Supporting the Policy Environment for Economic Development

ASSESSMENT OF THE MANDATORY BLENDING BIOFUEL POLICY IN MOZAMBIQUE

REPORT

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ACRONYMS

AAM	Associação Algodoeira de Moçambique
AQUA	Agência Nacional para o Controlo da Qualidade Ambiental
B3	Biodiesel blend of 3% of biodiesel and 97% of diesel fuel
B5	Biodiesel blend of 5% of biodiesel and 95% of diesel fuel
B7.5	Biodiesel blend of 3% of biodiesel and 94.5% of diesel fuel
B10	Biodiesel blend of 10% of biodiesel and 90% of diesel fuel
CDM	Clean Development Mechanism
DINOTER	Direcção Nacional de Ordenamento Territorial e Reassentamento
DNH	Direcção Nacional de Hidrocarbonetos e Combustíveis
DNTDT	Direcção Nacional das Terras e Desenvolvimento Territorial
DUAT	Direito de Uso e Aproveitamento da Terra
E10	Ethanol blend of 10% of ethanol and 90% of gasoline
E15	Ethanol blend of 15% of ethanol and 85% of gasoline
E20	Ethanol blend of 20% of ethanol and 80% of gasoline
ESR	Endogenous switching regression
EU	European Union
FOB	Free on board
GDP	Gross Domestic Product
GHG	Greenhouse gas
Ha	Hectare
IAOM	Instituto de Algodão e Oleaginosas de Moçambique
IEA	International Energy Agency
IIAM	Instituto de Investigação Agrária de Moçambique
INE	Instituto Nacional de Estatística
kg	kilograms
KI	Key informant
KII	Key informant interview
Lt	Liter
m^3	Cubic meter
MADER	Ministério da Agricultura e Desenvolvimento Rural
MIREME	Ministério dos Recursos Minerais e Energia
NBPS	National Biofuels Policy and Strategy
PAE	Pacote de Aceleração Economica
PPC	Plant protection chemicals
PSM	Propensity Score Matching
R^2	Coefficient of determination
RQ	Research question
Ton	Ton
TJ	TeraJoules

SUMÁRIO EXECUTIVO

Em resposta aos recentes choques económicos e climáticos, o Governo de Moçambique anunciou em Agosto de 2022 o seu Plano de recuperação económica, o chamado Pacote de Aceleração Económica (PAE). A Medida 10 do PAE propõe a introdução da mistura obrigatória de combustíveis importados com biocombustíveis produzidos no país. Os objectivos são a geração de emprego, a promoção de investimentos privados no sector agrário, substituições parciais de importações e mitigação de impactos ambientais.

Com o recém-lançado PAE, espera-se um novo impulso a indústria de biocombustíveis. No entanto, surgiram preocupações relativamente aos potenciais impactos adversos associados aos biocombustíveis. O objectivo geral do estudo proposto é realizar uma avaliação rápida da viabilidade e dos impactos esperados da Medida 10. Especificamente, o estudo aborda a viabilidade técnica da medida, incluindo os seus impactos na segurança alimentar e bem-estar; impactos ambientais e sociais; bem como impactos na substituição de importações.

A Medida 10 do PAE não representa a primeira tentativa do país de desenvolver uma indústria de biocombustíveis. Na verdade, de 2002 a 2008, o aumento constante dos preços do petróleo impulsionou a procura de combustíveis líquidos alternativos. A onda inicial de investimentos em biocombustíveis ocorreu durante o período de 2007-2012, com o desenvolvimento de medidas legais significativas, uma estratégia ambiciosa de biocombustíveis e regulamentos relevantes. Contudo, o sector dos biocombustíveis não conseguiu arrancar por diversas razões. No caso do biodiesel, uma das principais razões para o fracasso foi a dependência excessiva de uma única cultura, especificamente a jatrofa, que carecia de investigação científica substancial para apoiar a sua produção. Outros factores cruciais contribuíram para o revés dos biocombustíveis. Estas incluíram a crise financeira de 2008-2009, uma redução dos preços do petróleo, uma mudança no foco do governo moçambicano para a exploração de gás natural, processos burocráticos excessivos para autorização de projectos de investimento e preocupações levantadas pela sociedade civil sobre os efeitos adversos dos biocombustíveis. Consequentemente, o governo adiou as aprovações de investimentos para aguardar os resultados de novos estudos, desencorajando ainda mais os potenciais investidores.

O regulamento recentemente aprovado estabeleceu metas de mistura com prazos que devem ser alcançadas utilizando a produção nacional de biocombustíveis. No entanto, persiste uma lacuna política, uma vez que a Estratégia Nacional de Biocombustíveis de 2009 não foi actualizada. Notavelmente, as discussões sobre critérios de sustentabilidade estão ausentes do discurso político. Além disso, o actual quadro regulatório cria uma incerteza considerável para os produtores de biocombustíveis relativamente aos preços futuros dos biocombustíveis, prejudicando potencialmente os esforços de investimento.

O regulamento aprovado em setembro de 2023 estabelece mandatos específicos de combinação e um prazo para a sua implementação. Os mandatos de mistura deverão iniciar em Agosto de 2024. Este prazo será desafiador dado o tempo limitado para a instalação de fábricas e a falta de mecanismos de preços definidos. Consequentemente, a análise aqui proposta alarga as metas de misturas até 2026 para uma avaliação mais realística.

Este estudo avaliou a viabilidade dos mandatos de mistura previstos. A análise baseia-se nas matérias-primas que estão amplamente disseminadas em Moçambique e estão imediatamente disponíveis para a produção de biocombustíveis em larga escala. Estas são: cana-de-açúcar para etanol e óleo de soja e algodão para biodiesel. Outras matérias-primas poderiam ser consideradas (por exemplo, mapira doce para etanol) num horizonte temporal mais longo, se o seu potencial em Moçambique for comprovado.

A demanda estimada de E10 em 2026 requer 73.265 m3 de etanol para mistura. O melaço de cana disponível em seis grandes fábricas pode cobrir 34% da demanda estimada de etanol para 2026, deixando os 66% restantes para serem produzidos pela expansão do cultivo da cana-de-açúcar ou pela renúncia à produção de açúcar. Vários cenários considerados incluem diferentes rendimentos agrícolas e processos de "rotas de produção" (ou seja, etanol produzido através do melaço ou do xarope de cana-de-açúcar). Quando o etanol é produzido a partir do melaço, a área adicional necessária varia de 96 a 48 mil hectares. Com base em estudos sobre a disponibilidade de terras que datam de 10-15 anos atrás, a área de terra disponível em Moçambique excede estes requisitos. Se o etanol for produzido a partir do xarope de cana-de-açúcar, as necessidades de terra são muito menores, mas a produção a partir do xarope implica a renúncia às vendas de açúcar. Dado o atual nível dos preços do açúcar, é muito improvável que as fábricas de açúcar optem por esta solução.

Riscos importantes associados à expansão da produção da cana-de-açúcar são a maior marginalização das mulheres (que enfrentam barreiras muito fortes ao envolvimento na agricultura por contracto) e o aumento da migração de trabalhadores do sexo masculino para trabalhar nas plantações (com as mulheres a assumirem mais tarefas tradicionalmente atribuídas aos homens). Além disso, deve ser dada especial atenção ao empoderamento dos pequenos produtores de cana-de-açúcar ao invés das fábricas, uma vez que os pequenos produtores de cana-de-açúcar em Moçambique são tomadores de preços e a estrutura de monopsónio do sector da moagem de açúcar os coloca numa posição muito fraca quando negociam com as fábricas.

O biodiesel, por outro lado, enfrenta desafios maiores. Para a B3, o país necessitará de 50.450 m3 de biodiesel. A produção existente de algodão e soja (culturas seleccionadas para uma produção imediata de biocombustíveis em grande escala) só pode satisfazer uma pequena fracção da quantidade de óleo vegetal necessária para substituir os óleos importados e produzir o biodiesel necessário. A avaliação explora múltiplos cenários envolvendo diferentes combinações de factores: rendimentos agrícolas, taxas de extracção de petróleo e áreas expandidas. Todos os cenários indicam um aumento significativo na área de terra necessária para produzir B3 (variando de 1,1 a 3,7 milhões de hectares), com sérios impactos potenciais no desmatamento e na substituição de culturas alimentares.

A introdução de misturas mais elevadas de biodiesel, como B7,5 ou B10, no futuro poderá exacerbar estes desafios de uso da terra e de desflorestação, especialmente considerando que o crescimento económico projectado aumentará a procura de diesel misturado. Uma procura activa de melhorias de eficiência na extracção de petróleo e nas práticas agrícolas será essencial para reduzir a área de terra necessária.

Dadas estas considerações, a implementação de um mandato de mistura para o etanol parece mais viável do que um mandato de mistura para o biodiesel. Mas mesmo para o etanol, o E10 provavelmente exigiria um tempo mais longo do que o prazo actualmente previsto no regulamento.

Uma estratégia viável para alcançar as misturas de biodiesel pretendidas envolveria a importação de biodiesel ou óleos vegetais. No entanto, esta alternativa não estaria alinhada com os objectivos traçados na Medida 10 do PAE, como a geração de emprego e a redução da dependência de combustíveis importados. Em vez disso, agravaria o défice da balança de pagamentos do país.

Os modelos macroeconómicos revistos produziram resultados económicos positivos e sugeriram que o investimento em biocombustíveis gera empregos. No geral, não sugeriram efeitos negativos na segurança alimentar. A exceção a esta conclusão geral foi o caso da expansão do cultivo da cana-de-açúcar em áreas anteriormente ocupadas por culturas alimentares. Neste caso, de acordo com estes modelos, as famílias registaram perdas de bem-estar e uma redução no consumo de alimentos das famílias. Para o biodiesel, dada a maior extensão da área necessária, foi estimado nos modelos uma maior substituição de culturas alimentares.

Os estudos realizados a nível local não revelaram qualquer deterioração nas condições de segurança alimentar. Além disso, demonstraram que os agricultores que participam na produção da cana-de-açúcar e produção por contracto tendem a obter benefícios mais significativos em comparação com aqueles envolvidos no cultivo de jatropha, quer seja através do emprego em plantações ou através de esquemas de produção por contracto. No entanto, uma vez que a segurança alimentar é influenciada por uma multiplicidade de factores que variam de acordo com locais e condições específicas, não é aconselhável aplicar uma abordagem uniforme e única para todos.

É provável que sejam utilizadas duas abordagens principais de investimento: uma baseada em investimentos em grande escala e a outra em esquemas de produção por contracto. Os investimentos em grande escala têm uma vantagem significativa na medida em que fornecem o capital necessário para projetos substanciais. No entanto, estes também representam riscos sociais importantes. Os investimentos em grande escala causam facilmente a expropriação de terras para as comunidades rurais, com todas as consequências sociais relacionadas: distribuição de terras mais distorcida, mais migração para os centros urbanos (especialmente para os jovens) e uma redistribuição dos papéis de género, à medida que as mulheres assumem tarefas tradicionalmente atribuídas aos homens quando os homens migram.

Quando ocorrem investimentos em grande escala, é crucial garantir que as comunidades afectadas recebam uma compensação adequada e que sejam realizadas consultas significativas. O quadro jurídico moçambicano prevê disposições adequadas para consultas e compensações. No entanto, as consultas são caracterizadas por uma grande variedade de práticas quando são realizadas. Além disso, a falta de compensação adequada é uma preocupação comum.

Esquemas de produção por contracto são amplamente praticados para a produção de cana-de-açúcar e algodão. Com a recente mudança na regulamentação dos óleos de sementes, eles também poderão ser utilizados no cultivo da soja num futuro próximo. Embora as preocupações comuns comunicadas na agricultura contratual incluam a falta de transparência, os esquemas de produção por contracto causam menos perturbações sociais do que os investimentos em grande escala. Contudo, estes tendem a favorecer a participação dos homens em detrimento da participação das mulheres.

