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Nexusing Charcoal in South Mozambique: A Proposal To Integrate the Nexus Charcoal-Food-Water Analysis With a Participatory Analytical and Systemic Tool

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Nexus analysis identifies and explores the synergies and trade-offs between energy, food and water systems, considered as interdependent systems interacting with contextual drivers (e.g., climate change, poverty). The nexus is, thus, a valuable analytical and policy design supporting tool to address the widely discussed links between bioenergy, food and water. In fact, the Nexus provides a more integrative and broad approach in relation to the single isolated system approach that characterizes many bioenergy analysis and policies of the last decades. In particular, for the South of Mozambique, charcoal production, food insecurity and water scarcity have been related in separated studies and, thus, it would be expected that Nexus analysis has the potential to provide the basis for integrated policies and strategies focused on charcoal as a development factor. However, to date there is no Nexus analysis focused on charcoal in Mozambique, neither is there an assessment of the comprehensiveness and relevance of Nexus analysis when applied to charcoal energy systems. To address these gaps, this work applies the Nexus to the charcoal-food-water system in Mozambique, integrating national, regional and international studies analysing the isolated, or pairs of, systems. This integration results in a novel Nexus analysis graphic for charcoal-food-water relationship. Then, to access the comprehensiveness and depth of analysis, this Nexus analysis is critically compared with the 2MBio-A, a systems analytical and design framework based on a design tool specifically developed for Bioenergy (the 2MBio). The results reveal that Nexus analysis is "blind" to specific fundamental social, ecological and socio-historical dynamics of charcoal energy systems. The critical comparison also suggests the need to integrate the high level systems analysis of Nexus with non-deterministic, non-prescriptive participatory analysis tools, like the 2MBio-A, as a means to increase sensitivity to the specifics of charcoal systems while keeping the practical benefits of Nexus as a high level policy design tool. In conceptual terms, this integration promotes open, participatory, integrated, comprehensive and creative analysis and exploration of the Nexus across scales, disciplines and sectors, providing thus, a strong base to design inclusive, sound and robust policies, projects and strategies relating/integrating charcoal, food and water security.

Keywords: participatory nexus analysis, charcoal, 2MBio, mozambique, systems thinking, analytical frameworks

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INTRODUCTION

In recent years, the Nexus approach has gained considerable and increasing professional, academic and political attention as a relevant systems approach to inform and shape policy, funding and research on integrated energy, natural resources and environmental management (Kurian and Ardakanian, 2015; Boas et al., 2016; Wichelns, 2017).

The nexus' basic argument is that fundamental systems (or economic sectors) like water, energy and food/agriculture, are intrinsically interdependent and, thus, must be addressed through integrated approaches (Boas et al., 2016; Al-Saidi and Elagib, 2017). Addressing a system/sector in isolation and ignoring Nexus synergies and trade-offs can produce misleading results and are inadequate to provide basic services to the poorest and fail to adequately cope with climate change (Brouwer et al., 2018). Hence, rather than looking into systems in isolation, nexus approaches promote the trans-disciplinary and trans-sectorial joint analysis, assessment, modeling and management of the multi-faceted linkages and interactions between systems (Howartha and Monasterolo, 2016). While many systems composition and denominations exist, this study focuses on the well-known nexus Energy-Food-Water (from here on, the Nexus).

The Nexus puts emphasis on the dangers of scarcity and is seldom justified by a number of different drivers or influencing factors that, through direct or indirect feedback and feed-forward loops, can result in unsustainable depletion of resources (Allouche et al., 2015). These drivers tend to be interrelated and generally include (e.g., Biggs et al., 2015; Keairns et al., 2016): climate change and extreme events (e.g., floods, drought); socio-economic trends (e.g. demographic trends); ecological impacts; and institutional systems. Therefore, Nexus provides a conceptual framework to analyse how a specific interest focus (e.g., natural resources management) relates with: the interactions (trade-offs, synergies and linkages) between water, food and energy systems and associated "security"; the drivers or influencing factors pressing the dynamics those interactions and "security"; and specific aspects affecting and being affected by those interactions (**Figure 1**).

As a systems analysis, the Nexus has been included in policy goals such as circular economy, low-carbon economy, resource efficiency, sustainable development, access to clean water and social welfare (Yillia, 2016; Brears, 2018; Brouwer et al., 2018). Remarkably, such deterministic and modular Nexus framework, facilitates mathematical modeling of systems as resources, i.e., (sources of) water, (forms of) energy, and (specific) food crops. Consequently, it is possible to model and quantify resource demand, costs and trends for each isolated resource/system, as well as, the dynamic interaction between different resource/system, i.e., how a stress in one Nexus system can create pressures on the other systems (Gulati et al., 2013; Kling et al., 2017). Formally, these models link different knowledge sets (models) to support evidence-based adaptive strategies (Scott et al., 2015), identify and minimize trade-offs (Pittock et al., 2015; Kurian, 2017), and maximize synergies, efficiency, while reduce risks and improve resource governance (FAO, 2014; Gallagher et al., 2016).

Despite these objectives and potential, the Nexus has been considered a "new development buzzword" (Dupar and Oates, 2012) which is not exactly new, generating a "somewhat misplaced [enthusiasm]" (Wichelns, 2017) and presenting serious implementation challenges, particularly evident on Nexus modeling, both isolated for each systems or in integrated Nexus analysis. The most relevant Nexus modeling drawbacks include the lack of (Kaddoura and El Khatib, 2017; Kling et al., 2017; Liu et al., 2017): data in quantity, quality and consistency; systematic identification, analysis and exploration of synergies, trade-offs and impacts simultaneously across scales and levels of detail; aggregation methods "sensitive" to local specificities; incorporation of human and systems adaptation and behavior; methods to evaluate and compare models. Another critique of the Nexus refers to the existence of institutional and communication barriers across sectors and disciplines that hinder dramatically the applicability in real institutional settings (Conway et al., 2015; Endo et al., 2015; Leck et al., 2015; Wichelns, 2017). Finally, Allouche et al. (2015) also see the Nexus as part of the "neoliberal policy [that hides issues such as] resource inequality and access [. . .] the manufacture of scarcity and international political economy and geopolitics."

For the purpose of this work relevant gaps in Nexus research include: the water-centric focus (Endo et al., 2015; Smajgl et al., 2016); the general absence of analysis of charcoal energy systems (CES) or Sub-Saharan Africa contexts (Ferroukhi et al., 2015); and the lack of studies critically comparing nexus analysis with other systems approaches. These gaps are particularly relevant as CES are fundamental for many developing countries through multidimensional interactions with crucial socio-economic aspects (Mirzabaev et al., 2015; Martins et al., 2018). To address these Nexus research gaps, this work focuses on the Nexus for charcoal presenting a relational graphic (**Figure 3**) displaying the interactions between charcoal, water and energy for the case of Mozambique (section Uncovering The Nexus Charcoal-Food-Water In Mozambique). These compared results are then compared with a similar analytical exercise conducted with a novel systems analytical tool, the 2MBio-A (based on the design tool 2MBio, Martins et al., 2018), developed specifically for bioenergy and applied to the case of Mabalane district in southern Mozambique (section Charcoal Centred Systems Analysis For Mozambique). The critical comparison exposes the analytical limitations of Nexus and options are presented to integrate Nexus analysis with non-deterministic and non-normative tools, like the 2MBio-A or 2MBio, to amplify the analytical capabilities and comprehensiveness of Nexus analysis with more participatory and specific insights (section Constructive Discussion: Proposal For An Integrated Design Approach). The conclusion (section Conclusion) resumes the discussion and analysis of outcomes of the work and presents possible future work.

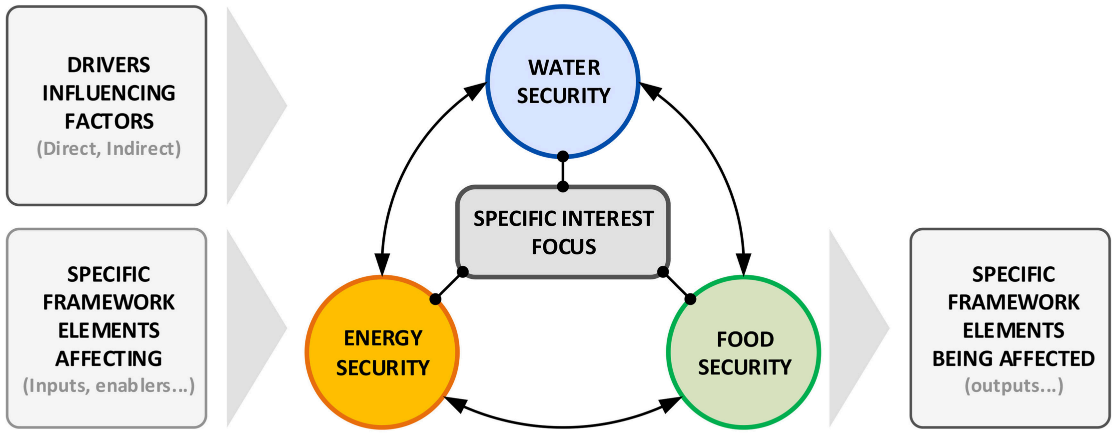

FIGURE 1 | Generic graphical representation of the Nexus analytical framework (the names and definition of the components might differ slightly depending on the author).

