Developments in the Built Environment 6 (2021) 100047

Contents lists available at ScienceDirect

Developments in the Built Environment

journal homepage: www.editorialmanager.com/dibe/default.aspx

Sustainable circular value chains: From rural waste to feasible urban construction materials solutions

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ARTICLE INFO

Keywords:
Sustainability
Circular economy
Urbanisation
Cement
CONCRETE
Vertical shaft kiln
Hydrolysis
Biochar
Polysaccharides
Sub-saharan africa
Africa

ABSTRACT

Urban regions in sub-Saharan Africa are growing significantly more rapid than their also growing rural counterparts. However, the employment perspectives in rural areas are decreasing, and thus the urban growth can become a driver for enhanced livelihoods in the rural areas. Since urbanisation in Africa requires high amount of concrete, the conversion of agricultural waste materials to sustainable concrete constituents does not only create new rural and urban income possibilities, it can also help Africa's construction industry to spearhead green concrete technologies, and thus to reduce carbon emission worldwide.

From vegetable wastes chemical admixtures can be derived as well as reactive mineral cement substitutes, which help to use concrete more efficiently and reduce the ordinary Portland cement clinker in concrete, respectively. The authors of this paper discuss the potentials and shortcomings of using agricultural waste materials for construction materials and propose a synergistic three-step process chain to obtain polysaccharides, biochar, and a reactive ash. The process requires boiling, hydrolysis and vertical shaft kiln technology, respectively, to obtain maximum useable products with minimum generation of climate gases. Eventually, the process chain is discussed in conjunction with possible rural to urban circular economic potentials in the concrete construction business.

1. Introduction

Concrete construction is a relevant contributor to global carbon emissions. The largest part of it results from the use of cement, which acts as binder in concrete. Cement alone is responsible for approximately 10% of the global carbon emissions (Scrivener et al., 2017). Each ton of cement emits 600–900 kg CO_2, predominantly from the decomposition of calcium carbonate, but also from the energy demand, processing and grinding (Scrivener et al., 2017; Maddalena et al., 2018; WWF Deutschland, 2019). While modern plants operate very efficiently, the carbon emissions from the ordinary Portland cement (OPC) clinker sintering process remain inevitable and can only be reduced by lower clinker consumption in concrete. In addition to the cement contribution, further carbon emissions in concrete technology result from processing, transportation and energy demand of concrete itself during casting on site or in a plant.

Concrete is the only material in the world that is sufficiently available to meet the global demand for construction materials. The global consumption of cementitious materials today is approximately 8.5 times higher than the entire global wood production and about 1.5 times

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https://doi.org/10.1016/j.dibe.2021.100047
Received 26 August 2020; Received in revised form 16 March 2021; Accepted 17 March 2021
Available online 26 March 2021

higher than the world's steel production (Scrivener et al., 2017). Thus, concrete is used in much larger quantities than any other construction material for producing structural elements, and it will continue to be used, since except for non-cement-stabilised compressed earth, other construction materials would possess higher embodied carbon and energy (Barcelo et al., 2014; Hammond and Jones, 2008). Cement stabilised compressed earth has a more negative environmental effect than concrete, because the amount of cement used for the same volume of materials is similar, but the resulting strength in concrete is much higher than in compressed earth, which is why overall material can be saved (Damineli et al., 2010).

Therefore, the high carbon emissions from concrete compared to other materials are mostly a result of its huge demand and consumption. This calls for more efficient use of concrete in future in order to reduce cross sections, and structural dimensioning that helps minimising the overall materials consumption. The most feasible way to reduce carbon emissions in concrete is replacing Portland cement clinker as much as possible with lower climate impact supplementary cementitious materials (SCMs), and to use cement as efficiently as possible (Scrivener et al., 2017). In this context, sub-Saharan Africa (SSA) provides high potentials to develop innovative and green technologies by leapfrogging established approaches from the past that cannot be considered as most sustainable anymore with today's knowledge (Schmidt et al., 2018; Schmidt, 2017). Despite enormous practical and economic challenges, the starting point for researchers and concrete technologists in Africa is ideal for sustainable innovation.

A per capita carbon emission of 2.7 kt (based on the global population of 2010) is considered as threshold value to limit the global warming to 2 °C until 2050 (Messner et al., 2010). While most regions can only approach this threshold from a significantly higher level, solely Central America and Sub-Saharan Africa can approach this value from a lower value (Fig. 1).

Since the cement and concrete related carbon emissions are linked to the sheer global demand, the construction demand linked to the rapidly growing urban population in SSA thwarts the high potential to keep the carbon emissions low. Fig. 2a shows that the urban population has grown more than twelvefold since 1960. This trend is more than three times higher than the also increasing overall global trend. Urbanisation, thus, is one of the major challenges SSA faces, and considering that most of the urban structures to cater for the enormous urban population growth still have to be built (Schmidt et al., 2020a; Schmidt et al., 2020), the respective carbon emissions will be significant.

However, unlike in most parts of the world, the rural population of SSA is also growing, just significantly slower than the urban population.

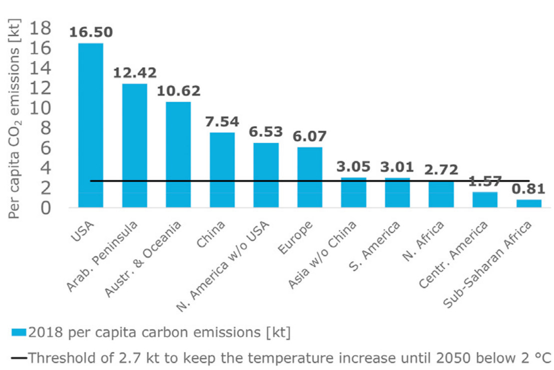

Fig. 1. Per capita carbon emissions in different regions compared to the threshold of 2.7 kt, which (based on the world's population of 2010) is the threshold to keep the temperature increase below 2 °C until 2050 - Source of carbon emission data: Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States; source of population data: United Nations Population Division, national statistical offices, Eurostat, and United Nations Statistical Division (https://www.indexmundi.co, 2020a; https://www.indexmundi.co, 2020b).

