Socio-economic and ecological potential of agroforestry in sub-Saharan Africa

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Summary

Climate change and growing world population exert pressure on agriculture and natural forest ecosystems.[1] Here, we explore the possible contribution of agroforestry to the necessary shift to sustainable land management in sub-Saharan Africa as well as occurring challenges in meeting socio-economic and ecological demands.

Positive social and economic outcomes of agroforestry are the provision of more resilient livelihoods, greater yields and thus higher food security, as well as increased wealth.[2–5] By involving women more actively and equitably, these positive outcomes are even improved.[6,7] Findings also indicate, that established agroforestry is more profitable than monocultures .[8] Development of local markets and financial support during the transition can further increase agroforestry benefits.[8,9] Stakeholder engagement ensures a better and long-term adoption of agroforestry practices.[7,10] However, upscaling of agroforestry practices can be hard due to land tenure issues, lack of social and financial capital and policies.[9,11]

Ecologically, trees influence resources, such as light, water and nutrients.[12] Agroforestry leads to an increased nutrient turnover, especially for nitrogen and potassium[13], prevents erosion[14] and can contribute to efficient rainwater usage[15] and pest inhibition[16]. Some agroforestry systems such as cocoa plantations show different soil properties along different timescales: in the short term, soil quality declines, when natural forests are converted into agroforestry systems, but in the long term, quality improves, although it does not reach its original quality again.[17,18] Traditional cocoa agroforestry systems have greater conservational potential than monocultures.[19]

Agroforestry can store atmospheric carbon in plants and trees as well as in a growing humus layer.[20,21] In sub-Saharan Africa, agroforestry can meet the high demand of wood, which is used for building, cooking and as an energy source. Therefore, destructive exploitation of rainforest can be prevented.[21–23]

Overall, agroforestry does show potential to sustainably improve land management due to the predominating positive effects mentioned above.

Rechercheaspekt A: potentials of different agroforestry systems

Janosch Hirzel

Short summary

Agroforestry systems are diverse and so are their potentials. Systems are most beneficial when trees are selected to improve soil fertility, are managed to minimize competition and soil moisture is not a limiting factor.[24] Improved fallows sequester carbon while also improving soil fertility.[11] Intercropping systems with leguminous trees and crops produced more crop yield due to the nitrogen fixing trees.[25] Multistrata agroforests are crucial in cocoa production as they improve cocoa yields, provide extra income for farmers and increase the resilience of the system against climate change.[1] Last but not least an alternative to the slash-and-burn technique, the slash-and-mulch technique, resulted in higher plantain yields if shade-tolerant plantain was grown under the remaining trees, which can additionally be used for timber production.[26]

Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis[24]

-meta analysis and literature review of papers on agroforestry in sub-Saharan Africa (SSA)
-increased crop yields, soil fertility, runoff control and infiltration, as well as reduced soil loss in agroforestry systems but no analysis of specific systems.
-eight agroforestry practices identified
-win-win situations in agroforestry systems when trees improve soil fertility, and soil moisture is not limiting, or trees are managed to minimize competition

Why promote improved fallows as a climate-smart agroforestry technology in sub-Saharan Africa?[11]

-literature review
-three pillars of Climate Smart Agriculture: mitigation and adaptation to climate change, maintaining productivity
-improved fallows: planting mainly legume trees/shrubs on fallow, then rotate with crop
-fallow phase improves soil fertility, around 100 kg N $ha^{-1}yr^{-1}$ - 200 kg N $ha^{-1}yr^{-1}$
- after fallow phase, vegetation is cut down and incorporated into soil
- fallow vegetation has carbon sequestering potential, but increase of flux of GHG into atmosphere?
- reduced weeds, pests and diseases when selecting tree legumes correctly
-improved fallows conserve soil moisture
- fodder production security during dry periods
-charcoal production
- up-scaling limited

The long-term effects of a gliricidia-maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties[25]

-highly populated areas of SSA
-gliricidia-maize intercropping agroforestry system improves soil fertility, increases maize yield
-leguminous tree fixates nitrogen, also pumping up nutrients (P, Ca, Mg, K) from deeper levels of the soil
- overall loss of nutrients in the soil due to export through higher crop yields and storage in tree wood
- higher soil moisture retention in gliricidia-maize system -> important for nutrient uptake and during midseason droughts
-yields in combined system higher
- N availability decreased under excessive rainfall and drought years