UNCOVERING THE NEXUS CHARCOAL-FOOD-WATER IN MOZAMBIQUE

Mozambique, a Sub-Saharancountry, has been for decades among the 20 least developed countries in the world (UNDP, 2016). Mozambique has more than 50% of its population experience chronic or periodic episodes of food insecurity (Batidzirai et al., 2006), and droughts and flood episodes related, directly or indirectly with climate change (e.g., Bullock and Hülsmann, 2015). Mozambique is highly dependent on wood fuel energy systems for cooking, mostly charcoal in cities and firewood in rural areas. An estimated 96% of the population (over 25 million people) rely on wood fuel (IEA, 2014), which represents 2.2% of total GDP (van der Plas et al., 2012), 76.5% of all national energy demand and over 15×10^6 tons of wood (worth 700million US$) taken from Mozambican forest every year (Ryan et al., 2016). Simultaneously around 51% of Mozambican population (45% in rural areas and 8% in cities) have no access to improved water sources (WHO/UNICEF, 2014) and large portions of the country are arid or semi-arid (Turton et al., 2008). At the policy level, the Government of Mozambique had long established clear policies for food security, including a main national strategy Plan for the Reduction of Absolute poverty (PARPA in Portuguese) and the 1991 Law of Water. However, and remarkably, charcoal is virtually absent from Mozambican policy while 98% of charcoal business is informal (Cumbe et al., 2005). Furthermore, issues with water, charcoal and food tend to be addressed by separated Ministries, with inexistent or poor effective inter-ministerial coordination. The policies relating water with food production exist, but highly criticized by their lack of suitable social and political considerations (van der Zaag et al., 2010; Alba et al., 2016; Ducrot, 2017). Therefore, Mozambique presents an interesting research opportunity to explore the Nexus focusing on charcoal in a socio-ecological context marked by climate change, poverty, water and food scarcity, and the absence of specific policies for charcoal or linking charcoal with water and food security.

The first task proposed by this research is to make explicit the Nexus water-charcoal-food and associated drivers in Mozambique. This task presents two important challenges: the scarcity of work on the Nexus applied to charcoal or Mozambique; and the existence of relevant Nexus research not identified as such. Hence, to support a comprehensive analysis and avoid a possible bypass of relevant information, this review includes: the work explicitly mentioning the Nexus on Mozambique (section Explicit Nexus Analysis Made On Mozambique, and Southern Africa); and "Nexus like" analysis linking water and/or food with charcoal energy systems or bioenergy in contexts similar to Mozambique (section Nexus And Systems Analysis Relevant For CES And Mozambique).

Explicit Nexus Analysis Made on Mozambique, and Southern Africa

The review of the workthat explicitly mentions the nexus and Mozambique (Bullock and Hülsmann, 2015; Nielsen et al., 2015) revealed an essentially water centric Nexus analysis, i.e., water is the main focal point of analysis and intervention. Bullock and Hülsmann (2015) identify a high, but unevenly distributed, potential for sustainable development based on hydropower for Mozambique and several vulnerabilities. Currently, hydropower supplies over 98% of the national electrical consumption, but the availability of water might refrain further growth. Nine of Mozambique's 11 main rivers are trans-boundary, which makes the country particularly dependent on neighboring countries' water policies, strategies and availability. Climate change intensified drought in the region and Mozambique further reducing rivers' downstream flow. Finally, population, industrialization and agriculture growth increased water usage for drinking processing and irrigation. Therefore, hydropower is presented as a synergetic solution, controlling river flow (and reducing flood effects), storing water, facilitating irrigation and improving, geographically, quantitatively and qualitatively, the availability of electrical supply for productive uses. Moreover, for Bullock and Hülsmann (2015), emphasize the role of Integrated

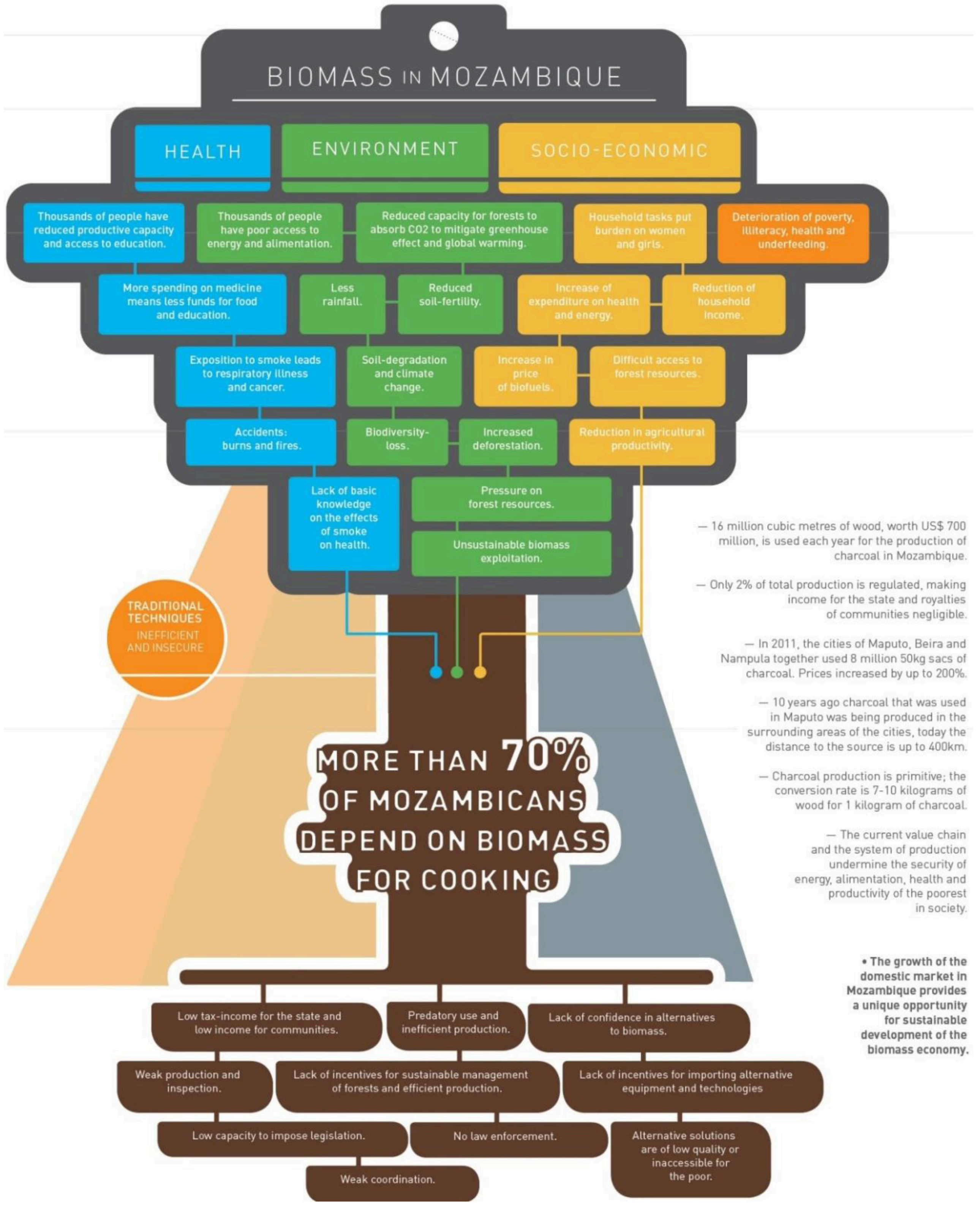

FIGURE 2 | Biomass Tree of Problems, created in a National Expert's Workshop at Maputo (Source: SNV, 2007).

DRIVERS OR INFLUENCING FACTORS

☐ **Climate change** (ENSO) **and extreme events** (floods, droughts, cyclones) ☐ **Soil scarcity and erosion** ☐ **Competing and combined uses of resources** ☐ **Deforestation**	☐ **Poverty; Urbanization; Population growth** ☐ **Energy intensification; Increased demand for woodfuels** ☐ **Globalised economy** (aid, capital/technology transfer) ☐ **Changing livelihood patterns** (energy, food, consumption) ☐ **Lack of suitable infrastructures and tecnology**	☐ **Governance** (week or absent law enforcement, Informality, lack of political coordination, corruption) ☐ **Power relations** (discrimination, structures and networks) ☐ **Geopolitics** (downstream location, conflict)