One reason for the more rapid urban population growth is the better livelihood perspective in sub-Saharan African cities. Fig. 2 shows a comparison of the evolution of service and agriculture business as share of total gross domestic product (GDP). Service, which is a typical urban business, has been markedly increasing, while agriculture decreased steadily. Furthermore, the percentage of employees in agriculture (as a percentage of total employees) has been significantly decreasing, while for the service sector a clear increase can be observed (Fig. 2). It is interesting to see that female employees have been overly negatively affected by rural employment reduction as well as in return positively by urban employment growth. Urban growth, thus, can be assumed to facilitate more gender equity, while the lack of employment perspectives in the current rural setting rather increases the gender gap.

Beyond the livelihood perspectives additional factors contribute to the interest of rural population to leave the rural areas to more urban environments. One major aspect is typically the lacking access to appropriate technologies, capital, health facilities and education. These reasons hinder the development of rural areas, although rural development could significantly contribute to a slower urban growth.

A workshop focusing on the future city visions of children from Mukuru Estate, a neglected urban settlement in Nairobi, Kenya, showed that most urban children wished for animal, trees, nature and space (Barucker-Sturzenbecher and Schmidt, 2019), which resembles a rural rather than an urban setting. In contrast to this, a similar workshop with young mothers and girls from Bagamoyo, a village in Tanzania, showed that the participants mostly lacked access to health facilities, education, finances, and service. The wishes resembled an urban setting rather than a rural setting (Schmidt et al., 2020). This clearly shows that urban dwellers wish for rural elements, and urban dwellers need more urban elements. Therefore, instead of overdeveloping already developed urban regions, more emphasis should be given to the development of the rural areas and to create more and better livelihood perspectives.

Certainly, the urban growth will continue to create employment perspectives in rural areas, due to the increased demand for food, energy, minerals and materials for production and service. Nevertheless, Fig. 2b shows that the livelihood potentials decrease in the classical rural businesses. Therefore, it becomes important to look at new rural potentials that come along with rapid urbanisation beyond food. For urbanisation, construction materials will be required in enormous amounts, concrete being the most important material. Along with the demand to reduce carbon emissions, today's unused agricultural by-products from mostly crop but also livestock farming can be considered as great potential to support green African urban innovation while new opportunities can be created for rural businesses.

2. Rural development potentials from green urban growth

Agricultural by-products can serve to construction materials in different ways. On the concrete scale, they can be used as coarse aggregates (Amziane et al., 2015, 2016) or as fibres (Agopyan et al., 2005; Savastano et al., 2000) to reduce weight and cost, and enhance mechanical properties. On the binder scale their ashes can be used as SCM and the organic components can be used as chemical admixtures to tailor the workability. The potential of large-scale use of fibres is limited, due to the challenge to streamline the varied fibre and aggregate materials to regulate their chemical and mechanical properties for robust use in composite condition, their large-scale use remains a challenge. However, the use of ashes of agricultural by-products to replace cement and the use of polysaccharides from bio-wastes can become a significant contribution to lower carbon emissions linked to urban construction. Sustainable urban construction needs sustainable concrete, and sustainable concrete needs SCMs and chemical admixtures to lower the water cement ratio.

Today, the use of SCMs is considered as viable solution to partly replace Portland cement clinker in the binder. Beyond the availability of a sufficient amount of SCMs, the marketed cement types determine, how much clinker can be reduced. The most established, globally most

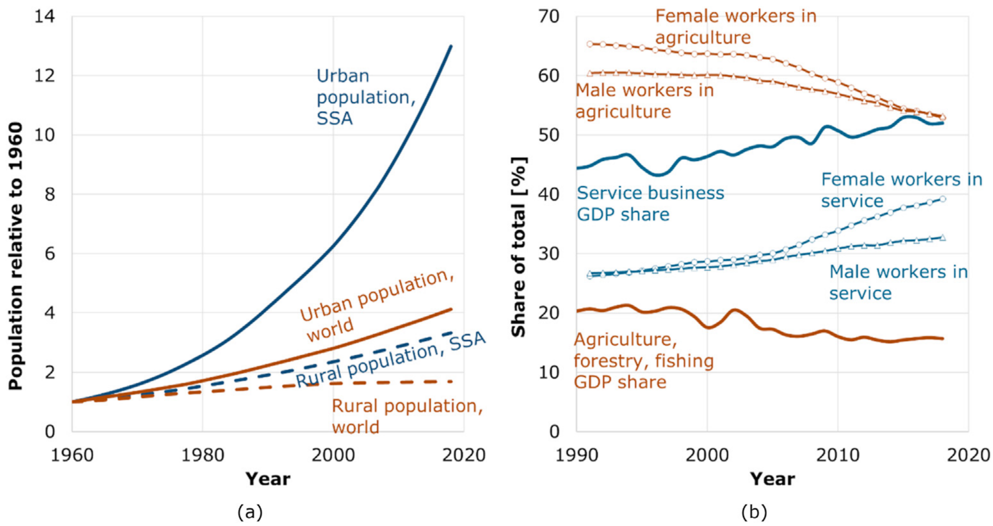

Fig. 2. Urban and rural population development in SSA and the world relative to 1960 (a) and development of service and agricultural, forestry and fishing business related to total national GDPs, employment of female and male workers in agriculture and service relative to total gender specific employment (b) - Data sourced from World Bank staff estimates based on the United Nations Population Division's World Urbanisation Prospects: 2018 Revision. (https://data.worldbank.or, 2020a; https://data.worldbank.or, 2020b), and World Bank national accounts data, and OECD National Accounts data files, International Labour Organization, ILOSTAT database. Data retrieved in March 1, 2020 (https://data.worldbank.or, 2020c; https://data.worldbank.or, 2020d; https://data.worldbank.or, 2020e; https://data.worldbank.or, 2020f; https://data.worldbank.or, 2020g), respectively.