A segurança energética e a substituição de importações estão entre os objectivos da Medida 10. No entanto, é pouco provável que os rácios de mistura esperados aumentem significativamente a segurança energética. No caso do biodiesel, as proporções de mistura propostas são bastante modestas, variando entre 3% e 10%, e atingir o limite superior deste intervalo parece impraticável neste momento. Quanto ao etanol, as proporções de mistura são maiores. Contudo, a gasolina representa apenas 22% das vendas actuais de produtos petrolíferos e o conteúdo energético do etanol é consideravelmente inferior ao da gasolina. Assim, em termos energéticos, a substituição de 20% da gasolina (a proporção de mistura mais elevada definida pelo regulamento) equivale a apenas 3% das vendas totais de produtos petrolíferos.

A avaliação fornecida neste estudo também abrange um exame de potenciais impactos ambientais. A redução das emissões de gases com efeito de estufa (GEE) depende principalmente do tipo de cobertura do solo convertida para a produção de biocombustíveis. O desbravamento de áreas com elevado teor de carbono, como as florestas, para o cultivo de matérias-primas para biocombustíveis representa um risco significativo de incorrer em passivos de carbono. As alterações indirectas no uso do solo introduzem riscos adicionais. A análise das áreas necessárias para a produção de biodiesel, conforme relatado neste estudo, indica que será necessária uma extensa expansão de terra para cumprir a meta de mistura de biodiesel. Tanto as alterações directas como indirectas no uso do solo poderiam ser facilmente desencadeadas, resultando potencialmente numa dívida de carbono significativa, em vez de fornecer créditos de carbono para biocombustíveis.

A nível local, não se espera que nenhuma das culturas consideradas tenha um efeito drástico no consumo de água. Contudo, para plantações de cana-de-açúcar em grande escala, haverá aumentos substanciais no consumo de água. É crucial focar na melhoria da eficiência hídrica dos sistemas de irrigação da cana-de-açúcar nesses casos. Prevê-se que a contaminação dos recursos hídricos seja baixa para a produção de soja e algodão de sequeiro. Além disso, alguns impactos adversos à saúde são inevitáveis quando a queima pré-colheita é empregada.

Embora a previsão das localizações precisas dos investimentos futuros seja altamente especulativa nesta fase, a análise das localizações dos investimentos e das manifestações de interesse dos projectos do período 2006-2008 sugere que o foco principal dos projectos comerciais será provavelmente em áreas com boas infra-estruturas. Isto poderia potencialmente exacerbar as disparidades regionais. O corredor Beira-Tete parece particularmente atraente para projectos de biodiesel.

As principais recomendações são as seguintes (detalhes na Secção 8.2):

1) A Política e Estratégia de Biocombustíveis deve ser actualizada.

2) O governo deve rever o calendário de implementação dos mandatos de mistura, estendendo-o por um período de tempo mais longo. A introdução de mandatos de mistura para o biodiesel deveria ser reconsiderada, ou pelo menos introduzida gradualmente durante um período de tempo muito mais longo do que os mandatos para o etanol.

3) Deve ser considerada uma promoção activa de produção e utilização de biocombustíveis em nichos estratégicos. Isto inclui o desenvolvimento da produção e utilização de biocombustíveis à escala local.

4) As capacidades nacionais das instituições relevantes para analisar propostas de investimento em projectos

devem ser reforçadas. Estes incluem a DNTDT, a Direcção Provincial das Terras em todas as províncias, a AQUA e a DNH.

5) Os direitos fundiários comunitários precisam de ser adequadamente protegidos quando se consideram investimentos em grande escala. Devem ser prestadas atenções especiais para garantir que sejam realizadas consultas e compensações adequadas.

6) O quadro específico de sustentabilidade social e ambiental dos biocombustíveis (incluindo critérios e indicadores) para projectos de biocombustíveis deve ser desenvolvido/actualizado para autorizar projectos em coordenação com o MTA. Estes devem incluir critérios de segurança alimentar e de empoderamento das mulheres.

7) O governo deve considerar a reactivação da comissão interministerial para os biocombustíveis e a criação de um grupo de trabalho para os biocombustíveis que envolva o sector público e privado, a academia e as organizações da sociedade civil para desenvolver o quadro de sustentabilidade necessário (ver recomendação 5).

8) O desenvolvimento de um zoneamento agroecológico actualizado deve ser seriamente considerado.

9) Devem ser promovidas culturas com potencial comprovado (rendimento agrícola, rendimento energético) e possivelmente de uso múltiplo (por exemplo, cana-de-açúcar para etanol e sementes de soja e algodão para biodiesel), mas a escolha de matéria-prima para a produção de biocombustíveis não deve ser restrita a determinadas culturas. Em qualquer caso, o governo não deve promover a utilização de culturas com potencial não comprovado. Além disso, deve ser evitado o uso de culturas alimentares básicas como matéria-prima para a produção de biocombustíveis.

10) A produção agrícola para o desenvolvimento de biocombustíveis deve ser promovida através da intensificação do uso da terra e da produção de biocombustíveis de segunda geração, e não através da expansão do uso da terra. Isto inclui a promoção de práticas agrícolas, tais como a rotação de culturas e o estabelecimento de sistemas de produção agro-florestais.

11) Melhorias na eficiência do uso da água (por exemplo, sistemas de irrigação gota-a-gota) devem ser promovidas em áreas com produção de cana-de-açúcar.

12) A política de industrialização moçambicana deve considerar uma maior promoção de unidades de processamento para extracção de sementes oleaginosas para acrescentar valor ao subsector de sementes oleaginosas.

EXECUTIVE SUMMARY

In response to recent multiple economic and climate shocks, the Government of Mozambique announced in August 2022 its economic recovery Plan, the so-called Economic Acceleration Package (PAE). Measure 10 of the PAE proposes the introduction of mandatory blending of imported fuel with biofuels produced in the country. The objectives are the generation of employment, the promotion of private investments in the agricultural sector, partial import substitutions, and mitigation of environmental impacts.

With the recently launched PAE, it is expected that the biofuels industry will regain momentum. However, concerns have emerged regarding the potential adverse impacts associated with biofuels. The general objective of the proposed study is to conduct a rapid assessment of the feasibility and expected impacts of Measure 10. Specifically, the study addresses the technical feasibility of the measure including its impacts in food security and welfare; environmental and social impacts; as well as impacts on import substitution.

Measure 10 of the Economic Acceleration Package does not represent the country's first endeavor to develop a biofuel industry. In fact, from 2002 to 2008, the steady increase in oil prices drove a search for alternative liquid fuels. The initial wave of biofuel investments occurred during the period of 2007-2012, with the development of significant legal measures, an ambitious biofuel strategy, and relevant regulations. However, the biofuel sector failed to take off for several reasons. For biodiesel, one main reason for failure was overreliance on a single crop, specifically jatropha, which lacked substantial scientific research to support production. Other crucial factors contributed to the biofuel setback. These included the 2008-2009 financial crisis, a decrease in oil prices, a shift in the Mozambican government's focus to gas field exploration, excessive bureaucratic processes for investment authorization, and concerns raised by civil society about the adverse effects of biofuels. Consequently, the government postponed investment approvals to await the outcomes of new studies, further discouraging potential investors.

The newly endorsed regulation has established time-bound blending targets that must be achieved using domestic production of biofuels. Nevertheless, a policy gap persists since the 2009 National Biofuel Strategy has not been updated. Notably, discussions regarding sustainability criteria are absent from the policy discourse. Additionally, the current regulatory framework creates considerable uncertainty for biofuel producers concerning future biofuel prices, potentially undermining investment efforts.

The regulation approved in September 2023 sets specific blending mandates and a timeframe for implementation. The blending mandates are supposed to start in August 2024. This will be very challenging given the limited time for factory setup and the lack of defined price mechanisms. Consequently, the analysis proposed here extends the blending targets to 2026 for a more realistic assessment.

This study assessed the feasibility of the envisaged blending mandates. The analysis is based on the feedstocks that are widely widespread in Mozambique and are immediately available for a large-scale biofuel production. These are sugarcane for ethanol and soybean and cottonseed oil for biodiesel. Other feedstocks could be considered (e.g. sweet sorghum for ethanol) over a longer time horizon if their potential in Mozambique is proved.

The estimated demand of E10 in 2026 requires 73,265 m^3 of ethanol for blending. The available sugarcane molasses from six major mills can cover 34% of the estimated ethanol demand for 2026, leaving the remaining

66% to be produced by expanding sugarcane cultivation or foregoing sugar production. Various scenarios considered include different agricultural yields and "production routes" processes (i.e., ethanol from molasses or ethanol from sugarcane syrup). When ethanol is produced from molasses, the additional land area ranges from 96,000 to 48,000 hectares. Using studies on land availability dating back to 10-15 years ago, the available land area in Mozambique exceeds these requirements. If ethanol is produced from sugarcane syrup, land requirements are much lower but production from syrup entails foregoing sugar sales. Given the current level of sugar prices, it is very unlikely that sugar mills would opt for this solution.

Important risks associated with sugarcane expansion are the further marginalization of women (who face very strong barriers to engaging in contract farming) and increased migration of male workers to work in plantations (with women taking on more tasks traditionally assigned to men). Also, special attention should be paid to empowering smallholder sugarcane farmers versus mills, as sugarcane smallholders in Mozambique are price-takers, and the monopsony structure of the sugar milling sector puts smallholders in a very weak position when negotiating with mills.

Biodiesel, on the other hand, faces greater challenges. For B3, the country will require 50,450 m^3 of biodiesel. The existing production of cotton and soy (selected crops for an immediate large-scale biofuel productions) can only meet a small fraction of the vegetable oil quantity needed to replace imported oils and produce the required biodiesel. The assessment explores multiple scenarios involving different factor combinations of agricultural yields, oil extraction rates, and expanded areas. All scenarios indicate a significant increase in land area required for B3 (ranging from 1.1 million to 3.7 million hectares), with serious potential impacts on deforestation and food crop replacement.

The introduction of higher biodiesel blends, like B7.5 or B10, in the future could exacerbate these land use and deforestation challenges, especially considering that the projected economic growth will increase demand for blended diesel fuel. An active pursuit of efficiency improvements in oil extraction and agricultural practices will be essential to reduce the land area needed.

Given these considerations, the implementation of a blending mandate for ethanol seems more feasible than a blending mandate for biodiesel. But even for ethanol, E10 would probably require a longer time than the timeline currently envisaged in the regulation.

A feasible strategy for achieving the targeted biodiesel blends would involve importing biodiesel or vegetable oils. However, this alternative would not align with the objectives outlined in Measure 10 of the PAE, such as generating employment and reducing reliance on imported fuels. Instead, it would worsen the country's balance of payments deficit.

The macroeconomic models reviewed yielded positive economic results and suggested that investment in biofuels generates jobs. Overall, they did not suggest negative effects on food security. The exception to this general conclusion was the case of an expansion of sugarcane cultivations in areas previously occupied by food crops. In this case, according to these models, households experienced welfare losses and a reduction in household consumption. For biodiesel, given the higher extension of area needed, more displacement of food crops was estimated in models.

Studies conducted at the local level have not revealed any deterioration in food security conditions. Also, they have shown that farmers participating in sugarcane feedstock production and outgrowing arrangements tend to experience more significant benefits compared to those engaged in jatropha cultivation, whether it be through employment in plantations or through smallholder out-growing schemes. Nevertheless, since food security is influenced by a multitude of factors that vary according to specific locations and conditions, it is not advisable to apply a uniform, one-size-fits-all approach.