	WATER	CHARCOAL/BIOCHAR	FOOD
WATER		• Water availability and quality ➔ CHP operation (steam, refrigeration) → energy security and irrigation cost and intensity • Water availability and quality ➔ Growth of dedicated crops for charcoal (and GHG emissions)	• Irrigation ➔ Crops (more harvests, crop diversity and yields) ➔ Food security → income • Irrigation ➔ Labour market (off-farm income vs abandon food production vs geographic concentration of food production and consumption) ➔ Income and food security • Water availability and quality ➔ Health (water bourn deceases, sanitation) ➔ food security
CHARCOAL/BIOCHAR	• CHP ➔ Afects water avalability (more vs overexploitation) • CHP ➔ Diversify water uses (drinking vs irrigation) • CHP ➔ Afects water quality (pollution vs desalination, heating, cooling) • CHP ➔ Water supply (extraction, pumping, treatment and purification, distribution) • Deforestation from charcoal ➔ Soil quality (erosion) and Climate change (less rainfall) ➔ Water availability (less underground water, droughts, less water retention on soils) • Income from charcoal ➔ Funds irrigation (e.g. acquisition, operation, maintenance) • CHP projects ➔ Equity on water entitlement and rights • Dedicated crops for charcoal making ➔ Water availability for other crops • Availability and quality of CHP electrical power ➔ irrigation and water treatment systems options • Dedicated energy crops (plantations) ➔ Pollute Water (fertilizers), • Biochar ➔ Increases water retention (less irrigation) • Biochar ➔ Treat wastewater for irrigation (cadmium and lead removal)		• CHP and charcoal sterilise and boil water ➔ Food security • CHP based irrigation ➔ see above • CHP and charcoal heat ➔ Food processing and conservation and cash-crops ➔ Food security → Income • CHP and charcoal heat ➔ Small industry (e.g. brick making) ➔ income → Food security • Lack of charcoal ➔ Cooking habits (e.g. Less nutritious food eaten row, uncooked or prepared fast) ➔ Food security • Charcoal production ➔ Heath (e.g. respiratory deceases, fires, accidents) ➔ Less time, labour and income for food • Charcoal production ➔ Soil quality (natural soil regeneration vs deforestation effects, see left) ➔ Diet and food security • Charcoal income ➔ Socio-economic environment (reinvested in productive uses vs exacerbate previous prevailing social inequity in access and use of resources vs abandon of food production vs availability of other valuable resources like construction wood or firewood) ➔ Income → Food security • Dedicated crops for charcoal ➔ Agriculture systems (land, water and labour availability vs nitrogen fixation) ➔ Food security and prices
FOOD	• Increased food production ➔ Water overexploitation and pollution ➔ Water cost and time spent to collect • Deforestation from farming ➔ Soil quality (erosion) and Climate change (less rainfall) ➔ Water availability (less underground water, droughts, less water retention on soils) • Agroforestry ➔ Water retention	• Food habits and urbanization ➔ increased demand for charcoal and CHP • Cultural habits ➔ Preference for charcoal and unavailability of economically viable alternatives • Increases agriculture production ➔ available cheap animal and agriculture wastes to compete with charcoal for energy • Agroforestry ➔ Trees/wood residue for charcoal/firewood	

FIGURE 3 | Relational table detailing the Nexus drivers and interactions (CHP- combined heat and power technology based on woody biomass or charcoal; ➔ Direct link; → indirect link; Sources: see sections Explicit Nexus Analysis Made On Mozambique, and Southern Africa–Uncovering The Nexus Charcoal-Food-Water In Mozambique).

Water Resources Management to bring about synergetic effects on the nexus.

Nielsen et al. (2015) conducted a nexus analysis on Mozambique to identify trade-offs. Interactions and possible synergies to justify and model the effect of a number of specific interventions in the nexus. Mozambican agriculture is characterized for: being virtually all rain-fed and presenting the lowest yields in SADC, underdeveloped extension services and limited access to inputs (e.g., fertilizers). Conversely, weak distribution network for products and inputs, hinder the development of a sustainable market and food security. In this context, wide variations in rain fall, increasingly frequent and intense floods and droughts, extreme dependence on upstream countries for water quantity and quality, uneven distribution of groundwater, inefficient use of water sources, lack of suitable infrastructures and distribution network, lack of skills and political coordination present major challenges for and water security and, in particular, for irrigation. In this regard, while hydropower could increase food security through irrigation, it might also compete with agriculture for water and significant water losses through evaporation of reservoirs are possible, which poses a threat to water security. Since Mozambique exports around 80% of its hydropower and, Nielsen et al. (2015) only around 20% of the population, and less than 8% of rural households, have access to electricity, the microlevel effects of hydropower in energy security are minimal. Still on the energy sector, Nielsen et al. (2015) acknowledges the overwhelming presence of firewood and charcoal for cooking, as well as, their possible impacts in the nexus. Respiratory diseases resulting from smoke emissions, and time and resources spent collecting firewood and producing charcoal affects the capacity to work and/or reduces the availability to engage in other on-farm or off-farm paid work opportunities, affecting ultimately food security. This "time link" and "health link" might have a gender dimension since women are responsible for collecting wood, cooking and usually spend more time in farms than men. Charcoal (more than firewood) is also linked with deforestation, which is, in turn, linked with soil erosion and water retention in soils. According to Nielsen et al. (2015), high urbanization rates, lack of suitable technological alternatives and political involvement form national governments drive the increasing demand for charcoal leading to increasing pressure on forest resources, soil erosion and poor watershed management. Nielsen et al. (2015) also evaluate the effects of agroforestry (the practice of planting crops together with woody plants) on the nexus. Nitrogen-fixing trees and the decomposition of leaves, fruits, and other biomass and residues produced by those trees, act as organic fertilizer with low ecologic impact, increasing soil fertility, reducing soil erosion from wind and water and resulting in higher agricultural output. The possibility to have fruit trees or legumes can also contribute to more food availability and dietary diversity. Mozambique had success history of intercrop of cashew trees (introduced by Portuguese from India) with cassava or maize by small farmers in almost one-third of the Mozambique. However, Civil war, the lack of renewal of trees and pressure from donors (notably the World Bank) resulted in the deterioration of the cashew sector in the 1980–1990s, with serious impacts on household income and food security at local level (Hanlon, 2000).

Remarkably, many of these water-centric analysis and conclusions are also in Nexus studies done for Southern Africa Development Community (SADC) and Southern Africa Region:

- Climate change will affect water availability, food production, livelihoods, electricity supplies and basic infrastructure. The ENSO (El Niño Southern Oscillation) is expected to produce an increasing frequency, intensity and unpredictability of extreme climate events, including the massive floods (465,000 people displaced between 2001 and 2008) and chronic droughts and cyclones (Obasi, 2005; Ward, 2010; Conway et al., 2015).
- Charcoal is absent of analysis or, if considered, is considered a problem to be solved by other forms of energy or technologies favored by existing institutional arrangements, e.g., centrally planned hydropower projects and "improved" or "modern" technological solutions (Schreiner and Baleta, 2015; Mabhaudhi et al., 2016; Muller, 2016).

These results are combined with section Nexus And Systems Analysis Relevant For CES And Mozambique in the nexus interaction graphic in section Nexus Causal Relations for Mozambique.

Nexus and Systems Analysis Relevant for CES and Mozambique

To complement the review on Nexus analysis explicitly mentioning Mozambique (section Explicit Nexus Analysis Made On Mozambique, and Southern Africa), a review was conducted focusing on studies that included: (1) systemic analysis linking charcoal with water and/or food in Mozambique; (2) relevant nexus analysis of bioenergy or CES in developing countries.

One of the few systemic analysis of CES from a "nexus like" perspective was developed by SNV (2007) in a workshop with Mozambican experts' (**Figure 2**). In this analysis, CES is perceived as a problem rooted in weak or unsuitable institutional and technological systems, high demand ("70% of Mozambicans depend on charcoal for cooking") and free easily accessible forest wood. These root problems could be understood as drivers for the Nexus with deep health, environmental and socio-economic effects.

Regarding the consequences, from a Nexus perspective, three interdependent dynamics are visible:

- Unsustainable CES promote deforestation, which degrades the soil and promotes climate change, reducing rainfall, which further increases soil degradation. These direct and indirect roots for soil degradation result in lower fertility and, thus, less food availability and lower income (e.g., to buy food).
- The inefficient technology used on charcoal production and consumption is associated with accidents, burns and fires and respiratory diseases, decreasing the household health, availability to work and, thus, income availability for food due to increasing spend on health care and decreasing work productivity, which may lead to food insecurity.
- The combination of the two dynamics above and the absence of strong, enforcing and suitable institutional and policy framework result in informal and unsustainable forest management, progressive scarcity of wood or increase of wood prices, leading to poverty and malnourishment, with higher impact on women and girls.

Some other studies complement this analysis highlighting a number of trade-offs, linkages and drivers or influencing factors relevant for the Nexus.

On the linkage charcoal-deforestation, Sitoe et al. (2016) and (Woollen et al., 2016) perceive deforestation as a multi-dimensional phenomenon, which includes land clearance for farming as an important factor.

Ryan et al. (2016)while linking deforestation with the breakage of nutrient cycle (e.g., nitrogen cycle), also considers that charcoal production, when part of shifting cultivation, boosts fertility on inherently infertile soils. Deforestation can also facilitate soil erosion, increasing the amount of sediments on rivers and lakes, thus reducing the water quality and affecting fish productivity (Ryan et al., 2016). Furthermore, deforestation reduces water infiltration in the soils reducing ground water recharge, dry season flows and precipitation, which has a negative impact on food production (Ryan et al., 2016). Over extraction of wood can also promote a decline in competitive wood-land-specific uses (e.g., firewood, medicines, construction materials), with possible welfare losses, especially for the most vulnerable (Woollen et al., 2016).

The scarcity of water and wood energy increases the time and income spent on acquiring those goods and reduces the investment on healthcare and/or in irrigation technology and water storage facilities, which in turn reduces food production, hygiene, and income generation (Cairncross and Cuff, 1987; Ng'ang'a et al., 2012; Magombeyi et al., 2013). Sanitation is included as healthcare. Indeed, areas subjected to drought, away from irrigation networks or low underground water levels are associated with food insecurity and poverty (Mabhaudhi et al., 2016). Conversely, the lack, or the price increase, of charcoal can also affect household's cooking habits. Protein-rich "hard" meals (e.g., with beans or meat) may be avoided or undercooked to conserve energy and families may rely heavily on low-protein "soft" foods (e.g., grains and greens) which can be prepared quickly (Brouwer et al., 1997). In other cases, families may stop boiling drinking water when faced with an energy shortage (Plummer, 1999).