available and industrially fully used SCMs are fly ash (FA) and ground granulated blast furnace slag (GGBS). Today their global occurrence can replace about 15% of the global cement production, but this will decrease to less than 10% in the future (Scrivener et al., 2017). Also, natural and calcined pozzolana are used. A proven major future potential for sustainable cement types are limestone calcined clay cement (LC3) types (Scrivener et al., 2017), but the large scale implementation of the latter techniques drags behind its potentials. These materials come along with new challenges arising from their diversity and they lack the same level of acceptance in the market, since unlike FA and GGBS they cannot look back on decades of experiences with their practical use. Often overlooked resources are vegetable ashes (Teixeira et al., 2016, 2019; Schmidt et al., 2019a; Msinjili et al., 2017a, 2017b; Olonade, 2017; Salau and Olonade, 2011; Thiedeitz et al., 2020). They occur in smaller amounts than FA and GGBS on a global scale and in significantly smaller amounts than clays, but locally they can become promising components. This particularly applies for SSA, because more than half of the unused arable land areas of the world are located in Africa (Perry, 2015). In addition, the yield per hectare for most crops has been steadily increasing on the African continent, indicating and increasing potential for vegetable ashes to be used in cement and concrete. The challenges of inhomogeneous supply are comparable to the challenges that occur with calcined clays, but in general with the increasing need to use sustainable materials, players in the concrete technology need to get acquainted more with process and quality control issues (Schmidt, 2019).

Research has shown that a variety of agricultural waste ashes do have pozzolanic properties such as ashes of rice husks (Msinjili et al., 2017a, 2017b), bagasse (Cordeiro et al., 2009, 2012), bamboo leaves (VillarCociña et al., 2011), cassava peels (Salau and Olonade, 2011; Olonade and Schmidt, 2018), maize cobs (Shakouri et al., 2020; Adesanya and Raheem, 2009), palm kernel shells (Bediako et al., 2017), groundnut shells (Bediako et al., 2017), or coconut shells (Joshuaet al.eng, 2018). They show different degrees of pozzolanic activity and can be used to different degree as Portland cement clinker replacement.

A data analysis made for this paper indicated that most possible agricultural waste ashes that qualify as reactive SCM occur in amounts significantly lower than 1% of the national cement production capacity, and therefore it is unlikely that the available volumes can become interesting for the cement industry. However, the waste ashes of maize cobs, cassava peels and in some countries rice husks and groundnut occur in sufficient amounts to be used as cement replacement. Fig. 3 shows the capacity of agricultural waste ashes from maize, cassava peels, rice husks, and groundnut shells to replace cement related to the total cement production capacity in the countries shown in the figure. For rice husks and cassava peels, the percentage ash yield from the waste was assumed to be 1%, which corresponds to 10% peels of which another 10% remain as ash. For maize the percentage ash yield was estimated to be 0.84% of which 55% were assumed to be waste, of which 1.5% remain as ash (Schwietzke et al., 2009; Karthik et al., 2017). For the groundnuts, a shell yield of 20% (Duc et al., 2019) of which 10% ash remain was assumed. In Fig. 3 the estimated ash volumes are shown relative to the respective country's cement production. A high replacement percentage, thus, does not automatically mean that the resource is produced at high levels, it can also mean that the local cement production capacity is low or vice versa. For example, Nigeria is the largest cassava producer in the world with about 20% of the global production, but the annual cement production capacity is also 43 Mt. The figure shows that particularly cassava and maize can become interesting cement replacements. In countries with more diverse range of agricultural products such as Guinea, Tanzania or Cameroon, the optimisation of blends of various reactive ashes can become an interesting approach. Creating new markets for biomass ashes can thus also be a driving force for more diversified agriculture, and where the amounts of pozzolanic ashes is not sufficient, blends with smaller amounts of other biomass can be successful (Teixeira et al., 2016, 2019), including the use of municipal waste (Parawira, 2009).

In some countries the possible clinker replacement rates are between

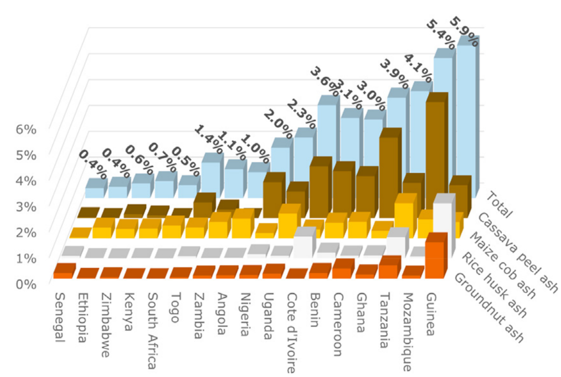

Fig. 3. Cement replacement capacity by ashes of maize cob, cassava peels, rice husks, and groundnut shells (based on total country's cement production capacity in 2015 (Ecobank, 2015)) – underlying food production data based on (FAOMaize; FAOCassava; FAORice; FAOGroundnut).

2% and 5%. This does not sound too much, but in order to achieve low clinker factors worldwide, every potential has to be used. Also, slag and fly ash are not endlessly available, and their available amounts globally can replace by max. 15% of the global cement production. In addition, their availability is rather decreasing than increasing, which is why alternatives are urgently required. In Africa the production volumes of agricultural products as well as the yield per hectare continue to grow significantly in the near future. For example, between 1960 and 2017 the production of cassava has more than quintupled and the yield per hectare increased by more than 60% (based on data provided by the Food and Agriculture Organization of the United Nations). Considering that the replacement only makes sense for cement plants that are close to the regions where agricultural wastes occur, for these cement plants cement savings between 10% and 15% could be possible. In some cases, for example in the case of rice husk ashes (RHA), the blended cements can even outperform pure OPC binders (Thiedeitz et al., 2020; Msinjili et al., 2016). Then these cements can be further blended with inert material to allow for even higher replacement ratios. It was shown that up to 25% cement can be replaced by blends of RHA ashes and limestone filler, by using their synergistic effect in which the limestone filler compensates for the workability loss induced by the RHA (Msinjili et al., 2016).