Two main investment approaches are likely to be used: one based on large-scale investments and the other on outgrowing schemes. Large-scale investments have a significant advantage in that they provide the necessary capital for substantial greenfield projects. However, they also pose important social risks. Large-scale investments easily cause land dispossession for rural communities, with all related social consequences: more skewed land distribution, more migration to urban centers (especially for the youth), and a redistribution of gender roles as women take on tasks traditionally assigned to men when men migrate.

When large-scale investments take place, it is crucial to ensure that affected communities receive appropriate compensation and that meaningful consultations are conducted. Mozambican legal framework makes adequate provisions for consultations and compensations. Nevertheless, consultations are characterized by a wide variety of practices when they are conducted. Also, a lack of adequate compensation is a common concern.

Outgrowing schemes are widely practiced for sugarcane and cotton production. With the recent change in the regulation of seed oils, they might also be used for soybean cultivation in the near future. While common concerns reported in contract farming include a lack of transparency, overall outgrowing schemes cause fewer social disruptions than large-scale investments. However, outgrowing schemes tend to favor men's participation over women's participation.

Energy security and import substitution are among the objectives of Measure 10. However, the expected blending ratios are unlikely to significantly enhance energy security. In the case of biodiesel, the proposed blending ratios are rather modest, ranging from 3% to 10%, and achieving the upper end of this range seems impractical at present. As for ethanol, the blending ratios are higher. However, gasoline accounts for only 22% of the current sales of oil products, and ethanol's energy content is considerably lower than that of gasoline. Thus, in terms of energy, replacing 20% of gasoline (the highest blending ratio set by the regulation) is equivalent to a mere 3% of total oil product sales.

The assessment provided in this study also encompasses an examination of potential environmental impacts. The reduction of greenhouse gas (GHG) emissions primarily depends on the type of land cover converted for biofuel production. Clearing areas with a high carbon stock, such as forests, for cultivating biofuel feedstocks poses a significant risk of incurring carbon liabilities. Indirect land use changes introduce additional risks. The assessment of land areas required for biodiesel, as reported in this study, indicates that extensive land expansion will be necessary to meet the biodiesel blending target. Both direct and indirect land use changes could be easily triggered, potentially resulting in a significant carbon debt rather than providing carbon credits for biofuels.

At the local level, none of the considered crops are expected to have a drastic effect on water consumption. However, for very large-scale sugarcane plantations there will be substantial increases in water consumption. It is crucial to focus on improving the water efficiency of sugarcane irrigation systems in such cases. The contamination of water resources is anticipated to be low for rainfed soybean and cotton production. Additionally, some adverse health impacts are unavoidable when pre-harvest burning is employed.

While predicting the precise locations of future investments is highly speculative at this stage, analyzing the locations of investments and project expressions of interest from the 2006-2008 period suggests that the primary focus of commercial projects will likely be on areas with good infrastructure. This could potentially exacerbate regional disparities. The Beira-Tete corridor appears particularly attractive for biodiesel projects.

Main recommendations are the following (reasonings in Section 8.2):

1) The Biofuel Policy and Strategy should be updated.
2) The government should review the implementation timeline for blending mandates, extending it over a longer period of time. The introduction of blending mandates for biodiesel should be reconsidered, or at least phased in over a much longer period of time than the mandates for ethanol.
3) An active promotion of strategic niches for biofuel production and use should be considered. This includes the development of biofuel production and use at a local scale.
4) National capacities of relevant institutions to review project investment proposals should be strengthened. These include the DNTDT, the Direcção Provincial das Terras in all provinces, AQUA and DNH.
5) Community land rights need to be appropriately protected when considering large-scale investments. Special attentions should be paid to ensure proper consultations and compensations take place.
6) Specific Social and environmental Biofuels sustainability framework (including criteria and indicators) for biofuel projects should be developed/updated to authorize projects in coordination with the MTA. These should include food security and women empowerment criteria.
7) The government should consider reactivating the inter-ministerial biofuels commission and creating a biofuels task force involving the public and private sector, academia and civil society organizations to develop the needed sustainability framework (see recommendation 5).
8) The development of an updated agro-ecological zoning should be seriously considered.
9) Crops with proven potential (agricultural yield, energy yield), and possibly multiple use (e.g., sugarcane for ethanol and soybean and cotton seeds for biodiesel) should be promoted, but the choice of feedstocks for biofuel production should not be restricted to certain crops. In any case, the government should not promote the use of crops with unproved potential. Also, the use of staple food crops as a feedstock for biofuel production should be avoided.
10) Agricultural production for biofuel development should be promoted through land-use intensification and second-generation biofuel production rather than through land-use expansion. This includes promoting agricultural practices such as crop rotations and establishing agro-forestry production systems.
11) Improvements in water use efficiency (e.g., drip irrigation systems) should be promoted in sugarcane planted areas.
12) The Mozambican industrialization policy should consider further promotion of processing units for vegetable oil seed extraction to add value to the oils seed sub-sector.

I. INTRODUCTION

The Mozambican economy has been affected by multiple internal and external shocks, including the effects of climate change, terrorist actions in Cabo Delgado, the COVID-19 pandemic, and more recently, the conflict in Ukraine. These factors exacerbate the challenges in implementing economic recovery programs and highlight certain structural weaknesses within the Mozambican economy.

In response to these events, the Government of Mozambique announced in August 2022 its economic recovery plan, the so-called Economic Acceleration Package (PAE, from its Portuguese acronym). The package is composed of 20 reform measures that aim to place the private sector at the heart of the country's economic transformation and development. Within the PAE, Measure 10 proposes the introduction of mandatory blending of imported fuel with biofuels produced in the country as a stimulus for the agricultural sector.

Rising oil prices and a disappointing growth in the traditional economic sector are drawing increasing attention to the biofuel sector. The debate surrounding biofuels in Mozambique has regained momentum with the announcement of Measure 10 of the PAE. In fact, as stated in the PAE, Measure 10 aims to support biofuel investments to generate employment opportunities, encourage private investments in the agricultural sector, promote partial import substitution, and mitigate environmental impacts.

This is not the first time that the government of Mozambique has tried to develop a biofuel sector. A National Biofuel Policy and Strategy was launched in 2009, and biofuel blending regulations were enacted in 2011. That regulation established a gradual mandatory blending of biodiesel with diesel (3%) and ethanol with gasoline (10%) from 2012 onward. Following the enactment of the Biofuel Policy and Strategy, the Mozambican government received 40 biofuel investment proposals by 2012, of which 14 were officially approved. Jatropha was widely planted to reach the biodiesel blending target. For ethanol, negotiations took place between the Ministry of Energy and existing sugar mills in the country to acquire sugarcane molasses as a raw material for ethanol production. Despite this initial enthusiasm, biofuel production never took off in Mozambique. All jatropha plantations were abandoned, and the small amount of ethanol that was produced is used for other purposes.

With the recently launched PAE measures, it is expected that the biofuels industry will regain momentum again. However, concerns have emerged regarding the potential adverse impacts associated with biofuels. Debates surrounding the sustainability of biofuels production are rooted in issues such as the competition between crop-based biofuels and food production, the land rights of local populations, and environmental impacts.

The general objective of the proposed study is to conduct a rapid assessment of the feasibility and expected impacts, both positive and negative, of Measure 10 on food security Specifically, the study addresses the technical feasibility of the measure including its impacts on food security and welfare; environmental and social impacts; as well as impacts on import substitution.

II. METHODOLOGY

To assess the feasibility and potential impacts of Measure 10 of the PAE the study was structured around the following research questions (RQ):

RQ1:Which have been the reasons for the underdevelopment of the biofuel sector in Mozambique?

RQ2: Which is the current state of the biofuel regulatory framework and policy development in Mozambique? How should the regulatory framework change?

RQ3: How feasible is a new biofuels development in Mozambique (as envisaged in the PAE) in terms of land needed to achieve the envisaged targets and economic advantages?

RQ4: Which are the possible food security, energy security, social and economic impacts of large-scale biofuels production in Mozambique?

Based on the type of questions and purpose noted above, the proposed analysis requires an evaluative approach with a keen eye towards making well-substantiated recommendations. Thus, the following methods were selected: an extensive literature review on biofuels in Mozambique, key informant interviews, and an analysis of the land use implications of the blending targets.

A very wide array of academic papers assessing the impacts of biofuels is available for Mozambique. Indeed, following the initial enthusiasm for biofuels and the numerous investment proposals submitted to the government, the biofuel sector received substantial attention in academia. Studies assessing the impacts of biofuels in Southern Africa were also taken into consideration.

A main limitation of relying extensively on findings from the literature review is that much of the academic research was conducted during a period when biofuels in Mozambique were of utmost interest. This means that the literature available for biofuels refers to 10-15-year-old cases. In order to mitigate this aspect, the search for relevant literature was expanded to cover the expected cash crops used for biofuels, rather than limiting the research to biofuels. This yielded much more recent results. Additionally, findings from the literature review were triangulated with those from interviews with key informants. During these interviews, the study team also collected updated quantitative data regarding the production and prices of the feedstocks considered.

In total, 53 key informant interviews (including one-on-one and group interviews[1]) were conducted with 93 individuals in Maputo, Inhambane, Sofala and Nampula.

[1] Group interviews included two or more respondents

The key informants for this study are disaggregated in the table below by respondent type and gender.

Table 1: Key informants by category and gender

Key informant type	Male	Female	Total
Government – central level	4	3	7
Government – local level	11	2	13
Companies	21	6	27
Industrial and business associations	4	0	4
Civil society organizations	7	11	18
Farmers	18	8	26
TOTAL	65	30	95

The feasibility analysis consisted of three main steps:

1. The study team initially estimated the future ethanol and biodiesel demand using a simple linear regression (more details below).
2. The second step involved the selection of most promising feedstocks and quantifying the potential ethanol and biodiesel production using the current feedstock quantity. By comparing the estimated biofuels demand from the first step with the quantity of biofuels that could potentially be produced from the existing crop production of the most promising feedstocks, the study team quantified the gap between current crop production and future biofuels demand. This gap serves as an initial indicator of the feasibility of mandated blending rates. A larger gap suggests that a certain blending rate is not feasible in the short term.
3. In the third step, the study team assessed the quantity of additional production and land required to meet the demands for the necessary feedstocks, thereby closing the mentioned gap.

III. BIOFUEL DEVELOPMENT IN MOZAMBIQUE

3.1. HISTORY OF BIOFUEL DEVELOPMENT

Biofuel development in Mozambique gained prominence in 2004. During the election campaign, the government encouraged Mozambican farmers to cultivate Jatropha on unused, marginal lands, aiming to transform Mozambique into an oil-exporting nation and reduce its reliance on oil imports. The initial plan was to plant 5 hectares of Jatropha in each of Mozambique's 128 districts. The Mozambican extension service began sourcing Jatropha seeds primarily from Malawi. Unfortunately, many of these seeds were of poor quality due to prolonged storage and unfavorable conditions, resulting in low germination rates. Additionally, there was a lack of effective follow-up support, leading to neglect in crop maintenance, causing many plants to die. Farmers producing Jatropha seeds did not know who to sell to, as there were no buyers or organized supply chains. Nevertheless, the Mozambican government's promotion of biofuels had attracted private investors and biofuel-related development projects. Large-scale Jatropha plantations were established with limited information available on seed varieties, best agricultural practices, production systems, and markets. The overall belief was that Jatropha was a drought-resistant crop and could easily grow on marginal land (Schut et al., 2010).

While Jatropha garnered political support as a "miracle crop" for biofuel production, there was also significant private sector and government interest in ethanol production. Sugarcane was the primary feedstock considered, with some minor interest in sweet sorghum (Ibid.).