In rural areas of Mozambique marked by extreme poverty, constant and intensive natural hazards, with few income generation options and with insufficient agriculture production, charcoal is a main poverty coping strategy (Clover, 2007; Brida et al., 2013; Jones et al., 2016). In southern Mozambique, after the 2000's massive floods and intensive drought, 60–70% of farmers engaged in off-farm activities for extra-income (Brida et al., 2013). Notably, 90% of households in that area are involved in charcoal making (Ng'ang'a et al., 2012) since this is the most profitable off-farm activity (Nhantumbo, 2010). The income resulting from charcoal, if reinvested on food production (e.g., working capital, invest in field opening and clearance, buy agricultural inputs or equipment), or irrigation systems can reinforce and multiply growth in the agricultural sector increasing food availability or surplus for sale (Mather, 2012; Djoudi et al., 2015; Jones et al., 2016; Ducrot, 2017). However, very few farmers do these investments and several irrigation programs implemented in Mozambique revealed to promote political centralization, reduce local participation, be poorly coordinated, promote inequality and threaten natural resource management (Eriksen and Silva, 2009; van der Zaag et al., 2010; Djoudi et al., 2015; Alba et al., 2016; Ducrot, 2017).

In the case of charcoal, an important Nexus driver and influencing factor is the institutional framework around forest in Mozambique. Alongside the land and water, forest belong to the state, but local communities' rights and resource management practices are considered while a charcoal production license system (supposedly) based on forest capability is in force. However, local institutions have been considerably reduced in post-independency and during the civil war (Pihale, 2003), governmental institutions are incapable to monitor or reinforce the law and the license price is considered unsuitable and the requirements unrealistic (Eriksen and Silva, 2009; Jones et al., 2016). Consequently, forest resources are seen as monetary free open-to-all resource, charcoal is a business running on informal and illegal channels, and most producers are unable to govern their resources due to weak institutional capacities (Baumert et al., 2016). Simultaneously, the lack of financial and public services, access to markets and knowledge (including technology and electricity) strongly reduce the options to increase productivity and diversify coping strategies to climate change and household income generation (Ng'ang'a et al., 2012; Ducrot, 2013). Definitely, the lack of options and the perceived cost-free benefit from charcoal making and growing demand from increasing number of urban poor, the need for cash income pushes farmers away from more resilient (but less profitable) agricultural strategies toward others that carry a greater degree of risk for capital-poor, small-scale farmers (Silva et al., 2010). Notably, these practices have implications on: the diversity, availability and access to other forest uses (Ryan et al., 2016); vulnerability to climate change, food security, land and soil quality (Ng'ang'a et al., 2012; Gomiero, 2016; Woollen et al., 2016).

Another data set and knowledge to inform the Nexus analysis on charcoal is research done on Nexus analysis focused on CES and/or bioenergy in developing countries.

A possible CES to consider is the combined heat and power technology, CHP, based on charcoal supplied by dedicated wood plantations or forest residues (e.g., Wetterlund et al., 2013; Sowlati, 2016; Tidwell, 2016) coupled with the relevant aspects of nexus analysis applied to biofuels in developing countries (Guta et al., 2015; Mirzabaev et al., 2015; Brears, 2018) and biochar (carbon-rich charcoal) production for soil remediation (Belmonte et al., 2017). This approach allowed to identify:

- Linkages water-charcoal/biochar: water for CHP (e.g., refrigeration, steam production); CHP for water supply (extraction, pumping, treatment and purification, distribution); effects of CHP on water quality (e.g., heating, cooling, desalination); biochar can treat wastewater for irrigation (cadmium and lead removal); CHP and biochar can pollute the water; energy effects on water entitlement rights and availability (e.g., overexploitation); the effect dedicated plantations on water (e.g., use of fertilizers); the overexploitation of trees (deforestation) on water cycles through soil erosion and land degradation; enhanced soil with biochar increases water retention and reduces irrigation requirement.
- Linkages food-water: water for agriculture; off-farm jobs linked with irrigation, and health improvement (e.g., sanitation, clean water, water-borne deceases), which affects work productivity and thus food security; the effect of agriculture on water quality (e.g., fertilizers).
- Linkages Charcoal/ biochar-food: CHP for food processing (e.g., conservation and storage); energy plantation for agroforestry might affect land quality to generate synergies (e.g., nitrogen fixation, more harvests per year, higher yields, diversification); biochar can increase crop productivity; CHP/charcoal/biochar might increase income (small business, agriculture), influencing food security and facilitating reinvestments in food/energy production; plantation might create resource competition (e.g., labor, land, water) or degradation of food resources (e.g., soil erosion, land degradation, water scarcity, oversupply of nutrients); charcoal production can generate accidents resulting in less working power.

While relevant for a comprehensive analysis, this combination of technological options (CHP and plantations) is still not a reality in Mozambique, mostly characterized by the use of firewood in rural areas and the production of charcoal from forest wood on local mold kilns to supply urban consumers.

Finally, there are two studies that explicitly relate the Nexus with Charcoal: Githiru et al. (2017) and González-López and Giampietro (2017). Githiru et al. (2017) poses the possibility that human-elephant conflicts could change the risk perception by farmers, changing their income strategies which include charcoal production. While a relevant and interesting element to be considered, there is no Nexus analysis explicating the possible interaction wildlife-charcoal-water-food. González-López and Giampietro (2017) uses a general accounting framework for the analysis of the metabolic pattern of social-ecological systems using the multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM) model to study the Nexus in relation with charcoal production in a rural village in Laos. The MuSIASEM applies a metabolic perspective to simulates human decisions in face of trade-offs and synergies between charcoal production and different activities under a scenario of limited availability of human activity and available land. While "metabolic patterns" and "relational analysis" are mentioned they are not presented, and thus, it is not possible to derive explicit interactions for the Nexus charcoal-water-food.

Nexus Causal Relations for Mozambique

To make the Nexus explicit in a schematic format, the results from section Explicit Nexus Analysis Made On Mozambique, and Southern Africa and Nexus And Systems Analysis Relevant For CES And Mozambique were collected and integrated in **Figure 3**, to show the drivers and effects that the system in the far left column have on the system on the top column. While not much different from other Nexus analysis representations (e.g., Biggs et al., 2015; Brears, 2018) **Figure 3** is the first integrated and comprehensive Nexus analysis centered on CES made for Mozambique.

CHARCOAL CENTRED SYSTEMS ANALYSIS FOR MOZAMBIQUE

In this section, a participatory analytical tool, the 2MBio-A, is presented for comparative purposes with the Nexus analysis (section Uncovering The Nexus Charcoal-Food-Water In Mozambique) and applied to the case of Mabalane, a charcoal production district in the south of Mozambique. The comparative results will be critically explored and discussed in section Constructive Discussion: Proposal For An Integrated Design Approach.

The 2MBio-A, a Systems Analysis for Charcoal Energy Systems

To assess comprehensiveness and depth of analysis of the Nexus focused on CES (section Uncovering The Nexus Charcoal-Food-Water In Mozambique) this work proposes the 2MBio-A as a tool to support an alternative systems analysis on the same system. The 2MBio-A is, in fact, the analytical version of the 2Mbio, a participatory design tool developed by the author and successfully used to facilitate the design of a creative synergetic firewood/food system from scratch in different settings, from rural communities to engaged groups of experts and academics (Martins, 2014; Martins et al., 2018).

The 2MBio is an ontological metamodel, i.e., a graphical illustration that makes explicit the basic elements (concepts, constructs and rules of interaction) of the bioenergy systems design. Moreover, the 2MBio theoretical basis considers design a continuous reflexive analytical activity (Schön, 1983). Furthermore, the 2MBio was specifically developed for the wood fuel energy systems (and bioenergy systems in general). These three structural aspects of the 2MBio made it naturally adaptable for the task of analysing CES possible interactions, simply by truncating the design process at its design stage. Therefore, while the 2MBio analyses the problem to design a grounded solution, the analytical version, the 2MBio-A, simply analyses the problem. Therefore, like the 2MBio, the 2MBio-A (**Figure 4**), offers a visual, explicit and formal platform representing 13 basic elements necessary and sufficient to produce comprehensive and meaningful analytical specification of any bioenergy system. The 2MBio-A is easy to use, non-normative and non-prescriptive and effectively allows a wide range of actors to develop contextualized, comprehensive and meaningful analysis of bioenergy systems.

Moreover, like the 2MBio, the 2MBio-A does not compel normative visions of efficiency or sustainability, instead, allows for users alone, or together with additional people, draw on their creativity, knowledge, experience, perspectives, by exploring the full extent of bioenergy systems analysis space represented by 13 basic elements organized as boxes on a piece of paper (see **Figure 4**). Each of the 13 basic elements are well defined, easy to understand and explicit, and are provide the space for users to write and draw directly on paper their ideas and perspectives. Thus, the proposed tool works as an interactive and common ground where participants make explicit their creativity in the participatory conceptual analysis of CES. In other words, the 2MBio-A promotes sense-making across different users, since, once filled, the 13 basic elements serve to translate abstract, tacit, implicit and individual mental models and views into concrete, explicit and common written/drawn specifications, making it available for others to discuss. As a result, through the 2MBio-A, users can establish a structured and constructive dialogue/debate while exploring, understanding, learning and refining their views on CES analysis. Significantly, being a low-tech, low cost tool, and allowing for drawing on it, the 2MBio-A facilitates wider participation of people from areas with low or no literacy, low electricity access and lack of computers.

Applied Contextualization: the Case of Mabalane

The 2MBio-A could be used on generic way, however, to contextualize the tool, the analysis will be carried in Mabalane, a district that presents a highly stress nexus situation, marked by water scarcity, low food production and high charcoal production under an overall scenario of poverty and climate change vulnerability.