However, the use of agricultural waste ashes has to be assessed within a broader context, considering supply chains, available amounts, and alternative uses of the ashes. This does not mean that those ashes occurring in lower volumes would not qualify as sustainable binder replacement locally, but within the urban construction context their contribution to clinker reduction in the binder may be limited. Meanwhile, these agro-wastes could still be used as supporting fuel in the kiln in the production of cement, while the so produced ash is blended with the clinker to form blended cement. This approach is currently being adopted in major cement industries in Nigeria.

A major obstacle for the implementation of reactive agricultural waste ashes in the cement and concrete business is the season depending occurrence and quantity as well as the large variety of ash qualities, depending upon multiple parameters such as used fertilisers, soil quality, time of harvest, processing and combustion, and many others. In order to resolve the problem, agricultural technologies and ashes can be combined to overcome quality scatter based on seasonality. However, the use of agricultural waste ashes as SCMs in the cement industry, where megatons of raw materials are needed, would require complex and costly logistics to collect, process and homogenise the raw materials from producers who are scattered across countries and regions (Fig. 4a). Therefore, the use of ashes from agricultural waste by cement producers may not always be the most economically viable option for rapid implementation.

However, pozzolanic materials can also be used during concrete production, where they help concrete producers to reduce the cement content in concrete. This case is shown in Fig. 4b. For the boundary framework of sub-Saharan Africa, where the construction material market is often characterised by smallholder concrete and tile producers, less logistics are required and therefore, local ash production that goes directly to the concrete producers can be more cost- and time-efficient. Farmers can directly burn the ashes or share a kiln with other farmers in the region. Mobile services could be possible as well. The produced ashes could directly be used by the closest concrete producers, who in return could reduce costs by using less Portland cement or use alternative tailored activators for different ash types (Provis and Schmidt, 2019; Shi et al., 2019; Habertet al., 2020). Furthermore, not only the smallholder businesses would benefit from the local value chains, but also the environmental impacts of constructions could be reduced due to shorter transportation distances and the cement replacement by agricultural waste ash. Alternatively, the ashes could also be used for mortars and tile adhesives, where the high surface areas of the ashes could possibly contribute positively to the properties.

For an ash to be used as SCM, the composition of the mineral oxides is a relevant parameter. In addition to the mineral content, agricultural waste materials typically contain high amounts of organic components, which are unsought in concrete. These organic components, typically polysaccharides, can be obtained before the burning process and converted to chemical admixtures for the modification of the rheological properties of concrete. These admixtures can be particularly important, when agricultural waste ashes are used to replace cement, since these often reduce the workability due to their high specific surface areas and porosity. As a result of organic admixture use, the processing can be eased, the water content can be reduced and cement can be used more efficiently, yet the desired fresh and hardened concrete properties can be attained.

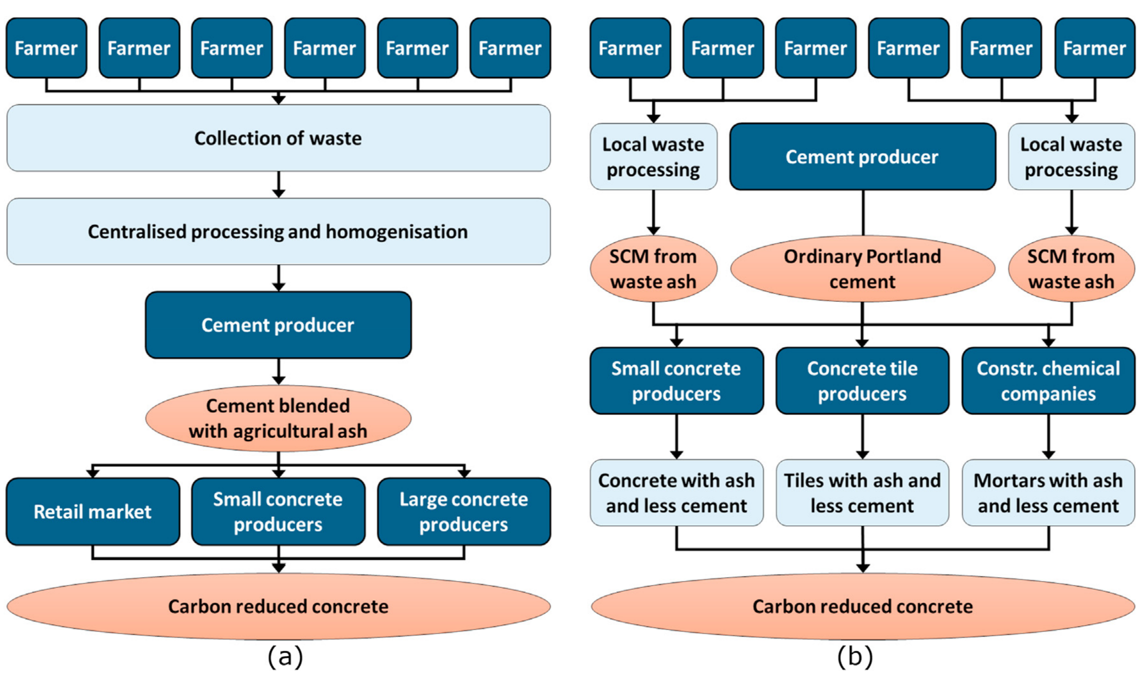

Fig. 4. Flow chart for large-scale implementation of agricultural ashes in cement and concrete, by blending cement and ash in the cement plant (a), and through smallholder businesses, where the ashes are used directly by concrete producers to reduce the cement content in concrete (b).

Various studies have shown that different polysaccharides can be used to plasticise or stabilise cement, mortar and concrete (Schmidt et al., 2017, 2019c, 2019d; Schmidt, 2015). They affect the slump retention and setting. Today, most chemical admixtures for concrete are based on naphtha for which the chemical processing takes place outside Africa. Plasticizers and retarders are important admixture types in Africa due to the challenges arising from varying high temperatures, environmental conditions and long haul. By avoiding unnecessary imports of admixtures, the use of locally harvested biopolymers can positively contribute to the environment and strengthen local markets (Schmidt et al., 2016). Obtaining these polymers can be conducted on top prior to the production of pozzolanic ashes without compromising the ash yield.