The first biofuel investment project was approved in October 2007. Concerns were raised about pressure on land, water, and food production, as well as worries about the lack of control over excessive expansion of biofuels, which sparked a heated debate involving the government, private sector, NGOs, and scholars. Consequently, significant land requests were temporarily halted from October 2007 to May 2008, during which time the government initiated a process of agro-ecological zoning.

The land zoning process was overseen by an inter-ministerial working group, where the Mozambican Institute of Agrarian Research (IIAM) was responsible for determining the agro-climatic appropriateness of various regions, and the National Directorate for Land and Forestry (DNTF) evaluated the availability of land. This zoning procedure was conducted on a 1:1,000,000 scale, identifying continuous land areas larger than 1,000 hectares. However, the 1:1,000,000 scale was deemed to allow for more than a broad overview of land availability. Also, most of the land suitability information was outdated and rainfall data were from the 1980s. The accuracy of the land availability data was called into question. A more accurate zoning on a scale of 1:250,000 was commissioned to a private company (Schut et al., 2010). Relevant work was initiated however to the best of the authors' knowledge, it was not completed.

In March 2009, the Mozambican government endorsed the National Biofuel Policy and Strategy (NBPS). The main objectives of the government were energy security, employment generation, and rural development. The important strategic pillars of the NBPS strategy were proposed limits on land allocation for biofuel production based on suitable agro-climatic regions through land zoning. The selected feedstocks for ethanol were sugarcane and sweet sorghum, and for biodiesel were copra and Jatropha. Sustainability criteria would be used to choose investment projects and allocate land titles. Additionally, the NBPS aimed to create a domestic market for biofuels through blending mandates. To address concerns about the potential negative effects of biofuels, the NBPS stated that sustainability criteria would be used as a policy instrument to allocate land titles and select investment projects.

A National Biofuel Taskforce was established to coordinate the governance of biofuel-related activities, which in June 2011 was replaced by a dedicated Inter-Ministerial Biofuels Commission. The financial crisis in Europe, coupled with the declining oil prices at the end of 2009 and throughout 2010, resulted in a significant slowdown in the biofuel industry. This economic downturn posed financial challenges for several companies. Notably, the reduced oil prices rendered various biofuels uncompetitive for export within just a few months (von Maltitz et al., 2014).

Due to the company's failure to uphold its contractual obligations, the Mozambican government revoked the land-use rights (DUAT) for one of the agro-industrial biofuel projects (named ProCana) in December 2009. The majority of both agro-industrial and smallholder biofuel projects using jatropha encountered serious problems, mainly stemming from underperforming crop yields (Schut et al., 2014). Indeed, as a key informant involved in jatropha production reported, this crop can survive with a minimal amount of water, but without adequate rainfall or irrigation, seed production is minimal. Before the surge in the popularity of jatropha, there were limited experiments and minimal expertise in cultivating jatropha as a domestic crop.

Overoptimistic assumptions on yields were often based on scientific reports that presented a wide range of economic, energy, and GHG emissions benefits of growing jatropha. Also, the Clean Development Mechanism (CDM) funding provided additional incentives for jatropha cultivation on land that had already been deforested or degraded, as it could be classified as a form of reforestation (Romijn, 2011). Several additional unsubstantiated claims regarding jatropha included pest resistance, ease of cultivation, and a short time lag from production to the first harvest (von Maltitz et al., 2014). On top of that, as reported by a key informant working for Petromoc, pilot biodiesel production using copra oil soon revealed that biodiesel from copra was also unprofitable because of the low availability of raw material and high oil price.

Different civil society organizations began advocating against biofuels by emphasizing the competition between biofuels and food production (commonly known as the "food or fuel" debate), as well as the issue of alleged land grabbing (see, for instance, Ribeiro and Matavel, 2009).

The government became cautious about granting DUATs for extensive land areas due to a delay in the development of the 1:250,000 agro-ecological zoning. This delay significantly hampered the progress of biofuel projects involved in the project application and land acquisition process. It led to an unstable investment environment for biofuel operators and generated adverse publicity. As reported by Atanassov (2013), without DUAT, it is difficult to secure investors' interest. Indeed, without definitive land use rights, the investment is categorized as "risky." In this regard, the biofuels producers of that time highlighted that the processes to obtain licenses and other permissions from the government were very slow and difficult.[2] Often, activities like land clearing and plantation establishment proceeded without the necessary DUAT (Schut et al., 2014).

Negotiations took place between the Ministry of Energy and the existing sugar mills in the country. In November 2011, the Biofuels Blending Regulation was enacted (Decree 58/2011). It introduced a phased blending of biodiesel with diesel (to reach 3% biodiesel) and ethanol with gasoline (to reach a 10% ethanol blend), which was supposed to start in 2012. The export of biofuels was allowed only after ensuring domestic biofuel requirements. The regulation also included an export tax on pure plant oils to stimulate the achievement of domestic biofuel blending targets. The new regulation demotivated foreign investors who intended to target the EU or other foreign markets.

Extensive work was conducted to develop a national government framework for sustainable biofuels, including its sustainability criteria and enforcing mechanisms, by a dedicated multi-actor working group (Schut et al., 2014).

[2] Interviewed by Atanassov (2013)

The framework was submitted to the Inter-Ministerial Biofuel Commission in 2012 but was never approved by the Council of Ministers.

As reported by a key informant interviewed, the discovery of gas fields completely changed the government's attention to this new energy source. According to data reported by Locke and Henley (2013), in January 2013, 209,327 hectares were authorized (97,530 hectares for ethanol feedstock production and 111,797 hectares for biodiesel feedstock production), but only 3% of the total authorized area was planted. The blending mandates with domestically produced biofuels were never enforced. The Inter-Ministerial Biofuel Commission was formally abolished by presidential decree in 2016. With the exception of very small-scale initiatives, biofuel production never took place. Currently, no biofuel is produced for transportation.

Biofuel development in Malawi[3]

Malawi is one of the few countries that has pursued consistent biofuels policies over decades, even after the oil price collapse of 1986. It is one of the most densely populated countries in sub-Saharan Africa and is experiencing growing pressure on its biomass resources. This primarily results from its heavy reliance on biomass. Malawi has some coal but relies entirely on imported petroleum products. In the 1970s, several African countries, including Malawi, initiated ethanol programs. However, Malawi stands out as the only country that has maintained a continuous ethanol blending practice since its inception in 1982.

High oil prices pose particular challenges for a landlocked nation like Malawi. These high prices affect the cost of all imported commodities and the costs associated with transporting products to export markets.

In 1979-1980, the country experienced a serious shortage of fuels. The government decided to invest in ethanol production. Malawi's single-party political system facilitated the swift transformation of energy security concerns into concrete outcomes through the introduction of a new ethanol blending program. The first ethanol distillery was established by the government and was soon privatized after it started production. The country's ethanol facility, ETHCO Ltd. (Ethanol Company of Malawi), was established in 1982 and has consistently produced fuel-grade ethanol, ranging from 10 to 20 million liters annually. The plant utilizes sugarcane molasses sourced from the nearby Dwangwa sugar factory as its feedstock. The availability of irrigation water from Lake Malawi has made the production process less vulnerable to interruptions caused by climate-related factors.

The company has faced important challenges in ensuring a consistent supply of feedstock (i.e., molasses). ETHCO operates independently of the adjacent Dwangwa sugar factory. As a result, price negotiations are needed, which cause uncertainties. This, coupled with excess plant capacity and the commitment to maintain blending targets, led ETHCO to secure additional sugarcane molasses supply from the Sucoma sugar factory, which is located several hundred kilometers to the south.

In 2004, a second distillery was founded. While it was promoted by the government Department of Energy for the purpose of enhancing energy security, it was exclusively financed by private investments. This new facility was upgraded with modern molecular sieve technology for dehydration. This technology was then applied in the first ETHCO plant. Indeed, while it requires higher initial capital costs compared to the traditional azeotropic distillation process, the molecular sieve technology prevents the contact of chemicals with ethanol, enhancing the company's market prospects for potable ethanol due to the adherence to high purity standards. Molecular sieves are more energy-efficient and offer the added advantage of achieving higher dehydration levels, resulting in extremely dry ethanol with a purity of 99.95%, which is better suited for fuel blending.

[3] This box was developed using informed included in Johnson and Silveira (2014) and from a key informant interview.

Public-private partnerships (for blending, distribution, and transportation) played an important role in the implementation program. The price of ethanol was based on a calculation formula so that it was always slightly lower than the price of imported gasoline. Consequently, profits were made depending on the difference between the ethanol production cost, gasoline import price, and blending volumes. In the initial years, prior to the oil price collapse in 1986, blends of ethanol exceeding 20% were occasionally utilized, which led to certain performance and reliability issues in older vehicles.

The oil price collapse in 1986 and the lower oil prices throughout the 1990s prompted adjustments in the market. ETHCO began exploring other end-use markets for ethanol, specifically industrial, pharmaceutical, and potable ethanol, with the purpose of fetching higher prices and promoting diversification of market outlets. As demand increased and supply decreased due to the competition for ethanol in these other markets, the level of blending reduced in the subsequent years, averaging closer to 10%.

Important changes took place in the 2000s. The domestic supply expanded with the establishment of the second distillery in 2004. With the introduction of unleaded fuel, ethanol assumed a new role in replacing lead as an anti-knock agent. Energy security issues gained importance again in the form of highly disruptive physical shortages and financial constraints. A mandatory minimum blend was enacted in 2004 and it was increased by 20% in the following decade. However, the enforcement of the blending mandate was often relaxed depending on the availability of feedstock (i.e., molasses). The price calculation formula was changed in 2018. The company is now allowed to charge 18% of profits over production costs.

The current demand for ethanol is approximately 60 million liters per year. However, with the available molasses (including imported molasses), the country can only produce approximately 20 million liters. In order to meet the 20% blending target, the ethanol company has started the construction of a third factory, which will produce ethanol directly from sugarcane syrup, rather than molasses. It should be noted that the production of ethanol through sugarcane syrup no longer uses a sugar production by-product (i.e., molasses), and it will imply foregoing profits from sugar sales. The company has deliberately decided to pursue this production route despite the fact that, at the current sugar prices, profits are higher for sugar production.

3.2. CURRENT STATE OF BIOFUELS POLICY AND REGULATORY DEVELOPMENT

With the Measure 10 of PAE, the government has set a clear policy objective for revitalizing biofuel production and use. It is clear, from PAE, that the main drivers of the measure are economic development and energy security. During the first decade of the 2000s, the biofuel sector was clearly dominated by foreign commercial investors whose main intention was to supply external markets (Schut et al., 2010). Conversely, nowadays, there is a clear focus on the domestic use of blended fuel.

The measure references the mitigation of environmental effects, however, it is not clear whether the blending mandate intends to mitigate greenhouse gas (GHG) emissions from fossil fuels or other negative environmental effects.

On September 19, 2023, the Council of Ministers endorsed a regulatory decree for biofuels, superseding Decree 58/2011. The objectives of this regulation align with those outlined in Measure 10. The regulation governs various aspects of biofuel production, including the licensing process, and delineates the roles and responsibilities of key stakeholders (i.e., the ministry in charge of energy aspects, the Ministry of Agriculture, the Regulatory Authority for Energy, and inspection authorities). Under the new regulation, it is stipulated that the export of biofuels is allowed only after domestic demand is fully met. The same rule applies to the exports of vegetable and animal oil and molasses for biofuel production. Furthermore, the regulation establishes a timeframe and considers the reduction or increase of specific blending mandates, which are detailed as follows:

- 10% for ethanol (called E10) and 3% for biodiesel (called B3) from August 2024 to December 2027
- 15% for ethanol (E15) ad 7.5% for biodiesel (B7.5) from January 2028 to December 2032
- 20% for ethanol (E20) and 10% for biodiesel (B10) from January 2033

The price-setting mechanism for biofuel is delegated to the ministry in charge of energy aspects. The regulation only mentions that it will be defined taking into consideration all necessary costs, including feedstock production and processing, transport, storage, and distribution costs. Finally, the regulation specifies taxes (including export taxes) and sanctions.

