28 January 2020).

Mwamlima et al. (2017) supports this notion and claims that efforts against deforestation in Tanzania are failing because charcoal is not recognised as an industry contributing to deforestation. Studies estimate that charcoal production has led to 40% of deforestation in Tanzania annually, while production
specifically for Dar es Salaam is estimated to cause between 100,000 and 125,000 ha of forest loss annually ([WB] World Bank 2010; Msuya et al. 2011). Mwamlima et al. (2017) has constructed eight scenarios for the future of forest in Tanzania, where seven out of eight scenarios predict that more than 1 million ha of forest will be lost annually due to charcoal production in Tanzania from 2007 through 2100 (Ramadhani 2007). Similarly, Msuya et al. (2011) predict that forest losses will increase from 10 303 ha in 2009 up to 2.8 million ha by 2030 due to charcoal production for Dar es Salaam alone. Assessing the future implications of this, holds some anticipation, yet, the above scenarios, combined with the prediction that charcoal consumption is increasing ([WB] World Bank 2010), indicates that the charcoal industry has a significant impact on the forest cover in Tanzania both now and for future generations energy needs.

**FS briquettes**

FS briquettes could help conserve Tanzania’s forest resources, mitigate climate change and reduce the disease burden from inadequate sanitation. Sanivation (2020) estimates that per one ton of their FS briquettes, one ton of CO2eq emissions can be offset, 22 trees are saved, 50 people are provided safe sanitation and thus reducing diarrhoeal disease by 47%. Furthermore, better faecal sludge management can help improve the health of many in the unplanned settlements of Dar es Salaam (Mkude et al. 2021). Finally, faecal sludge is in abundance in Dar es Salaam and is expected to increase with increasing population (ibid), thus meaning that it can be available to use as a cooking fuel for generations to come. However, our emissions tests show that similar to charcoal, FS briquettes emit high levels of carbon monoxide. Charcoal emits 2 385 ppm compared to 2 836 ppm for FS briquettes, thus indicating that as with charcoal, FS briquettes are best used for cooking outdoors.

**Good governance**

Charcoal

In an energy justice perspective, it is the duty of the state to ensure sustainable resource use (Sovacool and Dworkin 2015). In Tanzania, there are a range of initiatives to combat some of the environmental burdens of wood logging and harvesting for charcoal (Ellegård et al. 2002; [WB] World Bank 2010; Sander et al. 2013). Especially apparent is the government’s attempt to limit supply and demand by putting a two-week ban on charcoal production in 2006 ([WB] World Bank 2010). The ban proved to be inefficient and the charcoal business continued almost undisturbed ([WB] World Bank 2010). One of the reasons for this is that the complexity of the system fosters illegal activities, such as side payments, bypassing of regulation, in addition to complicating implementation of policy reforms, which could make the industry more sustainable ([WB] World Bank 2010; Sander et al. 2013; Mwamlima et al. 2017).

The government has a ‘Harvesting Plan’ that monitors logging activities (Forest Officer, 28 January 2020). Currently, the plan comprises 17 out of 79 villages in Kisarawe (Field notes 2020). Included in the plan are also initiatives of replanting and preserving wild trees (Forest Officer, 12 February 2020). Some achievements from the...
plan are the production of 3 153 tons of sustainable charcoal in 13 of the villages and over 100 000 ha conserved woodland in 22 villages ([SDC & TFCG] Swiss Agency for Development and Cooperation & Tanzania Forest Conservation Group (TFCG) 2018). As part of the plan, producers can obtain permits to log in reserved areas, but the process is strenuous and producers often turn to illegal logging or using fruit trees instead (field notes 2020), and thus, the complexity and lack of transparency become apparent in the process.

**FS briquettes**
For Sanivation (2020), having the city government of Naivasha prioritise and support their enterprise has been crucial to obtain funding for their project in Kenya. In Tanzania, such financial support is still not there, but the Vice President’s office (2020) has taken interest in the issue of reducing charcoal dependency by demanding that all public institutions (universities, schools, and the military) divert their charcoal usage towards alternatives. Current funding has been directed towards three companies with a total of 258800USD ([URT] United Republic of Tanzania Vice President’s Office 2020). However, these companies utilise dry bio-waste as opposed to faecal sludge for briquette production. This may be connected with general under prioritisation of investing in improved on-site sanitation systems (GLAAS 2020).

**Discussion**

**The synergies and trade-offs of charcoal versus FS briquettes**
This study shows that both FS briquettes and charcoal both have synergies and trade-offs from an energy justice perspective. Table 4 below synthesis the findings:

The trade-offs and synergies used to access energy justice cannot be analysed in isolation, and our results show connections between the different challenges and benefits. Paradoxically, rates of deforestation are negatively affected by the very same socio-economic activities, as continued unsustainable production, distribution, and demand for charcoal will increase forest loss, and then again contribute to the slack of accessibility, reliability and affordability. Furthermore, challenges of accessibility and reliability of charcoal during the rainy season affect the affordability of charcoal. This therefore indicates that a more diversified system may be better for the environment and bring more choices and stability to the end-user than charcoal currently does.