Eventually, the energy resulting from the ash burning process can be used for instance as fuel in kilns for firing of bricks. In this way, many biomass residues which hitherto are typically considered as waste, can then create three non-competing value chains related to urban construction as illustrated in Fig. 5. Due to the high and increasing production volumes of cassava in many African countries, the respective residues point out to be specifically qualified for this synergistic use (Schmidt et al., 2020; Schmidt and Barucker-Sturzenbecher, 2019). In most cases, cassava peels do not qualify in larger amount for livestock feeding, therefore the peels are often just dumped away and left to rot – with no further use or value creation. The result is unnecessary use of dumping areas and environmental pollution. Instead, the starch residues adhered to the peels can be converted to plasticising admixtures that help reduce water contents in concrete (Schmidt et al., 2019c; Schmidtet al., 2020b). The residual peels can be burnt later to be converted into environmentally friendly, low-cost cement replacement.

3. Optimising the process chains

In order to creatively and innovatively optimise the potential use of agricultural waste materials, process chains should be optimised and connected synergistically. Certainly, the best available process chain depends upon the given framework, infrastructure and available technological facilities. Therefore, no one-fit-all solution is possible, and multiple variations have to be assessed to create maximum benefit from agricultural wastes.

One possible three-step process chain, which is illustrated in Fig. 6 shall be discussed here, which combines the environmental friendliness of hydrolysis fuelling (ComephAssociates Ltd, 2016) with the advanced thermal efficiency of vertical shaft kilns (Piringer, 2017; Sahu et al., 2010). Alternative technology combinations would be possible using gasifiers, hydrothermal carbonisation systems, various fast and slow pyrolysis techniques and other kilns for the fuelling of pozzolanic materials. Many of these techniques are already used today to produce charcoal, biochar and other products for example in Ghana, Nigeria, Tanzania, or Malawi. They can be built and modified with low investment. Their efficiency along with their climate effect depends on the insulation, the specific crop processing and the raw materials, and thus have to be assessed individually based on the given boundary framework.

For the example given in Fig. 6, in a first step, the soluble organic components can be obtained to convert it to concrete admixtures. Since the adhered residual organic components often consist of large fractions of starch, the extraction can be done by dissolving the polymers in water at temperatures around 70 °C. Depending on the purity, the starch can be directly used as construction chemical or precursor, but residual fertiliser components such as sulphates and nitrates can negatively contribute to their performance, particularly, if the starches are combined with superplasticizers.

The residual components after obtaining the starch can then go to a second step: a hydrolysis process. Alternatively, the steps one and two can be combined by applying a hydrothermal carbonisation process, which would just make the extraction of the useful polysaccharides more complex. The resulting products of the pyrolysis are pyrolysis vinegar, pyrolysis oil, pyrolysis gas, and biochar. Some of the essential oils can be used as sealant component. Biomass from both crop and livestock farming qualify to be converted to asphalt components (Pahlavan et al., 2020; Finiet al., 2011). The gas can be collected for energy generation – ideally within the fuelling process chain. The biochar can be used directly

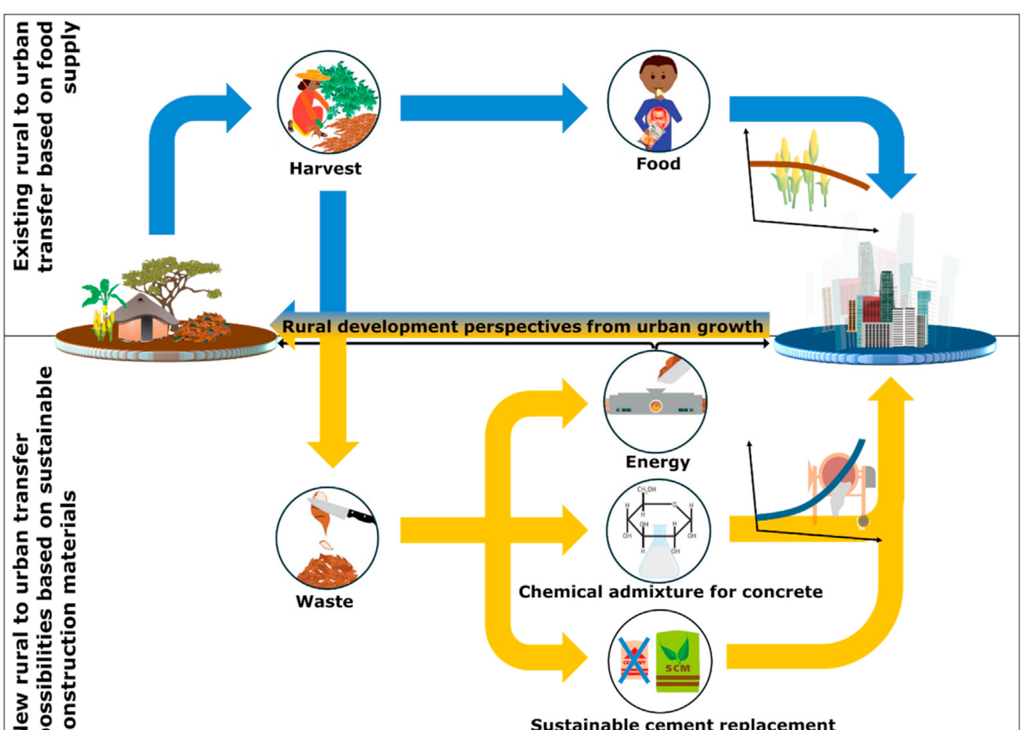

Fig. 5. Current and future rural to urban transfer possibilities.