In this way, the Regulation has established norms for the production and use of biofuels. Notably, the 2009 National Biofuel Strategy has not been officially revoked and, therefore, remains valid. However, it is clear that this strategy is now outdated. It identifies two vegetable oils (copra and jatropha) for biodiesel production and two crops for ethanol production (sugarcane and sweet sorghum). However, three of these feedstocks (sweet sorghum, jatropha oil, and copra oil) cannot make any significant contributions to biofuel production (see in next chapter). Additionally, the 2009 Strategy included provisions for implementing sustainability criteria to address potential risks (including food security risks) when selecting biofuel production projects, but the relevant governance framework for sustainability criteria was never approved.

Also, interviewed sugar mill managers reported concerns over price-setting mechanisms as the government indicated its current plan to initiate a competitive bidding process for biofuels supply, resulting in the selection of a single winner for one or two years. Such a mechanism would definitely be too risky for bidders, as it would leave non-winning bidders with an unsold product.

IV. FEEDSTOCK POTENTIAL AND SUB-SECTOR OVERVIEW

Given the high sugar content of sugarcane and its high photosynthetic efficiency, it is not surprising that most successful ethanol programs use sugarcane for ethanol production. This is the case in countries like Brazil and Malawi. Another crop used worldwide for ethanol production is cassava. To the best of the authors' knowledge, Thailand is the only country with significant ethanol production from cassava. In the 2000s, Mozambique also considered using cassava for ethanol production, but it was soon excluded due to its status as a staple food for a large part of the Mozambican population. A high demand for cassava for biofuel production could easily lead to significant food security problems. Furthermore, cassava has lower ethanol yields compared to sugarcane (Ecoenergy, 2008). Sweet sorghum was also considered by the NBPS as one of the two crops In this regard, two informants interviewed by the study team reported that this crop is particularly promising, as Mozambique already produces sorghum. This assertion is supported by relevant literature (Ahmad Dar et al., 2018; Ratnavathi et al., 2011; Taylor et al., 2019; Waniska et al., 2004). Indeed, sweet sorghum requires a much lower amount of water than sugarcane, yielding a high production of fermentable sugar stems per hectare in addition to grains and overall. However, sweet sorghum is not currently cultivated in Mozambique. Therefore, at this stage, any scenario analysis involving sweet sorghum would be more based on speculation than on real data.

Biodiesel can be produced from a large set of vegetable oils or animal fats. Globally, the majority of biodiesel production is based on palm oil, soybean oil, rapeseed oil, and, to a lesser extent, sunflower and cottonseed oil. Mozambique has a growing soybean sector and a well-established cotton sector. Indeed, cottonseed and soybean oils are the two oils also considered by the Instituto de Algodão e Oleaginosas de Moçambique (IAOM) for biodiesel production. Other oils considered are castor oil, groundnut oil, and copra. Castor seed production is minimal in Mozambique. Also, this oil has high value in the cosmetic, paint, and pharmaceutical industry. It is worth mentioning that castor bean seeds are regularly bought by biodiesel producers in Brazil in order to acquire the biofuel "social seal" since it is a crop commonly produced by family farms in the North-East. However, biodiesel companies have made it a common practice to buy castor seeds simply to comply with the "social seal" requirements. They then resell the oil to other industrial sectors without using it as a feedstock for biodiesel production (Repórter Brasil, 2010; Trentini and Saes, 2010).

Copra oil was considered for this study, but interviews with copra oil-producing companies revealed that vegetable oil mills are currently facing serious challenges to obtain the needed raw material for oil extraction. Moreover, the price of copra oil is rising, and all produced oil is exported. In these conditions, it is very unlikely that copra oil can serve as a competitive feedstock for biodiesel production. Also, a key informant involved in an old pilot biodiesel project (dating back to 2009-2010) reported that biodiesel production with copra oil was not viable because of the lack of raw material and the high price of oil. Jatropha oil is likewise excluded as an option because of the lack of real scientific research in Mozambique on performances and varieties and the social acceptance issues that jatropha would face as a result of negative past experiences. Groundnut is another food crop with almost no current use for oil extraction.

Based on the above considerations, this study focuses on ethanol production through sugarcane and biodiesel production using soybean and cottonseed oils. Indeed, these are the feedstocks available for an immediate use in large-scale biofuel production, and for which data are available to estimate the feasibility of the envisaged blending mandates.

4.1. MARKET STRUCTURES, POWER RELATIONS AND CONTRACT FARMING IN THE SUGARCANE AND VEGETABLE OILS SUB-SECTORS

Overview of Sugarcane Sub-Sector

The feedstock expected to be used for ethanol production is sugarcane. At independence in 1975, Mozambique emerged as the main sugarcane producer in the region, with an annual output of 325,000 tons. Following the country's independence, a two-decade civil war strongly affected sugarcane production. After the civil war, with the backing of the European Commission, the government was heavily involved in the restoration of sugarcane production as part of its broader economic recovery program (Chambati et al., 2018). Data retrieved from FAOSTAT reveals that the sugarcane products (made of molasses, raw cane sugar, and refined sugar) represented the second most important export products after tobacco in 2021.

During the peak of the agricultural season, the sugar value chain employs approximately 31,000 workers, encompassing plantation and mill laborers, harvesters, out-growers, and those involved in logistics (Banco de Moçambique, 2022). 36% of the total number of workers in the sector are permanent employees, while the rest are seasonal workers[4] with women actively participating in the sector. Of the total number of permanent workers, 15% are women, however, women tend to encounter greater barriers when seeking work as laborers on commercial farms. They often find it challenging to balance their duties on the plantation, attending to their own fields and children and family members. Accessing small, remote plots carved out of unused land or within cane fields places further burden on women's extremely labor-intensive days, which include manually grinding maize, cooking, cleaning, and caring for elderly family members and children in addition to formal sugar work in distant fields (Lazzarini, 2017).

Male migrant workers are a very important part of the seasonal workforce. Some authors explain that the use of migrant workers by sugar mills is not only a means to accommodate labor workforce needs but is also a deliberate strategy to reduce the risks of strikes and factory shutdowns (Joaquim et al., 2021).

There are seven sugar mills in Mozambique. The first group consists of four mills, which are located in Maputo and Sofala provinces and produce refined and conventional sugar. The second group includes three mills that produce organic sugar. The majority of production comes from the first group. Data on sugar production is included in Table 4.

Table 4: Sugar production by company

Mill	Location	Production capacity (Tons/year)	Average production per harvest in the 2017/2021 period (Tons/harvest)
Conventional sugar producing mills			
Maragra Açúcar, S.A	Maputo	96,000	70,701
Tongaat Hullett - Açucareira de Mafambisse	Sofala	90,000	38,399
Companhia de Sena, S.A.	Sofala	110,000	36,382
Tongaat Hullett - Açucareira de Xinavane, S.A.	Maputo	234,000	169,935
Sub-total		530,000	315,417
Organic sugar producing mills			
Pure Diets Moçambique	Maputo	10,000	n/a
Eco Farm Moçambique	Sofala	30,000	10,000
Eco Energia de Moçambique	Cabo Delgado	9,300	1,000
Sub-total		49,300	n/a

Source: Banco de Moçambique (2022)

[4] https://cartamz.com/index.php/economia-e-negocios/item/10041-mocambique-aposta-na-producao-de-500-mil-toneladas-de-acucar

The table shows that sugar production is essentially an oligopoly with four mills (belonging to three companies) dominating the market structure. The majority shareholding of these companies is from multinational corporations from South Africa, [5] France, and Mauritius.

The greatest part of sugarcane production in Mozambique comes from plantation estates (80-92%, depending on the source[6]), while the remaining 8-20% is produced by small-scale out-growers. This situation allows for greater production and market control by the estate, without the influence of small-scale producers. The oligopolistic nature of the sugar industry is the source of the market power for the four sugar mills in Mozambique (Paradza and Sulle, 2015). As reported by Chambati et al. (2018), in Mozambique, small-scale producers are price takers and their collective voice is weak due to fragmentation, thus limiting their influence on price determination. Smallholder associations are not linked to the national associations, which may have the power to influence sugarcane output price. Moreover, associations typically negotiate individually with milling companies, thus undermining their capacity to collectively speak with one voice. In other African countries, the production structure is very different. For instance, in South Africa and Kenya, small-scale producers contribute about 90 percent of cane output and they have power to control the market. The sugar farmer associations negotiate cane producer prices and they have been able to extract concessions from the milling companies, including being paid for the associated sugar by-products. The plantation estates are forced to make some concessions because a lack of supply by out-growers inevitably causes important losses for the estates (Chambati et al., 2018).

Starting from the end of the 90s, the sugar sector changed the paradigm of economic growth to contract smallholders. The development of contract farming was often promoted as a win-win solution to promote economic growth without risking land grabbing allegations. By contracting smallholders, sugar companies intend to expand production capacity (thus exploiting economies of scale) without acquiring new land. Indeed, land acquisitions require community consultations and are known to give rise to different kinds of conflicts. Typically, mills establish contracts with farmers' organizations (i.e., associations and cooperatives). Indeed, contracting farmers' organizations enables companies to overcome high transaction costs associated with many small-scale farmers. Also, the implementation of contracting schemes enables mills to mitigate the risks associated with strikes, as the costs of strikes would ultimately be borne by smallholders (and not only by the mills) (Joaquim et al., 2022).

Contract farming has been widely practiced by the sugar mills of Xinavane and Maragra. The contract arrangements developed by these two companies are very different. The Maragra Estate in Manhiça advances agricultural inputs, chemicals, and technical assistance on credit to farmers. Upon harvest, contracted farmers sell sugarcane to the company, which derives the price of sugarcane based on sugar/sucrose content of the delivered cane. With this agreement, the farmer retains control over land and the production process (Chambati et al., 2018).

The contract farming agreement is very different in Xinavane since Tongaat Hullett has different typologies of contracts (Joaquim et al., 2022). However, for the great majority of cases, the company takes over the management of land for a certain period (typically between seven and ten years). According to company officials [7] , this mechanism ensures loan repayment for land development and associated costs. The percentage of sugarcane provided by contracted out-growers to mills ranges from 21% to 40%[8] of the cane crushed.

A common problem reported by different studies is a lack of transparency regarding pricing issues and costs

[5] The majority shares of Maragra belongs to Illovo (South Africa), of Xinanvane and Mafambisse belongs to Tongatt Hullett (South Africa), of Sena Company belongs to Sena Holding (Mauricius) and Grupo Terios (France).
[6] Kegode (2015) and Dal Belo Leite et al. (2020)
[7] Interviewed by Chambati et al. (2018)
[8] Source: Interview with the manager of the Maragra sugar mills and Joaquim et al. (2022) for Xinavane

deducted (Chambati et al., 2018; Dal Belo Leite et al., 2020; Jelsma et al., 2010). Despite tangible crop management activities (e.g., weeding, spraying, harvest, etc.), input quantification is very difficult. Farmers are left with questions such as how much fertilizer, pesticide, and electricity for irrigation were employed. Moreover, in Dal Belo Leite et al. (2020)'s study, organizations complain that the provided reports are poorly detailed or that there was no report at all. Hence, farmers struggled to make sense of their payments at the end of the season.