Trade-offs between crop intensification and ecosystem services: the role of agroforestry in cocoa cultivation[1]

-paper stresses the importance of appropriate agroforestry techniques in cocoa production
-increased cocoa demand is promoting the intensification of cocoa cultivation
-leads to the surrender of shade trees, which provide several ecosystem services, and clearing of rain forest area
-appropriate cocoa cultivation with shade trees could improve cocoa yield, resilience of the system to climate change, sustainably stabilize cocoa production and secure the farmer's income

Yield of plantain grown under different tree densities and 'slash and mulch' versus 'slash and burn' management in an agrisilvicultural system in southern Cameroon[26]

- silviculture as an alternative to slash and burn to prevent deforestation
- timber trees with shade-tolerant plantains
- plantain very important crop in Cameroon
-various crop management treatments: burning, mulching, and intercropping with tannia
- two densities of timber trees (TSD): low density and high density
- highest plantain yields with low TSD, intercropped with tannia and mulched
- slash and mulch + low tree density > slash and burn
-> combining plantain with low density of timber trees results in higher plantain yields + extra money for timber
- no significant differences in weed bio mass in intercrop, mulched system compared to sole, mulched system.
- intercropping tannia with plantain doesn't effect plantain yield
=> low tree density is best for maximum plantain yield

Rechercheaspekt B: Social Benefits and Potential of Agroforestry

Hanna Salomon

Short summary

Agroforestry has high potential to intensify farming sustainably while mitigating climate change, increasing food security, and providing more resilient livelihoods.[3] Evergreen farming can further increase household income by increasing the overall profitability and decreasing the production costs.[2]

By addressing gender inequality in agroforestry and empowering women, the women's yield and income could be improved, and hunger simultaneously reduced.[27]Through education and enhancing equity, women get actively involved in agroforestry and increase their efficiency.[6]

Structured stakeholder engagement has the potential to include women and marginalized groups better and lead to faster and farther-reaching expansion of agroforestry due to the promotion of more diverse and adaptable technologies.[7]

Gender, agroforestry and food security in Africa[27]

The paper reviews the contribution of agroforestry to food security with a special emphasis on gender. In Africa, addressing gender imbalances in agroforestry practices could significantly decrease poverty while simultaneously enhance food security. The review focuses on papers with data from the East African region (Kenya, Uganda, Tanzania, and Rwanda). Constraints of women (factors) in agroforestry are listed and suggestions of resolving them (interventions) are made and visualized in a graph.

Does an agroforestry scheme with payment for ecosystem services (PES) economically empower women in sub-Saharan Africa?[6]

TIST (The International Small Group Tree Planting Program) is an agroforestry PES scheme in India, Kenya, Tanzania, and Uganda. This paper analysis the case study in Kenya by using different formulas and statistical methods to see if there is a difference in agroforestry participation, fertilizer application, farm size etc. between female TIST and non-TIST farmers. Tables display the results, which are further analyzed in the discussion and additional graphs. Furthermore, benefits of the TIST program such as increasing women's efficiency in agroforestry practices are mentioned and suggestions for improvements of the program such as ensuring including the poorest of the poor in the program are made.

Evergreen Agriculture: a robust approach to sustainable food security in Africa[2]

Case studies on evergreen agriculture in Zambia, Malawi, Niger, and Burkina Faso are analyzed. In the paper, evergreen agriculture "is defined as the integration of particular tree species into annual food crop systems". The authors compare yield and other factors such as usage of fertilizer collected by a survey, from prior and after the implementation of evergreen agriculture. Evergreen agriculture is shown to be a method to increase food production, household income, and increase resilience. The further adaption and scaling-up of evergreen agriculture in Africa is examined.

Agroforestry solutions to address food security and climate change challenges in Africa[3]

The paper provides an overview on how agroforestry can address food security and climate change problems in Africa by summarizing and linking important reports from that field. It also shows different factors that influence available agroforestry options and illustrates how different farming practices influence the socio-ecological system and various policy domains. The paper concludes that there is 'real potential' in adopting agroforestry practices in Africa because it enhances food security, climate change mitigation while protecting Africa's rural landscape.