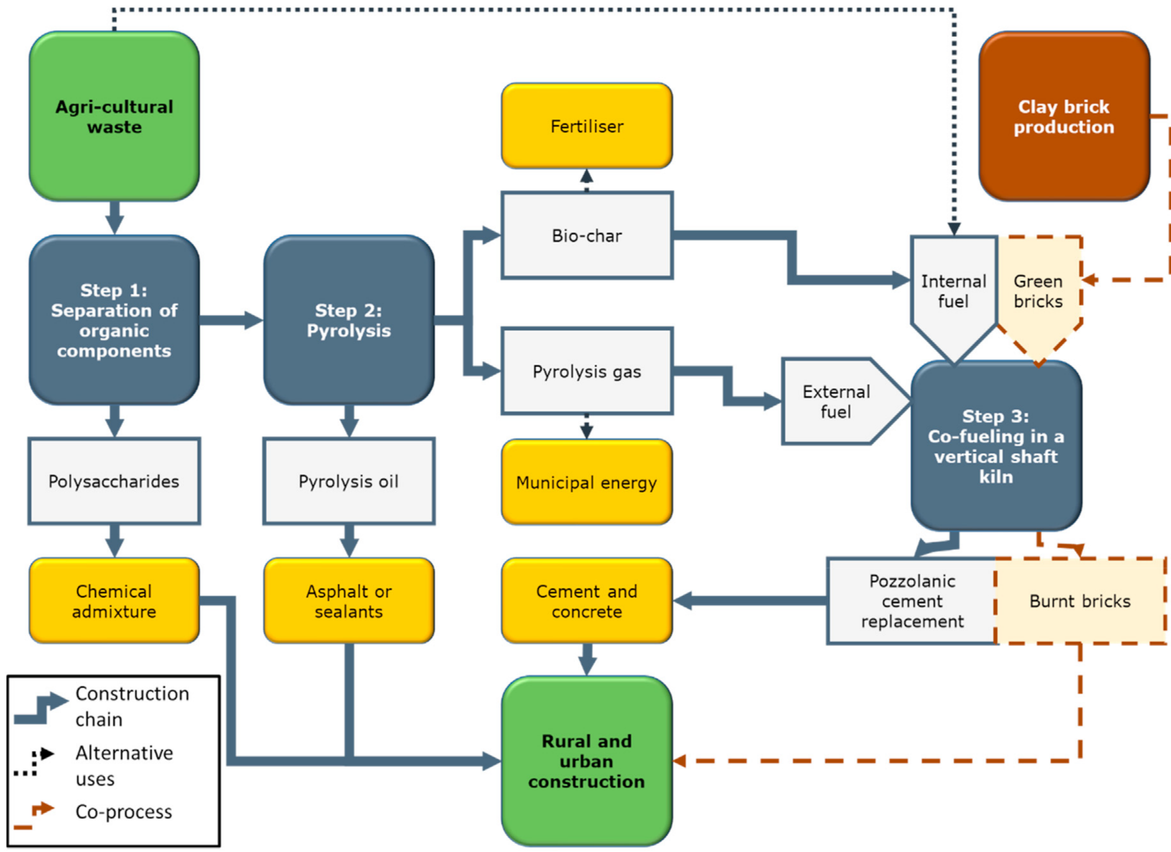

Fig. 6. Optimised use of agricultural waste in a three-step process involving pyrolysis and vertical shaft kiln stages.

in agriculture, if it does not qualify for further processing towards a pozzolanic cementitious material. If the content of amorphous silica and/or alumina is high, it can be further processed to a pozzolanic SCM, while it continues to positively contribute to the efficiency of the third step, the production of bricks in a vertical shaft kiln.

Here the feed of the green bricks is done from a loading zone on the top of the kiln. The fuelling takes place in a central firing zone. In order to enhance the fuelling process, the bricks to be fired are infilled with co-fuelling material. For the infilling the biochar can be used. For the fuelling of the central firing zone, the hydrolysis gas from the former process can be utilised, if it is not directly circulated back to the hydrolysis process or is used for other purposes. This way, the biochar as well as the pyrolysis gas can contribute to the brick production. And, beyond the bricks ideally a reactive cement replacement can be produced. However, the high temperatures in the central firing zone can be detrimental to the reactivity of the pozzolans, so that eventually a compromise solution could depend on the demands on the bricks and the cement replacement. If such compromise cannot be made, a vertical shaft kiln could still be used to produce pozzolans separately, without the synergy with the brick production, by operating the kiln between 750 °C and 900 °C – ideally tailored to the temperature the biomass requires for optimum reactivity. In this case, for cost-efficient and energy-efficient operation, a sufficient biomass supply has to be ensured. Alternatively, the ash production could be conducted in parallel to other lower temperature processes, for example drying of food products. Due to the high number of parameters, which depend upon the biomass origin, the technical possibilities, supply and final application, the assessment of the best practice requires the involvement of experts from multiple disciplines, including experts in health, climate and environmental issues to develop societally sound, sustainable circular economic value chains in the rural and urban setting.

4. Circular value chains based on rural waste and urban construction

Urban growth can become a driver for rural development when rural by-products are converted to urban construction materials. To achieve this, it is necessary to create innovative, circular economic supply and value chains. These require decision making processes based on the given boundary framework. An example is shown in Fig. 7.

Firstly, the available by-products from rural farming have to be assessed for their qualification as construction materials. The best use depends on multiple parameters such as origin, amount and distance to the next user or process step. Based on this, a decision has to be made, whether the by-products go back to agriculture or can be converted effectively to construction materials. Yield, demand, supply and other parameters determine whether the materials are better used in the local rural vicinity or if they can be used on a larger scale for urban construction and urban users to build with it. Depending on the constituents, the waste materials from construction and demolition can then be converted to products of interest in the rural environment such as soil stabilisers or fertilisers, which would close a full circle, where most of the by-products are upcycled and re-used. The case A. in Fig. 7 shows the linear flow from rural farming to construction for urban users and back.

In case the supply of biomass is not sufficient to be converted effectively to urban construction materials, the supply could still be sufficient for a purely rural value chain for construction materials. This case is shown as case B. in Fig. 7. Decision making and products compare to the circle A., but the dimensions are smaller.