Located in Gaza Province, Mabalane occupies 9,580 km^2 of the upper part of the Mozambican Limpopo Basin (**Figure 5A**). Around 98% of the families are engaged on subsistence agriculture mostly rain fed and, thus, extremely dependent on natural conditions, which are extremely unfavorable hazardous (Brida et al., 2013; Ducrot, 2017). The soils are very poor for agriculture, classed as loamy sand (82% sand, 13% silt, 5% clay), with a low carbon and nutrient content (0.4% C, 0.05% N) (Woollen et al., 2016). In practical terms, the options are between farming the sandy soil at the uplands, with a high risk of crop failure in drought years, or the fertile soil close to the Limpopo River with a high risk of floods (Brida et al., 2013;

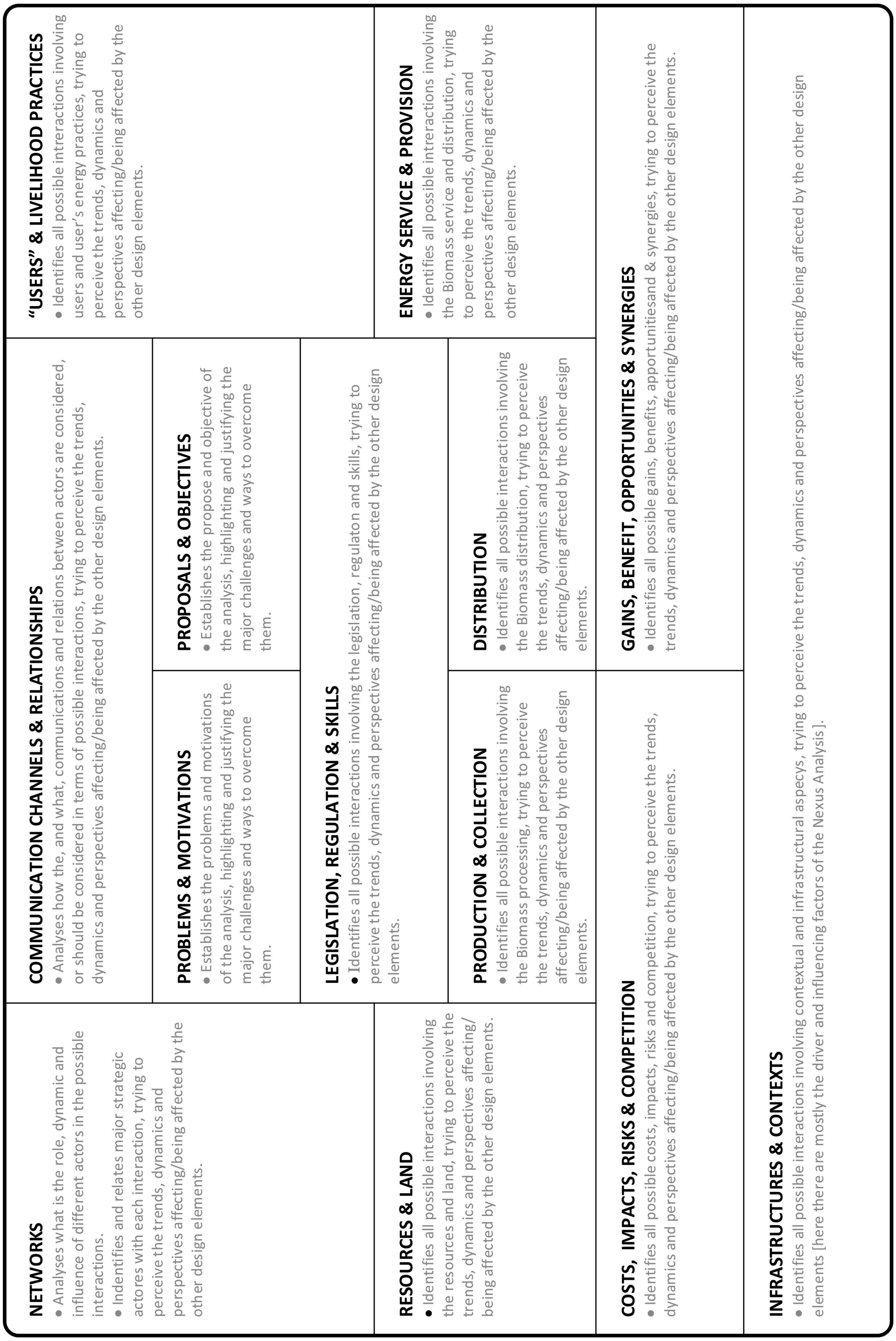

FIGURE 4 | The 2MBio-A layout including description of every basic element (Source: based on Martins, 2014).

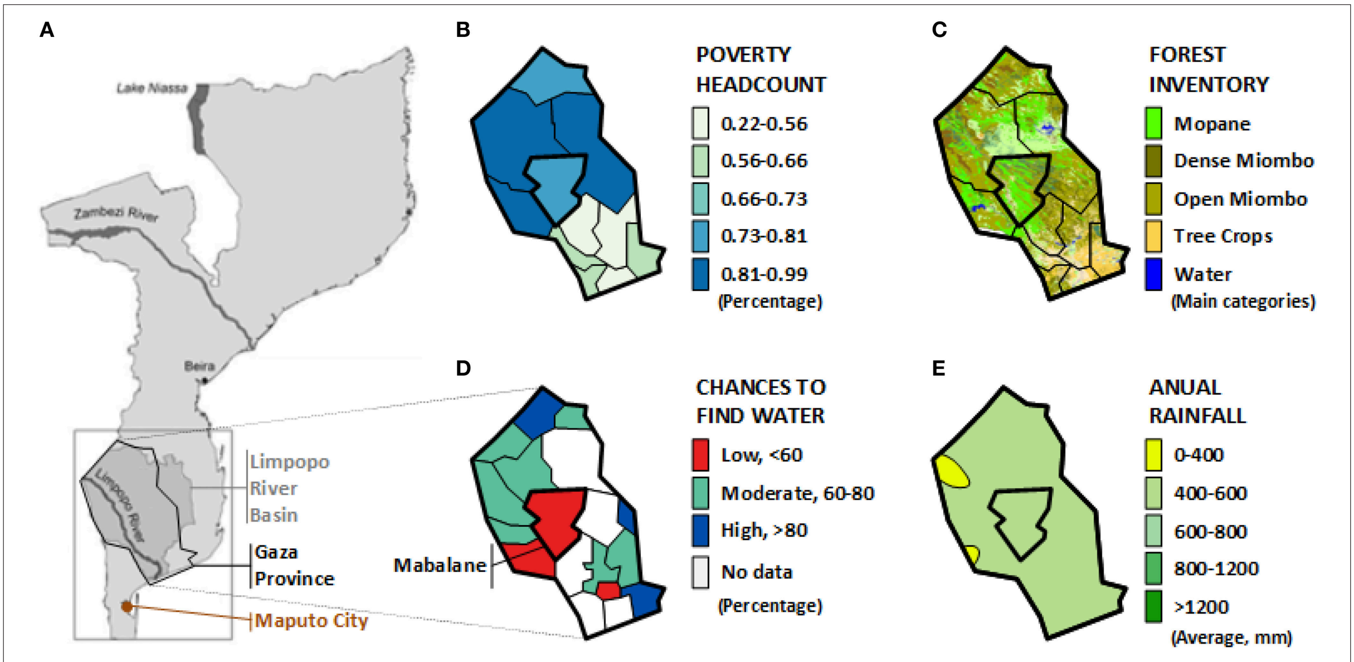

FIGURE 5 | Maps showing the relative location of the Limpopo River Basin, Gaza Province, Mabalane District and Maputo City in Mozambique, as well as, water, poverty and forest data [Source and full maps, **(A,E)**- (Ng'ang'a et al., 2012); **(B)** (Simler and Nhate, 2005); **(C)** (JICA, 2016); **(D)** (Ducrot, 2013)].

Ducrot, 2017). Moreover, following climate change tendencies in the region, drought periods become more extended, chronic and severe (Turton et al., 2008). Therefore, in the context of projected climatic changes and increases in climate variability, food security in those areas is at risk (Brida et al., 2013). According to the official ranking based on nutrition, food security and access to public good indicators, Mabalane is in the 4th quartile of the poorest districts of Mozambique, with around 72% of the population living below the national poverty line (**Figure 5B**) and one third to half of the households suffering from a food shortage period (Ducrot, 2017) which can last between 3 and 5 months depending on the year and the zone (FEWSNET, 2014).

A crucial issue in the district is water access. Around and 75% of the district area is already arid or semi-arid land with and annual rainfall between 400–470 mm and between 20–31 mm in the dry season (April to September) (Ng'ang'a et al., 2012; Ducrot, 2017) (**Figure 5E**). Between September and December, the Limpopo River is dry due for upstream water extraction and the management of the catchment area (Ducrot, 2017). Furthermore, Mabalane is one of the country's districts with the hardest access to good quality underground water. The boreholes should have more than 75 m, the rate of successful drilling is below 60%, and if successful there is a 70% chance to find water with an average salinity of 2,650 µS/cm while the limit is 2,500 µS/cm (**Figure 5D**; Ducrot, 2013). At the regional level, there is evidence that water resources of the Limpopo Basin are already stressed under today's climate conditions (Zhu and Ringler, 2012).