Structured stakeholder engagement leads to development of more diverse and inclusive agroforestry options[7]

The authors of the paper apply the structured stakeholder engagement method in the eastern part of the Democratic Republic of Congo. By conducting semi-structured interviews with farmers, local knowledge was gathered and later used to structure workshops where especially women and marginalized groups were encouraged to participate in. A guide was created including results from the interviews, the workshops, and scientific findings. This approach led to a guide with a wide diversity of technologies that are adaptable for various smallholders and benefit them and the ecosystem the most. However, existing restricting factors were mentioned.

Rechercheaspekt C: socio-economic perspective on potential of Agroforestry

Jan Streit

Short summary

Agroforestry has significant socio-economic benefits compared to monocultures and is more profitable.[8] Furthermore, it has proven benefits for farmers to become financially independent and to ensure food security during climate related extreme weather events.[4,5] To sustainably establish agroforestry, it's essential to understand the farmers individual incentives and it's necessary to include the farmer in the process of a shift to agroforestry.[10] To unlock further potential, focus is needed not only on the technology and farming techniques but also in the development of local markets and on the barriers of transition, such as the high investment costs in the first year, from a non-agroforestry system to land that includes trees.[9]

Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya[4]

Farmers with agroforestry systems could cope better during environmental hazards than farmers without. 43% farmers improvement in soil erosion and soil fertility after introducing agroforestry. Trees provided additional income. This includes selling fruit, timber, fuel wood and seedlings to local markets. livestock. Benefits of agroforestry are only visible in the long-term.
Long-term effect not explored in this study, but short-term highlights mainly benefits for farmers: farm productivity, household wealth, increased income diversity, reduced soil erosion and ultimately several coping strategies to withstand climate related hazards.

Points to improve financial challenges are:

- Improve market accessibility to enhance income generating opportunities provides agroforestry techniques.
- Couple access to farm implements and capital with agroforestry projects.
- Educational farm visits to change the farmers conception of agroforestry with on sight examples where they can see the benefits with their own eyes.

Drivers of farmers' decisions to adopt agroforestry: Evidence from the Sudanian savanna zone, Burkina Faso[10]

Study explores vis household surveys in form of interviews factors influencing farmers decision to protect and manage trees on their farmland. Key is to involve farmers in the decision-making, in the design of agroforestry programs, and to train farmers in natural resource management. Thus emphasizes agroforestry especially the roles it can play for food security, poverty alleviation and climate change adaption. Currently, there is a lack in training. Economic benefits such as firewood, protection and harvest provided by agroforestry are key to get farmers to motivate farmers to include trees on their farmland.

Climate risk adaptation by smallholder farmers: the roles of trees and agroforestry[5]

Highlights examples, which demonstrate the growing recognition of agroforestry as a tool in helping smallholder to adapt to multiple threats represented by changing climate. Challenges to be faced are in the following key areas: Research under what condition farmers adopt these systems, Policies that are incoherent and lacking, collaboration between different organizations on knowledge exchange and individualized implementation of agroforestry systems.

Carbon revenue in the profitability of agroforestry relative to monocultures[8]

Study evaluates the impact of carbon revenue on the profitability of agroforestry relative to dominant monocultures in Ethiopia in a model of stylized plots. Agroforestry was on average four times more profitable even when carbon revenues were excluded. This was mainly because of the higher price of fruit produces. A barrier to switch from monocultures to AFS (Agroforestry System) are the work requirement, possible lost produce, growing time of trees and upfront costs.

Trees of prosperity: Agroforestry, markets and the African smallholder[9]

Farmers have been introduced to agroforestry with little consideration for the markets for trees and tree production. The study presents case examples of products with high local demand: charcoal marketing, smallholder timber in Kenya, tree nursery enterprises, indigenous fruits in southern and central Africa, Calliandra seed.

The paper hypothesizes that, as elsewhere in the world markets in Africa is linked to overall growth in rural economies. Therefore, agroforestry should put emphasis not only on the tree planting and technologies alone but also on rural development. The focus should be on products for local and regional markets such as local fruits, timber and charcoal because products for international markets benefit only a few.