The study team could not access data on women's representation among smallholders. However, literature and interviewed key informants reported that out-grower schemes are male-dominated. The current land inheritance system explains (at least partially) the land distribution system in Mozambique. In this regard, Tostão et al. (2016) found that female-headed households have smaller farms, while ownership of larger farms tends to be male-headed. This has implications for women's participation in outgrowing schemes since they are less likely to engage in outgrowing schemes due to their limited control over land. Also, for men, access to capital is easier compared to women because they have access to other forms of employment at the estates or in South Africa (Chambati et al., 2018). A lower literacy rate among women and the fact that women are less conversant with Portuguese further marginalize women.

Asymmetries of information clearly undermine trust and give rise to land tenure issues, especially where farmers lose control over land (as in Xinavane). As per information provided by Dal Belo Leite et al. (2020), the transfer process of land use rights (i.e., DUATs) from farmers to the sugar mill is often not clear across organizations, and many feel somewhat trapped by the sugarcane contract. In their study, a key concern was the organization's inability to pay back the necessary loans to kick off sugarcane production. Indeed, the inability to pay back loans would cause them to lose their land use rights. Much of the uncertainty is rooted in the early stages of the contract when land use rights transfer is discussed. Farmers are commonly represented by community leaders, and it is not always clear whether the decisions and their consequences are agreed and understood by the whole community (Jelsma et al., 2010). Dal Belo Leite et al. (2020) even reported cases of organizations that successfully paid back their loans, but they did not receive their DUAT back (the sugar mill claimed that there is a huge amount of red tape at different administrative levels, which delays the process). This situation gave rise to land grabbing allegations.

Overview of Vegetable Oils Sub-Sector

Globally, the main raw materials used to produce biodiesel are vegetable oils. These oils are refined for cooking and seasoning food and can be used in the agri-food industry, cosmetics industry, or biodiesel production. In Mozambique, vegetable oil is used almost exclusively for cooking and seasoning food. According to data provided by the Instituto de Algodão e Oleaginosas de Moçambique (IAOM), there are 21 oil extracting facilities in Mozambique, with a total installed capacity of 232,584 tons.

In Mozambique, vegetable oil extraction is carried out by small and medium-sized companies that produce edible oil for the domestic market. While copra, sunflower, soybean, and cottonseed are supplied to the oil industry by farmers, a large part of the domestic edible oil market is supplied by large processors. These refine edible oil using crude vegetable oil, which is mainly imported from Argentina, Malaysia, Indonesia, South Africa, and other Asian and European countries. Overall, an analysis of data provided by COMTRADE and INE reveals that imports of vegetable edible oils are much larger than domestic production. [9] The great majority of consumed cooking oils are soybean oil and palm oil. The former is partially produced in Mozambique, while the latter is completely imported.

[9] Precise calculations are not included here because of clear inconsistencies among available data.

As specified above, the most promising vegetable oils for biodiesel production are cotton and soybean oils. This is because these two oils are largely perceived as by-products. Also, there is a large untapped potential for the production and use of these two vegetable oils.

Cotton is a crop that demands specific practices and the use of plant protection chemicals (PPC) to which Farmers need technical advice and access. Cotton production in Mozambique hinges upon a system of concessions based on contract farming, whereby the government allocates areas to companies. These companies provide technical assistance and inputs to farmers in a given concession area and have an exclusive right to buy all cotton produced in the area. In this way, farmers have access to needed agricultural inputs, credit (since input costs are discounted from purchases), technical assistance, a temporary provision of needed assets (sprayers and sacks), and a market outlet at a minimum sale price. More precisely, the Council of Ministers sets the minimum price for the marketing of seed cotton from small producers, below which companies cannot buy cotton seed. In this way, the government has a double role: on the one hand, it links producers in a given territory to a company (which obtains exclusive purchasing rights), and on the other hand, it approves the minimum price to purchase cotton seeds after negotiations between farmers and company representatives take place.

The price of cotton seed is decided annually, and the process takes place in two phases. In the first phase, an indicative price is set by consensus between the farmers, cotton companies, and the IAOM (the government body that coordinates the cotton sub-sector). This indicative price is released at the beginning of the campaign (November) to enable farmers to decide on the extent of the cotton areas to plant. Such a price is based on a formula that uses the international cotton price as a reference price. In the second phase, a minimum price is set below which companies are forbidden to buy cotton seed from farmers (however, they can pay above it). This minimum price is set by the government just before the harvest (in April-May).

Currently, there are eight land concessions which encompasses a five-year contract aligned with the presidential election cycle. However, only five cotton companies are actively engaged in the sector. An analysis of the 2019/2020 Agricultural Survey shows that 95% of all cotton production comes from smallholders. As per data provided by the Associação Algodoeira De Moçambique (AAM), there are more than 140,000 cotton farmers in the country.

The other most promising crop for oil production is soy. Soybean cultivation commenced during the 1980s when the socialist government sought to establish state-owned farms across the entire country. However, all projects failed during the civil war. It was only in the early 2000s that soybean production in Mozambique was resumed through different international development initiatives spearheaded by CLUSA and Technoserve. As a result, soybean was disseminated rapidly among smallholders. This expansion lured significant private enterprises interested in soybean production, primarily for use in chicken feed. Mozambique's poultry industry experienced substantial growth during the 2000s, leading to an unprecedented surge in demand for chicken feed. Even now, the domestic market has not fully satisfied the demand for soybeans in chicken feed production.

At the end of the 2000s, a CLUSA project established a seed revolving system in Zambezia and linked farmers to chicken producers in Manica and Nampula. This experience laid the foundations for some attempts of outgrowing schemes. However, in the same period, a parallel process of large-scale plantation establishment made the headlines with allegations of land grabbing cases.

Different contract farming attempts were made to engage soya smallholders, but they largely failed. Currently, almost all soya smallholders are involved through open market sourcing (Di Matteo et al., 2016). Contract farming failures in soybean production areas stemmed from non-compliance with contracts, largely due to side selling. Additionally, challenges arose in monitoring the marketing activities of out-growers, and the influx of both informal and formal grain traders further exacerbated the situation (Di Matteo et al., 2016). Another case reported by Di Matteo et al. (2016) as a reason for contract farming failure in the soya sector is the so-called "donor culture", which resulted in a misalignment of expectations between farmers and contract farming principals. In simpler terms, because most soybean farmers are accustomed to NGO-led technical assistance projects where the consequences of non-compliance are relatively small, many contract farmers fail to grasp or are reluctant to uphold contract farming agreements that operate under stricter market-oriented principles.

So far, the challenge of monitoring contracts stems from the fact that the soybean sector is not based on monopsony schemes, as in the cotton sector. Indeed, when there is only one buyer, selling is not possible, and contract enforcement is much easier for companies. Also, so far, there are no mechanisms to control smallholder production through consolidated production, as is commonplace in the sugarcane sector in the southern part of the country, where smallholder production is organized through block farms (Ibid.).

In December 2022, the Council of Ministers approved decree 75/2022 (called the regulation of oilseeds) that establishes the use of "fomento" and concession systems for other oilseeds, including soybeans. Consequently, it is expected that in the future, a concession and contract farming system similar to the one employed in the cotton sector will also be used for the soybean industry.

The country has three distinct zones with the most favorable agro-climatic conditions for dryland rainfed soybean production, which include Alta Zambézia, Angónia, and Chifunde in Tete, Barue in Manica, and Lichinga in Niassa. As reported in the 2020 official Agricultural Survey[10] Molumbo is the district with the largest soybean production, followed by Gurué (both in Zambezia). Angónia and Chifunde are the third and fourth soybean-producing districts. In Gurué, large companies like Hoyo Hoyo Agribusiness and Agromoz produce a great part of soybean. In the rest of the country, soybeans are mainly produced by smallholders (who also produce some of the soybeans in Gurué).

The area planted with soybeans has been constantly increasing and farmers' market participation is high. Indeed, a comparison in time of the agricultural surveys conducted by the Ministry of Agriculture shows that from 2014/2015 to 2019/2020, the percentage of farmers buying certified soybean seeds increased from 46.8% to 82.3%, the number of farmers selling soybeans increased from 39.7 thousand to 99.3 thousand, and the total quantity sold increased from 19.3 thousand tons to 40.0 thousand tons. The role of certified seeds is particularly important in raising yields. Indeed, soybean seeds' germination power diminishes drastically when seeds are stored.

Soybeans are grown by both men and women. Using a dataset with 1,109 respondents, Findeis et al. (2018) shed light on gender differences in soybean adoption across three regions: the northeast, the northwest, and central Mozambique. Women in the northeast region villages (in Zambezia, Nampula, and Niassa provinces) appear to have lower involvement in soybean cultivation. However, when provided with complimentary soybean seeds, women report being nearly as likely as men to plant the seed. This is an indication that women may face greater challenges in accessing soybean seeds. In comparison, in the northwest (Tete province), soybean is widely grown by both genders. Also, women in Tete villages are engaged, to a comparatively large extent, in all aspects of soybean production and sale. This may be due to the matrilineal household structure in the area. Women smallholders are less likely to participate in soybean cultivation in the northwest. However, the authors also reported interest among women to become more actively involved.

[10] MADER (2021)

V. FEASIBILITY ANALYSIS OF THE BLENDING MANDATES

This section intends to provide an analysis of the potential feasibility of the targets set by the recently approved regulation using sugarcane for ethanol production and soybean oil and cottonseed oil for biodiesel production. Indeed, these are the feedstocks with most potential for large-scale biofuel production in Mozambique (see above).

The recently approved regulation has established targets for ethanol and biodiesel blending mandates, set to commence in August 2024, a mere 10 months from the time of writing this report. It is the opinion of the authors of this work, that blending gasoline at 10% or diesel fuel at 3% with domestically produced biofuels in August 2024 is not feasible. The remaining time is too short to set up operating factories, establish price mechanisms, or address any missing regulations. Consequently, the assessment conducted here uses the blending targets (10% for ethanol and 3% for biodiesel), but moves them forward to 2026, which is more realistic.

5.1. ESTIMATION OF GASOLINE AND DIESEL CONSUMPTION IN 2026

The first step is the estimation of gasoline and diesel fuel consumed in 2026 in order to apply the blending ratios set in the regulation to this estimated quantity. Using the time series of the gasoline and diesel fuel sold in Mozambique from 2002 to 2022[11], the authors of this work regressed the quantity of fuel sold on the GDP at constant price.

The results show that the regression coefficient is highly significant[12] and the coefficient of determination (R^2) is very high for both gasoline and diesel fuel. More precisely, the R^2 for the gasoline model is 0.97 (meaning that 97% of the variance in gasoline consumption is explained by GDP) and for the diesel fuel model is 0.96. As per the results of the logarithmic version of the regression, for a 1 percentage increase in GDP (at constant price), gasoline consumption increases by 1.88% and diesel fuel consumption increases by 1.37%.

With the percentage increases estimated and the estimations of future GDP provided by the International Monetary Fund (IMF, 2023), it results in 2026 that the quantity of gasoline expected to be consumed in Mozambique is 708,941 m^3 and of diesel fuel is 1,681,637 m^3, respectively, if there are no external shocks. The IMF also provides a GDP growth forecast up to 2028. However, the study team decided to focus the analysis on 2026 since a longer time horizon implies greater uncertainty and higher forecast errors due to shocks. The remainder of the analysis included in this section assesses the feasibility of ethanol needed to satisfy the E10 and B3 blending requirements in 2026.