Despite these hard conditions, Mabalane is well endowed with easily accessible hard wood from the extensive forest of Mopane (Colophospermum mopane) (**Figure 5C**). Mopane is a dense hardwood species, which produces highly appreciated high-quality, slow-burning charcoal. In this scenario of generalized poverty, lack of opportunities and easy and free access to resources, charcoal production is major way to generate cash income. Indeed, Gaza is the region of the country with the higher number of licenses conceded, reaching a total annual volume of 542,203 allowed charcoal bags (around 43,000 tons) (MITANDER, 2016).

Finally, while 600 km away the Capital City Maputo, the two locations are linked by a road 80% paved with good quality tar and a cargo train running three times per week. Not surprisingly, Mabalane is currently the major charcoal producer district in the south, and virtually all its production is to supply the growing urban population of Maputo.

Applying the 2MBio-A on Mabalane: Unveiling and Expanding Linkages

The 2MBio-A was designed, and achieves the best results, when used in participatory exercises, however, to assure a common base of comparison with the Nexus analysis made above (section Uncovering The Nexus Charcoal-Food-Water In Mozambique) the 2MBio-A will be applied as a supporting tool for individual analysis by the author (**Figure 6**). The purpose is to use the 2MBio-A to identify relevant interactions (trade-offs, synergies, logical effects) for each basic element of the 2MBio-A (the "boxes") and among them. In other words, the purpose is to perceive how each basic element affects, and is affected by, the other design elements within a predefined systems analysis. For the presented case, CES was considered as a socio-ecological

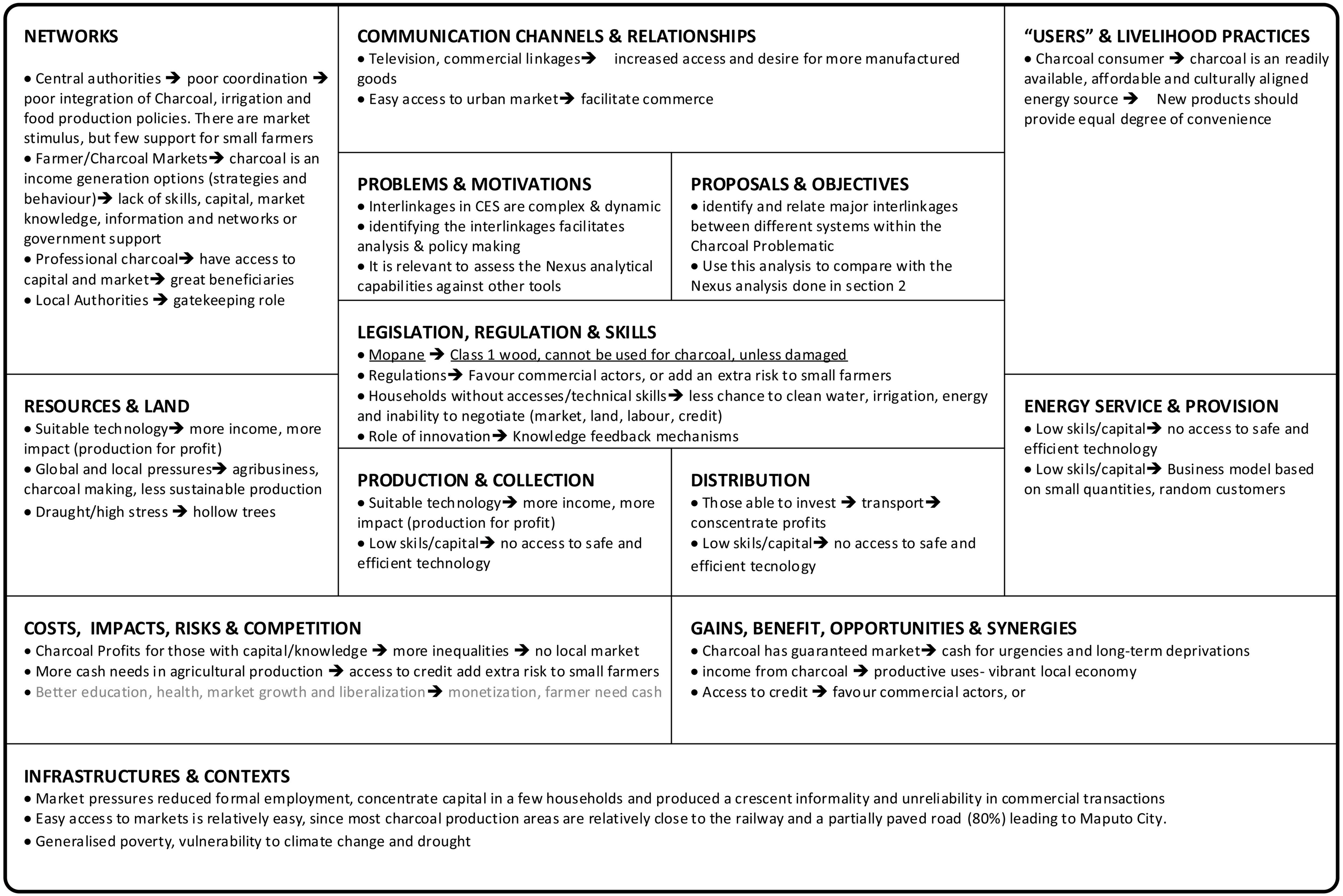

FIGURE 6 | The 2MBio-A fully described after one fast initial iteration.

system (or social-ecological system see: Martins, 2014; Homer-Dixon et al., 2015) and the interactions were written directly on the body of the 2MBio-A (**Figure 6**). This interactions represent the result of the author's experience and research conducted in the Mabalane area during 2015–2016, and display the first interaction with the 2MBio-A. Further analysis by the author and/or other user could result in higher refinement.

Before advancing for a deeper discussion on the use of the 2MBio-A in the nexus analysis, to be conducted on section Constructive Discussion: Proposal For An Integrated Design Approach, it is important to mention two aspects on the use of the 2MBio-A carried above (section Applying The 2MBio-A On Mabalane: Unveiling And Expanding Linkages above).

First, while not presented for economy of space, all the elements considered in Nexus analysis (**Figure 3**) are also included in **Figure 6**. Indeed, what is presented in **Figure 3** as drivers and influencing factors is what the 2MBio-A designates by Infrastructure and Context (the bottom box). Likewise, since most of the Nexus analysis have been developed around specific technologies, these technologies and their interaction within the Nexus could also be included along the supply chain section of the 2MBio-A, i.e., the central row comprising the elements (boxes) Resources and Land, Production and Collection, Distribution, and Energy Service and Provision. However, rather than an interaction water-energy, what would be presented would be, how that technology would interact with water, food and energy.

Secondly, while belonging to a specific element (box), the interactions identified in **Figure 6** might affect and be affected by other elements or interactions with other elements. Therefore, the 2MBio-A (as the 2MBio) relies on harrows to show such inter-basic elements interactions. In fact, methodologically, to assure coherency and comprehensiveness, the use of the 2Mbio-A requires that each aspect identified in each and every single basic element, must have correspondence (linkage) with all the others elements.

CONSTRUCTIVE DISCUSSION: PROPOSAL FOR AN INTEGRATED DESIGN APPROACH

Critical Discussion on the Nexus as a Viable Tool to Analyse Charcoal Energy Systems

The basic premises and application of the nexus approach to the water-charcoal-food in Mozambique is valid and potentially useful, however presents a number of gaps, challenges and problems.

Probably the most notorious gap of the Nexus approach to Mozambique and charcoal is the absence of the forest as a Nexus component. The Nexus studies on Mozambique identify deforestation, the possible competitive use of forest resource, and the effect of dedicated plantations on water and food systems (**Figure 3**), but in every case, forest is part of system or resource, not a complex and dynamic socio-ecologic system. Nevertheless, Mopane forest is crucial for charcoal production, a source of welfare, food and resources and crucial for the water system (Bila and Mabjaia, 2012), and throughout Southern Africa, the Miombo forest supports directly the livelihood for over 100 million people in both urban and rural areas (Campbell et al., 2007; Syampungani et al., 2009). The lack of nature is, actually, also a common critique of the current Nexus formulation (Krchnak et al., 2011; Allouche et al., 2015).

Another gap detected is the often mentioned absence of social systems and concerns in Nexus approach (Ringler et al., 2013; Allouche et al., 2015; Foran, 2015; Leck et al., 2015). In the Nexus analysis (section Uncovering The Nexus Charcoal-Food-Water In Mozambique), poverty, livelihoods patterns, geopolitics and socio-economic phenomena are mentioned as Nexus drivers, but the actual linkage with the water-food-energy security is focused on how those drivers affect the physical and economic "availability" of resources. However, "availability" also includes "access to resources, the capacity to utilize resources as well as dynamics of social power relations and the strength of institutions" (Biggs et al., 2015), which are contextual, dynamic, complex and produced historically (Ringler et al., 2013; Foran, 2015). Remarkably, the need to understand the local perceptions and copping strategies within the context of differential social access to wood fuel has long been identified as gap in natural resources management in Southern Africa (Katerere, 1999; Moyo and Sill, 1999).

Likewise, for the case of food systems, the Nexus analysis identified fertilizer use as a driver (Nielsen et al., 2015), but affecting the Nexus through economic perspectives involving quantifiable linkages and assumptions, missing thus the cultural, social and political insight involved. On the other hand, the systems analysis proposed allowed the exploration of interaction between water and charcoal systems with critical inputs like land tenure, access to agriculture extension and financial services or rural labor market and dynamics. This incomplete economic analysis is also part of more generic criticism (Wichelns, 2017).