Rechercheaspekt D: nutrient cycling and soil fertility

Hanna-Sophie Wiedemeier

Short summary

Agroforestry systems are an opportunity to limit anthropogenic pressures on natural forest ecosystems, improve food security and prevent soil degradation.[28] Trees alter the availabilities of crop growth resources such as light, water and nutrients and therefore influence crop production.[12] Trees have a beneficial impact since they root deeper and dead roots provide significant inputs of organic matter and nutrients.[28] A major agricultural land use type in the tropical rainforest belt of West Africa are cocoa agroecosystems, which are often associated with many ecological changes such as deforestation and accelerated soil degradation.[17] In cocoa agroecosystems different ages of plantations (e.g. cocoa) show different soil properties.[17,18] Traditional cacao agroforestry systems have a greater potential for conservation of ecosystem services closer to a natural forest state than monocultures.[19]

Long term impact of Acacia auriculiformis woodlots growing in rotation with cassava and maize on the carbon and nutrient contents of savannah sandy soils in the humid tropics (Democratic Republic of Congo)[28]

investigation of influence of acacia woodlots on soil fertility (rotational agroforestry); confirmed: afforestation with legume trees increases SOC and tot N and decreases pH; decline in productivity can be explained by decrease in most major mineral elements (Ca, Mg, K): more export than input

Separating the effects of trees on crops: The case of Faidherbia albida and millet in Niger[12]

influence of F. albida (leguminous tree) on millet production in Sahel; F. albida influences productivity positively – albida effect = nutrient effect or physical effect?; physical –> strive for high tree densities; high N-fertilizer application: production under F. albida trees not higher than in open area; albida effect is mainly nutrient effect (N + P); + effect from increased water availability is likely offset by a - effect of reduced light

Development of a composite soil degradation assessment index for cocoa agroecosystems in southwestern Nigeria[17]

development of soil degradation index; degradation under cocoa agroecosystems is mainly attributed to a decline in soil nutrients, loss of soil organic matter, increase in soil acidity and breakdown of soil textural characteristics; soils under cocoa agroforestry systems of age 11-40 were less degraded than soils under plantations of age 1-10 or 41-80.

Effect of land-use conversion from forest to cocoa agroforest on soil characteristics and quality of a Ferric Lixisol in lowland humid Ghana[18]

investigation of changes in and responses of soil physico-chemical properties and soil quality to land-use change (natural vegetation -> cocoa plantation); short term: significant soil quality decline but in long term (15-30 years): quality improvement (still not as good as natural); C and TN decreased at first and then slowly increased again; available P declined consistently; Exchangeable cations (Ca, K, Mg) and CEC remained stable with a tendency to improve; explanation could be "nutrient pumping"-effect

Marginal effects on biodiversity, carbon sequestration and nutrient cycling of transitions from tropical forests to cacao farming systems[19]

review article; investigation of changes to biodiversity, carbon sequestration and nutrient cycling conditions due to transition from natural forest to agroforestry and monoculture; agroforestry systems show a tendency to differ less from native forest baseline

Rechercheaspekt E: ecological aspects, nutrient and water cycles

Chiara Lauber

Short summary

In sub-Saharan Africa, farmers suffer decreasing soil fertility. In agroforestry systems, litter and biologically nitrogen fixing trees increase the nutrient turnover. Particularly nitrogen and potassium availability can be increased by agroforestry systems.[14] For example Faidherbia albidia if planted in combination with maize provides the majority of nutrients that inorganic fertilizer otherwise would do, except for phosphorus.[13] However, trees/shrubs and crops compete also for nutrients. To minimize this effect, hedges should be pruned in dry season. If the pruning is used as mulch, it further helps to prevent erosion.[29] Agroforestry systems contribute to efficient rainwater-usage by reducing evapotranspiration of soil, reducing surface runoff and providing a better water infiltration rate. The greatest impact comes from litter/mulch; canopies only have a positive influence on the water cycle, if there are leaves in dry season, but not in wet season. [15] Agroforestry systems promote biodiversity. Therefore, pests are more likely exposed to predators. Additionally the disruption of spatial patterns by shrubs/trees inhibits pests.[16]

Agroforestry in Sustainable Agriculture Systems (Chapter 1) [14]