An additional purely urban circular chain can be created in conjunction with urban farming, which is shown as case C. in Fig. 7. Harvesting part of the food supply directly in urban regions can become

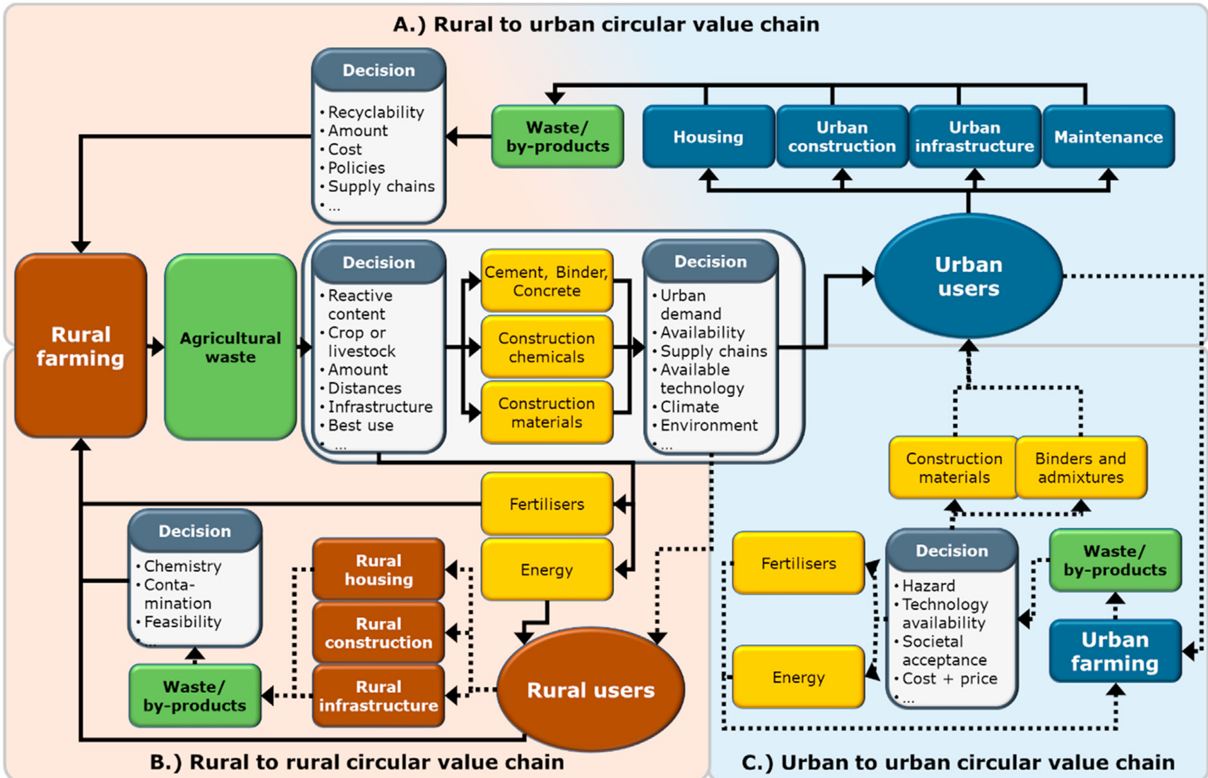

Fig. 7. Circular value chain options from rural by-products to urban construction.

attractive for future cities, not only for crop but also for livestock farming (Schmidt et al., 2020a). Converting animal manure cleanly into technical products through hydrolysis (Pahlavan et al., 2020) offers the potential to conduct farming also in an urban setting. The urban circular chain is identical to the value chain from rural by products, but the entire economic value chain remains within the urban environment. It can complement the supply with concrete constituents, since also small amounts of biomass can positively contribute to sustainable concrete technology (Teixeira et al., 2016, 2019), but in order to meet the urban demand with bio-based binder components, it is likely that the supply from rural areas remains inevitable.

5. Participatory transformation of urban and rural areas

Fig. 7 indicates that circular value chains require decision making processes based on specific local boundary conditions. The decision whether a resource qualifies for large scale urban use, smaller scale rural use or alternative use depends upon information and assessment from various perspectives. For circular processes to operate smoothly, functioning communication is typically presumed. In reality, various heterogeneous actors with often diverging interests and information backgrounds are involved. Fig. 7 shows that between different process stages, decisions have to be taken, which may strongly depend upon the interests of the stakeholders involved in the decision-making process, and which may oppose to the interests of others. In urban construction, often the interests of investors and residents diverge (Serumaga-Musisi, 2018).

Urbanism takes place in multiple shapes and with multiple stakeholders in parallel. Often in Asia, Latin America and Africa the informal or so-called kinetic city represents the most contemporary city (Mehrotra and Filipe Hernández, 2010). It is of amorphous nature, and permanently reinvents itself and adapts to new conditions, following a local logic, driven by the daily demands of urban dwellers. Materials for construction are often recycled materials with limited durability. The opposite pole of co-existing urban shapes is the so-called static city, where typically concrete, steel, and bricks can be found as construction materials. These intertwined city shapes also clearly underpin the existing social and economic inequalities, which are exacerbated by globalisation. The coexistence of multiple urban shapes needs increasing attention in conjunction with urban growth. Often urbanisation challenges are only considered from the perspective of stakeholders of the static city. The informal urbanism is either overlooked or only looked at from a humanitarian angle, although it is a crucial driver of intrinsic innovation. The informal economies act within all urban shapes. Construction based value chains can serve both the formal and informal sectors. Rural to urban and urban to urban circular concepts can be developed with mutual benefit to the different actors in urban growth and rural development, if all perspectives and interests are treated on an equitable scale.

In order to be sustainable for a society, the process and value chains in construction materials for urban growth, thus, have to be integrative and participatory to become a social innovation.