The gaps identified above, result from the specific combination of elements and drives selected for the Nexus approach, as well as, how Nexus analysis frames resource management. Since the Nexus is essentially a systems approach, the resulting analysis is dependent on the boundaries set, purpose and conceptualization applied. Remarkably, boundary setting is a highly subjective and political task (Ulrich, 2003; Chang et al., 2016), and what the system does not see (outside limits or vision) the system does not analyse. In fact, the definition of appropriate boundaries is critical, since the results will differ, depending on Garcia and You (2016): the number of systems considered; the combinations of systems chosen; the size, kind and number of spatial and temporal scales used; and the actors involved.

This focus on quantification is defined from the origin, since the Nexus aims to support modeling with quantifiable, optimizable and grounded on data models (section Introduction). Furthermore, the current analytical focus is on natural resource management from a deterministic, technocratic and economic perspective, favoring pre-defined visions of sustainability, resource use, security and better technological solutions. The purpose of analysis is to provide strong evidence based on mathematical equilibrium models, in which resource allocation can be optimized and efficiency improved (Allouche et al., 2015; Garcia and You, 2016). Even the trade-offs identified, rather than express multiple perspectives on the interactions, present the multiplication of deterministic assumptions, i.e., cause, effects and mutual interactions belong all to a limited set of pre-determined possibilities. Notably, this perspective promotes the commodification of resources and the parameterization of interactions bypassing, oversimplifying or simply ignoring situations, options or interactions that cannot be "quantifiable," e.g., social dynamics, perceptions, innovative capacities and behaviors (Ringler et al., 2013; Foran, 2015).

The solution so far has been the use of qualitative methods (e.g., interviews), or the use of agent based simulation, which try to simulate real humans behaviors (Garcia and You, 2016). However, even if these techniques capture the complexity of human behavior, at some point the data must be aggregated or extrapolated across scales, losing its richness and, if improperly done, leading to erroneous research conclusions and misguided policy (Nielsen et al., 2015). Consequently, the Nexus tends to favor economical, technological views such as hydropower and other "clean renewable energy," by-passing social and ecological considerations and "backwards and informal" technologies, such as charcoal.

On the other hand, the 2MBio-A instead of forcing the focus on a somewhat arbitrary number of systems applies systems and design thinking to identify which would be the basic elements of analysis of a given energy system. This ontological approach, focused on basic elements of analysis has many advantages. The 2MBio-A is not dependent on the purpose of the user. Many Nexus analysis have been proposed comprising different combinations of systems, interests and even sequences of the same systems. This diversity renders any comparison exercise difficult if not impossible. However, what is lost in "comparability" is not gained in depth or creativity of analysis. Conversely, the basic elements approach, allows for a necessary and sufficient number of blocks to be used for analytical and design purposes, facilitates comparison across models and modelers, and being non-normative and non-deterministic, allows for total freedom of analysis. Note that while the Nexus forces the view on its elementary systems, the 13 block layout of the 2MBio-A invites the users to navigate at their will to whatever systems they want, the way they wanted, as long as they check each box and relate every box. In any case, the modular nature of the 2MBio-A facilitates the addition of new elements without losing comparability because the reference set is already identified. Therefore, explicitly including nature (Resources and Land), livelihoods and socio-cultural behavior ("Users" and Livelihood Practices), and deliberately seeking for social, political and cultural dimensions of each interaction it was possible to address the complexity of charcoal systems, identify and contextualize multiple perspectives relevant for the definition of suitable, integrated and situated analysis for charcoal.

Particularly relevant was the effect that climate conditions have on Mopane and, consequently, on the legal nature of charcoal making. This finding, another undetected interaction in the Nexus, refers to the fact that, while legally forbidden to be used for charcoal making, since most Mopane trees are hollow, i.e., defective, they can actually be used for charcoal. In a fieldwork to Mabalane conducted in 2015 the author collected samples of 81 Mopane trees of different legal diameters in Mabalane-Sede and Combumune (two main charcoal production points) and identified 76% of trees as hollow. An empirical observation of the wood piled in the train station in Mabalane-Sede ready to be sent to Maputo also confirms these numbers. The reason why so many trees are hollow seem to be a common phenomenon in several ecosystems (Ruxton, 2014; Sheil et al., 2017). Studies suggest that this is an adaptation mechanism with microbial or animal consumption of interior wood producing nutrients to feed new growth via the trees roots or, in an alternative explanation, such loss of wood comes at very little cost to the tree and so investment in costly chemical defense of this wood is not economic (Ruxton, 2014). Interestingly, the lack of water is presented as the local explanation and the fact is used to legitimize the mono-exploration of Mopane. In practical terms, this interaction exposes how a biological adaptation, combined with an unsuited legal framework, generates the institutional and legal basis that legitimize an economic activity.

This being said, it is not the intention of this work to claim that the 2MBio-A or 2MBio are better approaches that the Nexus analysis. The point is that presented as an integrated all-encompassing analysis, the Nexus "forces" the analysis into a narrow set of knowledge and experiences, imposes a quantification on complex interactions that cannot be easily understood, communicated and even less quantified. To a certain point, by focusing on a certain approach and set o systems, the Nexus becomes "blind" to relevant elements, interactions and dynamics. Considering the scales involved, the disciplinary diversity required and creative and innovative approaches required to address trade-off (e.g., Ringler et al., 2013), it is possible that, posed as it is, the Nexus may become a sterile exercise unable to fulfill the task it was set to achieve. At least by itself.

Beyond the Nexus With the Nexus: Toward the Integrated and Participatory Nexus

Considering any Nexus as complex socio-ecological systems, three major challenges emerge as fundamental to propose more comprehensive, integrated and encompassing analysis: the challenge of identifying and analysing the interlinkages, trade-offs and synergies among the Nexus Systems (e.g., Liu et al., 2017); communicate that analysis across disciplines, sectors and cultures (e.g., Wichelns, 2017); and promote creativity (Ringler et al., 2013). More than improve modeling techniques (which has its merit, Kling et al., 2017; Veldhuis and Yang, 2017), arguably it is necessary to promote participation and dialogue (e.g., Mirzabaev et al., 2015; Howartha and Monasterolo, 2016; Kling et al., 2017; Veldhuis and Yang, 2017). Sometimes under other denominations, like "co-decision" (Veldhuis and Yang, 2017) or "transdisciplinary [...] knowledge co-production" (Kling et al., 2017) the purpose is to Promote the "active engagement of stakeholders from different sectors in all the phases of knowledge development to acquire a clearer picture of their needs and expertise in the decision making process" (Howartha and Monasterolo, 2016). Therefore. More than simple passive consultation, it is necessary to refocus the politics and philosophy of the Nexus toward a more inclusive and democratic process (Allouche et al., 2015; Leese and Meisch, 2015). Acknowledging the nexus as a complex problem that cannot be solved solely by high-level, top-down determinist and technocratic approaches, this political shift calls for plurality, diversity and multiplicity in "nexused challenges" (Allouche et al., 2015). Besides considering social and ecological dimensions, the nexus analysis should involve, value and acknowledge multiple criteria, scales, actors, perspectives, knowledge and ways of knowing and understanding problems and solutions (Allouche et al., 2015; Leese and Meisch, 2015; Pittock et al., 2015). Importantly, within the nexus analysis, natural resources management should also include contextualized definitions of development, and address rights, equity and power relations (Allouche et al., 2015; Foran, 2015; Leese and Meisch, 2015). Therefore, recognizing the political nature of decision-making in nexus, the purpose is to promote more democratic, adaptive, deliberative and reflexive forms of understanding and act upon the challenges posed by nexus (Stein et al., 2014; Allouche et al., 2015).

In practical terms, the implementation of this perspective it is necessary to create tools that promote active and creative participation; dialogue; and are adapted to the users' context.

Participation is repeatedly considered a basic element/process in nexus analysis. Acknowledging the complex and transdisciplinary nature of Nexus analysis, the active engagement of scientists and non-experts from different sectors in all stages and scales of decision-making is required to capture lessons emerging from different experiences (Kurian, 2017), build a clearer picture of needs and expertise (Howartha and Monasterolo, 2016) and explore and test different perspectives (Pittock et al., 2015). Participation is also considered a process to bring the nexus analysis, its challenges and trade-offs, to concrete actors in real contexts (Stein et al., 2014). For Leck et al., (2015), stronger processes of co-production between researchers and nexus stakeholders are crucial to overcome the institutional barriers that affect nexus implementation, while the absence of participation is a cause for the lack of ownership and consequent failure of nexus based projects in Southern Africa (e.g., Prasad et al., 2012). In Mozambique, in nexus related studies, participation is considered to be useful to blend equity perceptions of politicians, technicians and population and better integration of natural resources management in the planning process (Ducrot, 2013), or to identify perceptions otherwise overlooked by aggregating processes (Nielsen et al., 2015).

Closely related with participation, dialogue is a central element in FAO's perspective on the nexus linking the resource base with the goals (FAO, 2014). In this framework, dialogue makes explicit the different goals, interests and uses of resource base of stakeholders', shares the understanding each actor holds on the nexus problems and solutions, implements and coordinates action, while offering a process to reconcile differences and build common ground (FAO, 2014; Pittock et al., 2015; Smajgl et al., 2016). Therefore, implicitly, dialogue also favors learning, inclusive and participatory dynamics.