-Trees in agricultural systems increased nutrient turnover and availability; mostly by litter, but also by nitrogen fixing trees
-It is not clear, how much of this BFN is available for crops.
-Trees are animal shelter: nutrient supply by excreta
-Depth of nutrient uptake increased by trees (especially for water-soluble nutrients)
-inorganic P has to be added in agroforestry systems
-Trees: erosion prevention
-hard to distinguish nutrient effect from other effects (light, soil, water)

Agroforestry in Sustainable Agriculture Systems (Chapter 3) [15]

-Soil water can be lost in 4 ways: Evapotranspiration of soil and plants, transpiration, deep percolation and surface runoff.
-Canopies

- in dry season: absorb solar radiation and thus reduce water loss through evapotranspiration.
- in wet season: can reduce the amount of water infiltrating into the soil by catching water, which directly evaporates.

-Mulching:

- reduces the radiation on the soil, protects the soil from raindrops (which can harm the soil structure), maintains good surface infiltration (hydraulic conductivity increases with hedgerow), reduces surface runoff and promotes surface rooting (which also lowers evapotranspiration).
- is food for earthworms (their population increases), which contribute to better soil aggregation and stability.
- can reduce soil temperature and increase soil moisture.

Most agroforestry tree species don't have deep rooting systems, so they rather compete for water with crop.
Research is needed to find optimal species.

Quantifying nutrient deposition and yield levels of maize (Zea mays) under Faidherbia albida agroforestry system in Zambia[13]

In Zambia, the Faidherbia albidia tree is known to be good in combination with maize:
-Dry season: canopies lead to a higher crop yield

-wet season: the litter acts like a fertilizer
-the wood is useful for households.
-Its litter was tested on maize fields with clayey and sandy loam texture: If it was the sole source of nutrients, Faidherbia litter would supply 30-71% N, 10-25% P and 60-100% K of the recommended application rate.
-The nutrient supply depends on the age of the tree

Agroforestry and the Mitigation of Land Degradation in the Humid and Sub-humid Tropics of Africa[29]

- annually and per ha, 22 kg nitrogen, 2.5 kg phosphorus and 15 kg potassium are lost in Africa
-3 agroforestry systems have potential in humid and sub-humid tropics: Barrier hedges, tree/shrub combinations and multi-strata systems
-Barrier hedges are pruned in dry season, so they compete less for resources with crop. pruning is used as fodder and not as mulch, the probability of erosion is higher.
-High canopies have a disadvantage: Raindrops merge on the leaves and accelerate when falling, so the erosion actually increases. That is why multi-strata systems should be preferred
- Adequate species are, for example, leguminous trees and shrubs, which usually keep their leaves in dry season and additionally produce edible dry matter
- In Asian and South American countries, some home gardens are agroforestry systems and supply carbohydrates and proteins for families.

Agroforestry systems: helping smallholders adapt to climate risks while mitigating climate change[16]

-For humid and subhumid tropics, the potential agroforestry systems are alley cropping and multi-strata systems.
- Trees can modify temperature through shading and moisture, they also decrease wind speed, lead to fewer fluctuations in conditions
- Trees and shrubs contribute to disruption of spatial patterns, which inhibits the reproduction of pests. Also, more diversity, for example more predators, is an advantage regarding pests
- Not only adapting, also mitigation of climate risks by storing carbon: This can also be a money source for farmers, because carbon storing is paid.

Rechercheaspekt F: CO_2 mitigation potential

Marc Reusser

Short summary

Agroforestry provides different ways to sequestrate carbon. In a direct way by planting trees and plants carbon is stored in the biomass.[21] Due to higher biomass on the ground from leaves and branches, the humus layer of the soil can grow which has a large positive impact on the carbon storage in the soil.[20,21] Agroforestry can provide wood as an alternative carbon neutral energy source compared to fossil fuels and in some cases overweighs the carbon loss due to deforestation.[22] Depending on the land and the climate, agroforestry can store between 3 and 60 tC/ha (50-100 years).[22] Especially in Sub Sahara Africa with high demands of wood as an energy source, agroforestry can help overcome the shortages of firewood and therefore prevent destructive exploitation. Wood can also be used for building and acts as a more sustainable alternative compared to other raw materials such as concrete or metal.[23] Other greenhouse gases such as CH4, N2O and NO are not clearly increasing due to agroforestry or if they do it is unlikely that they overweigh all the other positive carbon capture effects.[30]

Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa[20]

Especially low-income countries depend on a secure agriculture. Agroforestry can have a positive effect on yields as well as ecosystem services by mitigating climate change as well as expand the agricultural production in Africa. This can be a win- win solution for two of the major problems Africa will be facing in the coming years. It is important to show the small hold farmers the benefits of agroforestry in terms of the higher resilience to climate adaption (e.g. droughts) and the improved production. Africa's food security is currently at stake. Due to missing agricultural policies and fertilizer the soil decreases in fertility. Agroforestry can improve the soil fertility because an increase of organic matter (e.g. leaves) and nitrogen form leguminous trees. A well-organized agroforestry system can play a crucial role in buffering water scarcity and also improve its resilience to any change in climate.

Carbon sequestration in tropical agroforestry systems[21]

As suggested by the Kyoto protocol, agroforestry is a method to store carbon in the terrestrial (plant and soil) sphere. It is estimated that agricultural lands can store between 42 and 90 Pg of Carbon from the Atmosphere (over the next 50-100 years). It has been shown that trees within the agricultural field often improve the productivity of the system and also act as C sinks. Since the climate is very different across the world, a variety of agroforestry systems exist which include local climate and socio-economic factors. In Africa, agrosilviculture has a potential of storing between 29-53 MgC/ha (in 50years). With adequate management of trees that are suited for that area and pastures there is a big carbon sequestration potential. In the equatorial region of Africa perennial crops like cacao or coffee are often mixed with trees since there are many positive tree-crop interactions.

CO_2 Mitigation by Agroforestry[22]

Agroforestry has an estimated carbon mitigation potential of 3 up to 60 MgC /ha. With additional measures such as: protection of existing forest, conservation of soil productivity, substitution of fossil fuel by wood as an energy source can improve the mitigation of carbon by up to 20 times. Based on the current state of a landscape there is different potential and measures to take to sequestrate carbon. Degraded lands have a potential for plantations, secondary land or fellow forest can be protected and agricultural sites can be used for agroforestry. Agroforestry can help overcome the shortage of firewood and therefore prevent destructive exploitation. If increment and burning of wood are in balance,

firewood is a CO2 neutral energy source. Wood is also a way more sustainable raw material for building than most other energy intensive raw materials like concrete, metal or plastic.

Fluxes of CH_4, CO_2, NO, and N_2O in an improved fallow agroforestry system in eastern Amazonia[23]

Besides the well know greenhouse gas CO2, soils also play a major role as sinks and/or sources of trace gases such as CH4, N2O and NO. Many studies show, that agroforestry has a big potential to store carbon, but it is important to know if agroforestry doesn't increase other greenhouse gas emissions. Agricultural areas usually have higher NO and N2O emissions due to the higher nitrate availability and therefore an increase in microbial nitrification and denitrification. With leguminous trees binding nitrogen, one could expect the nitrogen-oxide emissions to increase which did not happen. Also, the CO2 emissions did not appear to rise nor did the CH4 uptake sink. In this paper there is therefore no other gaseous emissions which could compromise the carbon-sequestration of agroforestry. However, there is other studies that show lower CH4 uptake and higher N-oxide emission with N-fixing trees. The key role of whether soils emit more N-oxides than without agroforestry could be the structure of the soil.

Potential of agroforestry techniques in mitigating CO2 emissions in Nigeria: some preliminary estimates[30]

In Nigeria the dependency on natural vegetable resources is very high. Approximately 90% of the energy use is covered with wood burning. In many tropical countries deforestation is happening to make room for the slash and burn agriculture and to cover the demand of fire wood. There are different agroforestry types proposed with different types of wood as product. The cheapest way to store carbon is by producing sawlogs and the most expensive wood type is the fuelwood. Estimates show that with an intensification in the agroforestry can outweigh the 1.3 % deforestation rate by the factor 3. Therefore, agroforestry has a large potential in Nigeria but since the prices for timber are very low, the implementation costs for agroforestry should be low enough so that there is an economic benefit for farmers.

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