Our results also show that FS briquettes have the potential of being as cheap as charcoal for the end-user and more abundant for generations to come, especially to people in Dar es Salaam’s many unplanned settlements. Yet, there are also trade-offs of FS briquettes. One major challenge is making the briquettes acceptable amongst users. Yet our results also indicate that urban consumers’ dislike of charcoal gives a window of opportunity to introduce alternatives that comply with their context-specific cooking needs and cooking utensils. Contributing to this could be demonstrating the FS briquettes to end-users when disseminating the product. As an example, Sanivation finds that demonstrating the briquettes to end-users is essential ([UN] United Nation 2018). In their experience, end-users do not think the FS briquettes looks like faeces, smells like faeces or burns like it when they demonstrate them ([UN] United Nation 2018). This is also what we experienced during our workshop (18 May 2019). Adding positively to the demonstrations, could be government certification as it builds legitimacy for FS briquettes as a commercial product. For example, through certifications from the national standards set out by the Tanzanian Bureau of Standards (adapted from ISO 17225–8 2016).

Finally, given the nature of current energy and sanitation systems, like other energy alternatives, FS briquettes would benefit from being subsided. However, not for the end-user but rather for start-up projects, this would in turn ensure the possibility of selling the briquettes at an everyday lower cost than charcoal. For FS briquettes start-ups to break even, financial support from development and private sector partners and governments is therefore crucial, just as Sanivation has experienced during their now over 11-year long process of refining their products ([UN] United Nation 2018). Given former energy use patterns in Dar es Salaam (Doggart et al. 2020) and the time it may take to scale-up FS briquette businesses, it is unlikely that a complete transition from charcoal to FS briquettes will happen soon, but the FS briquettes can potentially be an alternative cooking fuel which can be produced and distributed in a sustainable and just manner.
Table 4. Synergies and trade-offs.

| Energy source | Availability/Accessibility | Reliability | Affordability | Acceptance | Sustainability | Good governance |
|---------------|---------------------------|-------------|---------------|------------|----------------|-----------------|
| FS Briquettes | **Synergies** Faecal sludge is highly abundant | It is available throughout the year | Has potential of being as cheap as charcoal | Has the same cooking abilities as charcoal | Several synergetic affects towards SDGs | Government initiatives are emerging |
|               | **Trade-offs** But it can be difficult to access it | The rainy season may affect its quality | In need of start-up financial support | Acceptance of its origin is difficult | Emits more CO than charcoal | More support is needed and can be difficult because of taboos |
| Charcoal      | **Synergies** For the end-user charcoal is easily available | Mostly accessible | Affordable on a day-to-day basis | Highly accepted | Potential of being more sustainable – renewable resource currently unsustainably managed | Government initiatives have been attempted |
|               | **Trade-offs** For producers wood for charcoal is becoming more difficult to obtain | But more expensive and of worse quality in rainy season due to more difficulties in accessing it | Although affordable on a day-to-day basis, the long-term cost is high and volatile | End-users dislike the smoke and smudge | Most government initiatives have been unsuccessful for many reasons, including lack of transparency and corruption |
Conclusion

Charcoal remains as the main urban cooking fuel in Dar es Salaam despite posing significant energy injustices. Not only does this study demonstrate how accessibility and availability of charcoal are hampered throughout the year, but major price fluctuations in the dry vs. the wet rainy season also reduce its affordability, despite it still being the cheapest cooking fuel for the majority of end-users. Present and future charcoal use is also likely to be highly unsustainable since future demand will outgrow reforestation of trees. By contrast FS briquettes, which relies predominately on a recycled and never-ending resource, ought to have higher energy justice potential than charcoal by comparison. But our hypothetical exercise shows that the future potential of FS briquettes also comes with evident and significant challenges. First, the current sanitation infrastructure of Dar es Salaam, particularly in the unplanned settlements of the city, poses significant, and perhaps impossible barriers to access the faecal sludge needed for future briquette production. Second, the added dimension of acceptability reveals that while end-users may be able to use existing cooking utilities to cook with FS briquettes, the origin of the FS briquettes is riddled with taboos. Finally, FS manufacturing necessitates high initial investment costs, which in a low-income country like Tanzania requires financial capital to be leveraged from the government or private sector. These may not be insurmountable barriers, however, as the case of Sanivation in neighbouring Kenya has proved. Indeed, here partnering with the government has facilitated the scaling up of production and distribution from a small to a larger enterprise. Similarly, the government of Tanzania could contribute to enabling FS-briquette production and use by prioritising faecal sludge management, by demonstrating FS benefits to end-users and legitimising them through certification, as well as encouraging private sector development through governmental subsidies or engaging in public–private partnerships.

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Contributions

Conceptualisation, LMSF and SG; methodology and data collection, LMSF, SG, and PW; formal analysis, LMSF and PW; writing—original draft preparation, LMSF; writing—review and editing, LMSF and SG; visualisations, LMSF; supervision, SG; funding acquisition, SG and LMSF.

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