Regarding the adaptability to the user contexts, it is relevant to mention two practical aspects. First, the need to focus on the user and its context, particularly if the purpose is to address CES in developing countries. Each actor involved in the nexus analysis has its own framings, different definitions of the problem, and particular histories, languages and cultures (Allouche et al., 2015; Leck et al., 2015). Secondly, the importance of visual knowledge as motivator of creativity and interaction. Visualization has long been useful to tackle complex problems (Conklin, 2005). In the nexus analysis, particularly when combined with participatory modeling, facilitate discussion and joint learning, allow for rapid data collection (Stein et al., 2014; Legrand, 2015). The main benefit of visualization is the "making explicit" of tacit relationships, assumptions and expectations allowing, thus, actors from different backgrounds to engage in structured discussions and exploration as part of the nexus analysis (Stein et al., 2014; Kurian, 2017).

Since the 2MBio-A (as well as the 2MBio) fulfills these design criteria, this research proposes an integrated and participatory Nexus approach based on those tools. However, the Nexus modeling toolkit, the Nexus social network mapping (Stein et al., 2014) or the Nexus Games (Mochizuki et al., 2017) might be interesting options.

The use of the 2MBio to design Nexus based approaches, or the 2MBio-A, to analyse the Nexus, is quite intuitive, has 3+1 steps and is depicted in **Figure 7**:

1. Setup- Definition of the groups for the participatory analysis workshop. Care should be taken to make groups with a wide selection of relevant and representative array of perspectives, interests or ideas.
2. Composition- In the participatory analysis workshop, the participants decide upon which components should be part of the nexus to analyse (A in **Figure 7**). If the purpose is specifically the Nexus, an option should be given to include extra components. This initial choice will express the users' particular concerns and perceptions on the chosen Nexus.
3. Specification- With the nexus components chosen, the users will perform the nexus analysis in each of the DEs (boxes) having the respective DE as the center of the analysis. For instance, if the nexus charcoal-food-water was selected in 1, in the DE "Resources and Land", the nexus is charcoal-water-food-forest-land and all the interactions should be considered according to the users perspectives (e.g., social, economic, cultural). The relations are written or drawn in the DE, indicating with arrows which component affects which and how. In each DE the users should also include pertinent remarks or comments, e.g., meta-information on choices, drivers, historical tendencies.
4. Consolidation- Since the 2MBio-A is an ontological and modular tool, it is always possible to compare, combine and/or integrate side-by-side, DE-by-DE two or more different specified 2MBio-A. If any of these processes is done within the same region or case study, this represent a case-study consolidation. If any of these processes is done across administrative borders (e.g., between a village and a national 2MBio-A), the consolidation is across geographical scales.

Note that the use of the 2MBio-A does not "make" the Nexus Modelling and complete analysis. What the 2MBio-A provides is an entry-level platform for the Nexus analysis. By entry level it is, by no means, to say basic or simple, since it can be rather

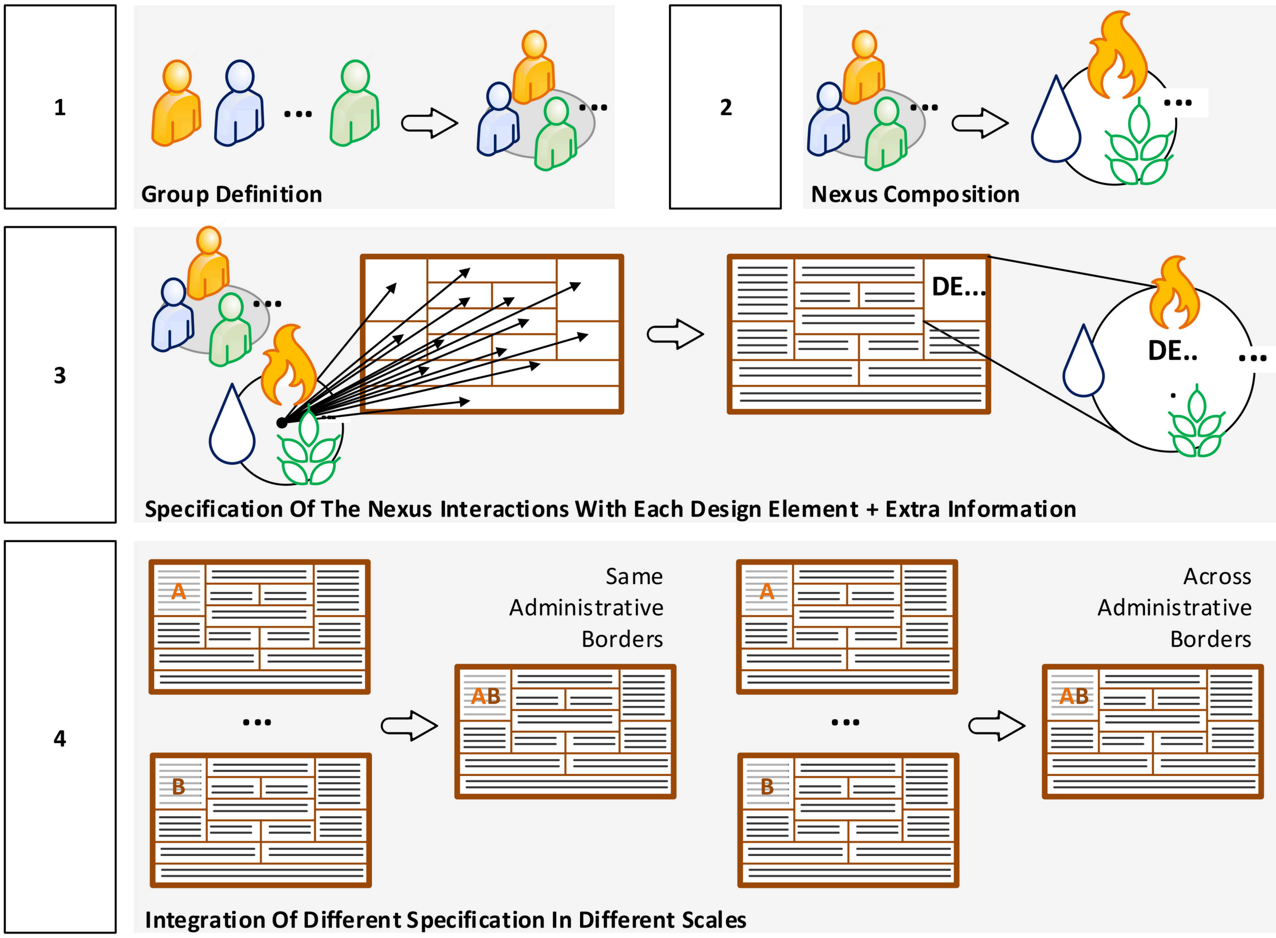

FIGURE 7 | Schematic representation of the 2MBio-A used as a focused Nexus Charcoal-Water-Food tool with the different steps and some possible applications (Source: the Author).

deep and sophisticated. The meaning of entry-level is to highlight the interface nature of the proposed integration based on the 2MBio-A. This participatory, dialogue and visual approach has the potential to orient the modeling, design and analysis effort faster and more effectively to otherwise blind spots of Nexus analysis.

CONCLUSION

Charcoal energy systems, CES, is a complex socio-ecological system dynamically interwoven into other systems, including, the water, the food and the energy systems. On this regard, the Nexus (charcoal-food-water) does provide an interesting and potential useful conceptual support an integrated analysis of resource management linking data research to policy-making. The relevance of this analysis for policy-making is clear when it is realized that over 70% of the population relies exclusively on charcoal and firewood, extreme climate disasters (e.g., floods, droughts) are common and still there is no real law enforcement on the subject.

However, nexus approaches seem to drive on normative and prescriptive political agendas based on technical knowledge and, surprisingly, there is no Nexus analysis focused on CES. Likewise, there are no comparative study between a Nexus analysis and any other systems approach for the some purpose. To bridge this gap, a Nexus analysis was made for Mozambique based on relevant existing studies. For comparison purposes, a participatory bioenergy systems conceptual design tool developed by the author, the 2MBio, was adapted to perform the same kind of analysis on the CES defined for Mabalane, a major charcoal production area in South Mozambique. Nexus approach failed to identify relevant links with ecology and livelihoods culture and social dynamics. In particular, Nexus was blind to the inequalities in rural areas, to the effect of dry climate and soil on the biology of trees and how these links affected the legitimacy of charcoal makers under present legal framework. Thus, overly focused on three systems the Nexus seems to replicate the problems of the centralized strategies on a different level.

Recognizing, however, the potential provided by the systems thinking behind the Nexus to detect interlinkages, synergies and trade-offs in charcoal problematics, this research proposed an integrated approach based on the 2MBio-A. The 2MBio-A keeps the modular, simple to use, intuitive and visual structure of the 2MBio to promote a non-deterministic, non-prescriptive and structured dialogue to further analysis and exploration of the nexus. While charcoal-centric, the 2MBio-A provides users with the liberty to define the composition of the nexus, identify and register (i.e., make explicit and available to discussion) in a participatory way the interactions drivers and any other useful information to facilitate analysis of the chosen Nexus. Since the 2MBio provides a structured, comprehensive platform for analysis, the result is a contextualized, participatory and comprehensive specification of Nexus analysis. Moreover, and still relying on the modular structure of the 2MBio, the 2MBio-A approach provides the possibility to compare different specifications defined for different contexts, promoting thus, integration across scales. Furthermore, the 2MBio-A provides a comprehensive platform for deep analysis, from which more detailed and formalized Nexus modeling can be built.

While further work is necessary to implement and test the 2MBio-A in real settings to refine and improve the process. The integration proposed, acknowledges the relevance of diverse knowledge, the need to align policy with reality, the existence of multiple uncertainties and, the fact that resource management is a political process, to present an approach that supports participation, dialogue, openness while providing a structured but non-normative platform for comparison and integration across scales.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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