However, equitable social innovation typically does not arise from itself, but requires careful company through communication infrastructure and experts: ("[…] scholars and professionals from across the field of communication are called upon to play a critical role in helping urban communities understand and manage change." (Matsaganis et al., 2012)). Therefore, it seems indispensable to accompany the above-described value chains by a carefully adapted participatory communication concept involving the actors concerned, which aims at the successful handling of "purely density-related communication topics" and the development of sustainable habitats (Jassem and Drucker, 2018; Schiewer and Hess-Lüttich, 2010). The inevitability of such a framework has also been underpinned by the GLOBE Global Consensus on Sustainability in the Built Environment (JCSS et al., 2020). To create such a framework is the task of politics in concomitance with academia and industry players.

6. Discussion of potentials and research needs

Urban populations in developing countries especially in Africa continue to grow and along with it the demand for construction materials. Hence, a high potential is given for research and development in the construction industry to implement knowledge driven approaches and leapfrogging technologies. This will lead Africa for instance to potentially becoming global green concrete pioneer. Due to an increasing gap between the urban and rural livelihood potentials it is important to look at synergies between urban growth and rural development. Converting agricultural by-products to construction materials constituents seems to be a promising approach.

Two possible ways of using agricultural by-products for better concrete technology are feasible, organic admixtures and inorganic cement replacements.

- A large variety of agricultural materials and by-products contain important polysaccharides. They can be converted to construction chemicals to be used to enhance the efficiency of concrete production by reducing the water to cement ratio and helping to avoid evaporation during curing. Some organic components are easily soluble in water and can be easily extracted.
- For the extraction of more complex organic constituents, pyrolysis and hydrothermal carbonisation seems to be viable approaches to obtain multiple products that can be used in the construction industry.
- The use of locally obtained construction chemicals is particularly interesting in SSA to reduce the costs for imported precursors and products and helps to avoid the use of naphtha-based chemicals.
- Ideally, these polysaccharides can be obtained from agricultural wastes, which later can be converted to a supplementary cementitious material. Cassava peels for example, which have little further value today, can be converted to plasticizers based on cassava starch and in addition to a cement replacement based on cassava peel ash.
- Many more agricultural wastes can be converted to supplementary cementitious materials and help to reduce the carbon footprint of concrete. Among others for many countries of SSA beyond cassava peels, particularly the ashes of groundnut shells, rice husks, and maize cobs seem to be promising due to their wide-range availability. Locally and regionally, other by-products can become interesting, such as sugar cane bagasse, palm kernel, coconut shell.
- Even though the agricultural production as well as its efficiency in SSA will grow, bio-based by-products are limited and the SCM yield is low compared to the demand for cementitious construction materials in the future. Therefore, agricultural ashes can become particularly interesting for ternary cementitious binders, e.g. blended additionally with limestone filler, calcined clay, slag, or natural pozzolana.
- Due to the inhomogeneity of agricultural ashes, their collection on a large scale as well as their homogenisation could become a logistic and technical challenge. Therefore, the ashes could be better produced locally by the farmers to be directly sold to concrete producers, who in return can reduce their Portland cement content. This way, also local livelihoods can be enhanced.

An ideal process chain would first obtain the water-soluble organic components, then produce further organic products in a pyrolysis step, and in a last step the residual wastes can be burnt to become supplementary cementitious materials. Then a higher temperature burning process will be required, which is ideally combined with another high temperature process. Co-firing the agricultural ashes in a vertical shaft kiln during the production of clay bricks seems to be a feasible option, but the temperatures must not be too high to obtain the maximum pozzolanic activity. Therefore, process chains, kiln technology and co-processes have to be carefully evaluated. In order to develop most sustainable value chains, it is necessary to optimise processes and develop synergies. This also means to use technologies mindfully, with consideration of the given boundary frameworks, supply chains, health and environmental aspects, and with special focus on the development of circular and energy saving processes.

A pilot process involving pyrolysis and ashing has been built on the campus of the University of Ghana. Future research will assess the feasibility of the concept with various material sources. The obtained chemicals and supplementary cementitious materials will be assessed concerning their feasibility as constituents for high-performance mortars and ordinary concrete. In parallel, data is being collected from cassava farmers to assess, how rural agricultural wastes can create new livelihood potentials.

Beyond this, in future research it will be interesting to study the extent to which biomass can be incorporated beneficially in concrete in Africa on a larger scale. Future research should focus on how biomass ashes that are not directly optimised for concrete technology can still be used, such as ashes from energy production and municipal waste incineration. Due to the enormous impact of bio-economic approaches on both the rural and urban development, it is important to coordinate research activities in circular bio-based economic concepts between multiple disciplines and to develop solutions with high societal impact.

7. Summary and conclusions

The conversion of unused bio-based wastes can become an interesting perspective for more sustainable construction. This is particularly interesting for countries and regions of the global South, because of the growing agricultural potentials and an accelerated urbanisation that demands for sustainable materials. The present paper proposes potentially viable concepts for the development of livelihoods, and supply and value chains, which involve using organic and inorganic components in parallel for sustainable concrete construction:

- Organic components can be converted to rheology modifying admixtures to help reducing the water in concrete, and
- the residual components can be converted to supplementary cementitious materials for a reduced carbon footprint of local cement production.
- In order to maximise synergies and circularity, the processing can be combined with the production of further construction materials, e.g. brick production.

This way, the inevitable urbanisation can become more sustainable, local, and participatory. And it contributes to rural developments as well, which could help slowing down the rapid urbanisation, which is a great challenge in many regions of the global South.

While value chains for organic admixtures are feasible due to the low amounts required in concrete technology, this looks different for supplementary cementitious materials. To date, the available bio-ashes that would be feasible for large scale cement processing in Africa cannot yet contribute to a significant reduction of the overall clinker factor by more than 6%. However, with increasing effectiveness of agricultural processing, this will change quickly. Further research is mostly requirement in identifying more bio-based resources and how cements with multiple ashes can perform.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Parts of the presented works on kiln processes and cassava peel processing have been developed within the projects INFRACOST and LocalCare, respectively. The authors highly appreciate the funding provided by the Federal Ministry of Education and Research in the schemes CLIENT II and GAIIA.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dibe.2021.100047.

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