5.2. ETHANOL FEASIBILITY ASSESSMENT

In 2026, the estimated E10 demand is 732,651[13] m^3, which includes 73,265 m^3 of ethanol. The study team collected data of molasses production from six sugarcane mills (the six mills produce at least 90% of the sugar produced in Mozambique[14]) during the 2022/2023 agricultural season. Of the required ethanol volume, 26,622 m^3 can be produced through molasses currently produced by six considered mills (details for the estimations are included in Annex I). This quantity of ethanol is equivalent to 34% of the ethanol needed to meet the E10 target in 2026. Even without considering the increased demand for ethanol caused by economic growth, thus comparing the ethanol demand to blend 10% of ethanol with 90% of the gasoline consumed in 2022, it results that available

[11] Data provided by the National Directorate of Hydrocarbons and Fuels of the Ministry of Energy and Mineral Resources.
[12] P > |t| 000 both for gasoline and diesel oil
[13] Estimated from ethanol energy density
[14] Estimated by the authors using sugar production data included in Banco de Moçambique (2022)

molasses would be sufficient to produce only 48% of the needed ethanol. The rest of the needed ethanol has to be produced by expanding the production of the needed raw material.

The interviewed mills have plans to expand sugarcane production in the next future through increasing agriculture productivity and land use extension (e.g., Marromeu, Maragra, Mafambisse). For instance, one mill plans to reestablish production capacity lost due to recent floods, another mill plans to use drip irrigation and another one plans to source sugarcane from smallholders in another district. Taking these expansion plans into account, the study team estimated that total ethanol production could reach 32,493 m^3, which is equivalent to 44% of the ethanol needed to meet the E10 demand in 2026. In case increased demand for ethanol due to economic growth is not taken into account, available molasses would be sufficient to produce 63% of the needed ethanol for E10.

In order to assess the land use needed for ethanol production, various scenarios are employed, which are based on different combinations of agricultural yields and raw materials. Rather than predicting the exact effects of each scenario, this approach intends to assess how much land each scenario requires. Two potential raw materials are considered: lower grade sugarcane molasses and sugarcane syrup. The former is the typical raw material used for ethanol production. Molasses is a low-value product that is used for mixed animal feed and Mozambican mills sell domestically or abroad to ethanol producers and feed factories. Currently, the price of molasses is relatively high (approximately 100 USD/Ton as reported by interviewed sugar mills) because the war in Ukraine has stopped exports of molasses from Russia and Ukraine. However, in the past, for Mozambican sugar mills, the disposal of molasses was often a source of costs. Sugar cane syrup (or juice) has a much higher sugar content than molasses, and it is used for sugar production. Thus, the use of sugarcane syrup for ethanol production entails foregoing sales of sugar.

The characteristics of each scenario are reported below:

A. The ethanol production process is based on the use of molasses. Agricultural average yields are those reported in the most recent agricultural survey for large farms: 58 tons/ha. This scenario is called Business as Usual Ethanol (BaU E).

B. The ethanol production process is based on molasses once again. Agricultural average yields are assumed to increase by 50% to reach 87 tons/ha. To provide a few comparison terms, this level of assumed yield is lower than the sugarcane yield in Eswatini (96.9 Ton/ha), Malawi (107.8 Ton/ha), or Zambia (103.6 Ton/ha) but higher than the sugarcane yields in Zimbabwe (75.4 Ton/ha) or in South Africa (64.5 Ton/ha). This scenario is called BaU E Plus.

C. The ethanol production is produced through currently available molasses, and the additional needed ethanol is produced using sugarcane syrup. Yields are the same as those used in BaU. This scenario is called Syrup.

D. 50% of the ethanol production is obtained from syrup and 50% from the production of molasses. Agricultural yields are the same, assumed in BaU and in Syrup. This scenario is called Syrup50.

E. Existing molasses is used to produce ethanol. The remaining is produced by syrup obtained from new sugarcane planted areas. Yields are the same as in Bau E and BaU E Plus. This scenario is called New Syrup. It is similar to the old ProCana project, which planned to plant sugarcane only for the purpose of ethanol production.

Details for assumed parameters and sources are included in an Excel spreadsheet in Annex I. The Excel spreadsheet allows for different combinations of agricultural yields, efficiency of the ethanol processing process, quantity of ethanol produced through the "syrup route" vs the "molasses route", ethanol blending targets, and total ethanol demand.

The land needed under each scenario is included in Table 3.

Table 3: Land use implications of E10

Main assumptions	Unit	BaU E	BaU E Plus	Syrup	Syrup 50	New Syrup
Agricultural yield	Ton /ha	58	87	58	58	58
Molasse (M) or cane (C) yield[15]	Lt/Ton	260	260	75	C: 75 M: 260	C: 75 M: 260
Results						
Additional planted area with respect to 2022/2023	Hectare	96,072	47,758	0	23,600	11,200
Foregone sugar production[16]	Ton	0	0	65,725	50,534	1,155

For the scenarios that assume the use of molasses, the additional land area required to reach the ethanol needed for E10 ranges from 96,000 hectares to 49,000 hectares (BaU E to BaU E Plus). Currently, sugar mills source sugarcane from an area of approximately 50,000hectares. Thus, 97,000 to 145,000 hectares under sugarcane production are required to meet the targeted E10 blend in 2026 using only molasses.

The estimated extensions are much lower than the available land area suitable for sugarcane production in Mozambique reported in the 2008 agricultural zoning or in the analysis done by Moreira et al. (2018). Indeed, the agricultural zoning estimated that the total quantity of land available suitable for sugarcane production ranges from 2,600,400 hectares to 5,115,200 hectares. Using very different methods, Moreira et al. (2018) estimated that the land area with high potential for sugarcane production ranges from 1,577,000 hectares to 2,822,000 hectares. In any case, it should be noted that both reference studies are relatively old since the agro-ecological zoning was done in 2007 and Moreira et al. (2018) used data from 2013.

The scenario that does not require any additional land planted is based on ethanol production from sugarcane syrup. However, this scenario entails a foregone sugar production of 65,725 tons. This is equivalent to 70% of the cane sugar exported in 2022[17]. The viability of this scenario depends on the relative price of ethanol and sugar. Given the very high current price of sugar, it is very unlikely that mills are willing to forego sugar production to produce ethanol.

The current regulation mandates that the blending ratio be increased to 15% in 2028. Using the IMF GDP forecast, it results that E15 in 2028 requires 174,487 m^3 of ethanol. This is 2.4 times the amount of ethanol required in 2026 for E10. The primary reason for this significant increase is the IMF's prediction of substantial GDP growth in 2027 and 2028, with projected rates of 13.1% and 12.1%, respectively. This expected robust economic growth contributes to an increase in gasoline demand. It is worth noting that the country already experienced similar double-digit growth rates in the 1996-1999 period. While GDP growth forecasts over a long period of time are inherently affected by a high degree of error, the estimated ethanol quantity in 2028 is an indication of how much ethanol production should increase when the blending rate is increased and the economy grows significantly.

5.3. BIODIESEL FEASIBILITY ASSESSMENT

The estimated B3 demand in 2026 is 1,681,637 m^3, which is equivalent to 50,450 m^3 of biodiesel. This study

[15] For the scenarios where ethanol is produced through the "molasse route" (BaU and Bau Plus) the yields refer to liters of ethanol produced per ton of molasse, while for the two scenarios assuming the "syrup route" the yields refer to the liter of ethanol per ton of sugarcane.

[16] It assumed that the sugar yield per ton of cane is 10.3% (Banco de Moçambique, 2022)

[17] Source: Estimated using date from COMTRADE

considered that soybean and cottonseed oils are the two most promising vegetable oils for biodiesel production. The country in the 2022/2023 agricultural season produced 77,664 tons of soybean[18] and 24,733 tons of cottonseed.[19] Using the current extraction rate[20] of vegetable oil mills in Mozambique, this quantity of seeds could produce 11,669 tons of vegetable oil. Mozambique is a net vegetable oil importer. As per COMTRADE data, in 2022 the combined imports of crude and refined palm and soybean oils, the two most consumed oils, amounted to 218,000-233,000 tons (depending on where one considers imports reported or imports reported by sourcing countries). So, any use of edible vegetable oils to produce biodiesel could easily provoke a strong upward price pressure on soybean oil bought by Mozambican consumers. In this regard, the NBPS emphasized the need for ensuring food security. Also, a stated objective of Measure 10 is import substitution. Consequently, it is assumed here that any vegetable oil production obtained through soybean or cottonseed first substitutes imports of soybean or cottonseed oil, and only once imports of soybean and cottonseed oil have been substituted, the remaining oil is used to produce biodiesel.[21]

In 2022, the sum of imported soybean oil and cottonseed oil was 178,983 tons, of which 95% was soybean oil. The annual imports of soybean oil from the 2000-2022 period were regressed against the GDP at a constant price. The linear regression yields a highly significant slope coefficient and an R^2 of 0.88. The result is that for each percentage point of GDP increase (at constant prices), the imports of soybean oil increase by 2.3%. Using the IMF GDP forecast, the 2026 soybean oil imports are estimated to be 206,656 tons.

The current production of soybeans and cotton seeds would only be sufficient to meet 4.6% of the country's vegetable oil needs required to replace imported soybean and cottonseed oils and to produce the necessary biodiesel for B3 in 2026. In case biodiesel is produced without replacing imported oils, then the available produced soybeans and cotton seeds would be enough to produce only 25% of the B3 target in 2026.

Even without taking into account the increased demand for biodiesel caused by economic growth, thus comparing the biodiesel need to blend 3% of biodiesel with 97% of the diesel consumed in 2022, it results that the quantity of soybeans and cotton seeds produced in the 2022/2023 agricultural campaign would only be sufficient to replace 5.4% of the oils needed to substitute imported oils in 2022 and to produce the required quantity of biodiesel.

The scenarios considered are the result of different combinations of soya and cotton area expansions, improvements in agricultural yields, and vegetable oil extraction rates. The following scenarios are considered here:

A. The soya and cotton areas are expanded to produce the needed oil in the same proportion as they were in the 2022/2023 agricultural campaign. Agricultural yields are assumed to be the same average yields of the 2022/2023 agricultural campaign, and the extraction oil rates are those reported by IAOM, which were obtained through tests in two main oil Mozambican mills. This scenario is called BaU B.

B. As in BaU B, in this second scenario, soya and cotton areas are expanded in the same proportion as the areas cultivated with these two crops in 2022/2023. Vegetable oil extraction rates are increased to 19% for soybean oil (the typical extraction rate in Brazil) and 15% for cottonseed oil, which entails the use of combined mechanical and solvent extraction technology. This scenario is called BaU B EFF.

[18] Source: IAOM

[19] Source AAM for the quantity of unginned (with fiber) seed cotton. It is assumed that the weight of the seed is 54% (reported by a cotton gin manager interviewed)

[20] Extraction rates assumed were provided by IAOM following tests done in two large mills in Mozambique. These are 12% for soybean oil and 10% for cottonseed oil.

[21] Palm oil is another edible oil that is imported in significant quantity. However, this work does not assume that palm oil has to be substituted with domestic production of vegetable oil since palm oil is not a perfect substitute of any domestically produced vegetable oil. This hypothesis favors biodiesel production since less land is needed.

C. In this third scenario, it is assumed that yields of soybean production increase by 100%, thus from the current 0.61 Tons/ha to 1.22 Tons/ha. As shown by the mid-term evaluation of a USAID-funded project that focused on technological transfer and the use of improved seeds in Mozambique, this level of yield can be achieved even with rainfed production, with the use of high-yielding seeds and proper agricultural practices (Borzoni and Cunguara, 2019). The planted area increases proportionally to the 2022/2023 area planted with cotton and soya. Also, improved efficiency in extraction rates is assumed as in the previous scenario. This scenario is called Soya EFF.

D. Only soybean-planted areas are expanded. Yields and extraction rates remain the same as in the previous scenario. This scenario is called Soya EFF Plus.

As for ethanol, details for assumed parameters and sources are included in an Excel spreadsheet in Annex I. The Excel spreadsheet made available allows for different combinations of agricultural yields, efficiency of oil extraction, quantity of biodiesel produced through cottonseed and soybean oil, biodiesel blending rates, and total biodiesel demand. Thus, the land area needed under each scenario is included in Table 4.

Table 4: Land use implications of B3

Main assumptions	Unit	BaU B	BaU B EFF	Soya EFF	Soya EFF Plus
Soybean yield[22]	Ton /ha	0.61	0.61	1.22	1.22
Soybean oil extraction rate	Perc	12%	19%	19%	19%
Cottonseed oil extraction rate	Perc	10%	15%	15%	15%
Results					
Additional planted area	Hectare	3,733,325	2,199,274	1,131,995	1,008,577

As the results included in Table 3 show, the land needed for B3 is much higher than that of E10. To the best of the authors' knowledge, there are no studies quantifying the area available for soybean and cotton cultivation. A possible point of reference is the 2008 Agricultural zoning. That study estimated that the total extension of land available for any agricultural use was almost 7 million hectares. According to data from FAOSTAT, the agricultural land area has expanded by 2.4 million hectares from 2007 (when the agricultural zoning was done) to 2021. This expansion has likely occurred at the expense of forests, as during the same period the forest cover decreased by 3.14 million hectares.

Given the large extension of land needed to replace soybean oil imports and produce the needed biodiesel, the introduction of B3 could easily cause a replacement of existing crops and/or further deforestation. This is because all scenarios assume that additional vegetable oil production should first substitute imported soybean and cottonseed oil.

The effects will be even greater for B7.5 or B10. Indeed, with the current IMF GDP forecast growth, the B7.5 in 2028 would require 107,712 m^3 of biodiesel, which is 3.5 times the amount needed in 2026. An analysis across the four considered scenarios suggests that efficiency improvements (for oil extraction and for agricultural yields) should be actively pursued in order to reduce the land needed.

[22] Cotton yields are assumed to remain the same across all scenarios

VI. LOCATION FOR INVESTMENTS ON BIOFUELS FEEDSTOCK

This section provides considerations on the likely locations of biofuel investments in Mozambique. Two main groups of information are used: i) the location of biofuel concrete investments and proposals during the 2007-2008 period, and ii) the availability of resources, key infrastructure, and the location of complementary investments to absorb the production of by-products. In this way, this study does not intend to speculate about the future location of investments; the intention is rather to identify areas where interest is likely to emerge and to provide a basis for further analysis.

Schut et al. (2010) analyzed data regarding 38 biofuel investment proposals[23] covering the period from 2006 to 2008. Seven of these were about ethanol production (to be produced from sugarcane and some sweet sorghum) and 31 from biodiesel (to be produced mainly from jatropha). 71% of the projects prepared[24] were located in Maputo, Gaza, Inhambane, Sofala, and Manica provinces. The remaining projects were located in Zambezia, Niassa, Nampula, and Cabo Delgado provinces. Regarding planned processing and storage facilities, 90% of the projects were in the provinces of Maputo, Manica, and Sofala. As the authors noted, it seems that there was a relation between the location of processing and storage facilities and that of the agricultural feedstock production projects, as 50% of the projects were located in Maputo, Manica, and Sofala provinces.

Once data on implemented projects and expressions of interest are combined with those on existing and planned storage and processing facilities at that time, the difference between north and south Mozambique is even more evident, as 80% of the total biofuel-related projects were supposed to take place in Maputo, Gaza, Inhambane, Sofala, and Manica provinces, while only 20% in Zambezia, Niassa, Nampula, and Cabo Delgado provinces. Overall, the higher concentration of biofuel projects found by Schut et al. (2010) was located in the Beira corridor, around Quelimane, and around the southern coast between Inhambane and Maputo. Based on these considerations, Schut and his colleagues conclude that biofuel development mainly takes place near good infrastructure and that the majority of commercial biofuel projects have no interest in locating in remote areas of Mozambique.

It should be noted that in Schut et al. (2010)'s analysis, the intended feedstock for planned biodiesel was mainly jatropha, which was supposed to produce seeds in many different climatic conditions. Currently, the main vegetable oils expected to be utilized for biofuel production are cottonseed and soybean oil. According to the study team's analysis and different key informants' views, the locations for further investment in oil extraction facilities (and consequently for biodiesel) are the Beira-Tete corridor. In this area, the soil and climate are suitable for soya and cotton production. Indeed, soya and cotton are traditionally cultivated here. The infrastructure and logistic services are also well developed. In addition, private and public actors playing an important role in the soybean and cotton value chains make the area particularly attractive for agro-business development. Another interesting area for feedstock production for biodiesel is the Nacala corridor. Here soybean and cotton are important products and the railway could facilitate transports of vegetable oils from Niassa to the coast. Also, soybean has expanded largely in Niassa and one key informant reported that a main problem in that area was a general lack of market outlet.

For ethanol an attractive area is the Sofala province. In this area there are three sugar mills, whose molasses are exported. The existence of the railway could facilitate transportation of the needed raw materials to processing

[23] Of the 38 proposals, 17 were formally presented to the relevant government authority, while the rest were in the process of being prepared.
[24] Including the 38 projects

facilities. As per information provided by a key informant, the Buzi district has a large potential for further expansion of sugarcane production since a large estate was previously producing sugarcane and has currently a very large expansion of uncultivated land. Moreover, there is the advantage that Buzi has an ethanol distillery that is not currently producing.

VII. IMPACTS OF BIOFUELS DEVELOPMENT

Biofuel development in the African context has become a contentious issue among stakeholders, including development practitioners, policymakers, and civil society organizations. Concerns have been raised about unintended negative social, economic, and environmental consequences (Gasparatos and Stromberg, 2012; Wolde-Georgis and Glantz, 2010). Moreover, numerous biofuel projects in African countries have been based on industrial plantations, potentially resulting in an unfair distribution of advantages as plantations could involve the displacement of rural communities from their land (Amigun et al., 2011; Jumbe et al., 2009; Ntauzi, 2022; Ribeiro and Matavel, 2009).

This section intends to describe the main possible impacts of large-scale biofuel production in Mozambique. Given that the blending mandates are not yet effective and consequently their effects still have to take place, biofuel impacts are assessed mainly through a literature review of studies conducted in Mozambique for biofuels from the 2005-2013 period. More recent studies assessing the impacts of general large-scale agricultural commercial investments in the country were also considered.

7.1. IMPACTS ON FOOD SECURITY AND WELFARE

There is some consensus that biofuel expansion has contributed to the international food price increase during the 2007–2008 food crisis (Mitchell, 2008; Mueller et al., 2011). However, the actual magnitude of this effect is far from agreed upon (Gasparatos et al., 2015; Mueller et al., 2011).

Although food security indicators have improved in Mozambique in recent years, the number of undernourished people in 2020-2022[25] was 9.8 million, which was equivalent to 30 percent of the population (FAO, 2023). So it is no surprise that, among all possible impacts of biofuels, potential threats to food security have been the greatest concern for policymakers, civil society organizations, and development practitioners.

For Mozambique, the effects of biofuels on welfare and food security have been studied at the national level and the local level. At the national level, these studies consist of prospective studies using general equilibrium models (Arndt et al., 2011; Arndt et al., 2009; Hartley et al., 2019) or input-output models (da Cunha et al., 2018). These studies estimated the effects of biofuels investments to reach certain biofuels production targets during the first 2007-2013 period. They used social accounting matrices as input data. The results are summarized in Table 5.

Table 5: Main results and assumptions of models estimating impacts of biofuels in Mozambique at the national level

Source	Target	Main assumption	Main results
Hartley et al. (2019)	1,400 million liters of ethanol produced per year from 2015 to 2025 Sugarcane output increases by 17.5 million tons per annum, requiring about 19,000 ha of new land each year	Scenario 1: The structure of sugarcane farming system is maintained (87.5% of sugarcane is produced by commercial farmers and 12.5% by community farmers); Scenario 2: Sugarcane comes equally from estates and from smallholders; Scenario 3: Same as Scenario 1 but it includes cogeneration from bagasse Scenario 4: Needed additional	Average annual real GDP growth increases by 0.003% pts in Scenario 1 versus 0.018% pts in scenario 3, which is equivalent to a 0.03% and 0.17% increase in the level of real GDP by 2025. The ethanol industry is estimated to create around 56,000 jobs directly through feedstock and processing activities by 2025. Welfare losses are experienced under scenario 4 as lower land availability for non-ethanol use results in lower production. Household food consumption increases in all scenarios excluding scenario 4

[25] 3-year average

Source	Target	Main assumption	Main results
		sugarcane production will result in a displacement of food crops for 50% of the land needed by smallholder farmers considered under Scenario 1 All scenarios assume an additional sugarcane area is planted for ethanol production only. The syrup conversion route is applied	
Arndt et al. (2009)	- 210 million liters of sugarcane ethanol per year - 198 million liters of jatropha biodiesel per year - 210 million liters of sugarcane ethanol plus 198 million liters of jatropha biodiesel per year	Half of production of biofuel crops occurs on unused land and the remainder on land under cultivation. Sugarcane production is plantation based, while jatropha production is based on smallholder out-growers Ethanol conversion occurs through the "syrup technology route". Areas needed are 280,000 hectares for sugarcane and 550,000-830,000 hectares for jatropha depending on the scenario used.	Average annual GDP growth rate increases by 6.09-6.74% (depending on the scenario/target considered) Expansion of sugarcane generates jobs for 94,000 farm laborers. Jatropha production employs 271,000 smallholder farmers. Biofuel processing employs 36,000 and 55,000 manufacturing jobs for ethanol and biodiesel production, respectively. While food prices and imports increase relative to the baseline, overall, welfare and food security broadly increase due to enhanced purchasing power. However, certain households may be adversely affected.
Arndt et al. (2011)	198 million of jatropha biodiesel produced per year	550,000 hectares of jatropha planted. Half comes from new areas brought under cultivation and the rest from displacing other crops. All jatropha production is undertaken through smallholder outgrower schemes. Three scenarios: 20%, 50% and 80% of women employment	Expanding feedstock production accelerates economic growth and reduces poverty. The sector will employ an additional 268,000 smallholder farmers, while downstream biofuel processing will generate a further 61,000 manufacturing jobs. National poverty declines regardless of how intensively women are employed in the new biofuels sectors. While some of the displaced lands come from food crops, it is actually the non-biofuel export crops that are most severely affected by expanding biofuels production. A stronger trade-off between biofuels and food availability emerges when female labor is used intensively, as women are drawn away from food production. A skills-shortage among female workers also limits poverty reduction
da Cunha et al. (2018)	4.11 billion liters of fuel ethanol, and 2.7 TWh of electricity per year	600,000 hectares of sugarcane needed, which is cultivated on unused land (no crop displacement).	GDP increases by 27.7% in comparison to baseline (2011). 3.3 million jobs generated. Human development index increases by 0.031 points

Overall, the macro-economic models used indicate an improvement in welfare and a reduction in poverty, followed by accelerated economic growth and job creation. This is the result of additional investments for biofuel biofuels and the assumptions made. Indeed, when assumptions consist of additional land expansion without replacement of existing crops, it is not surprising that agricultural investment results in an estimated increase in economic growth. Another result is that scenarios reflecting out-growing schemes have a higher potential for improving household welfare than those based on estate plantations. This is due to the greater use of unskilled labor and the accrual of land rents to smallholders, compared with the more capital-intensive plantation approach (Arndt et al., 2009; Hartley et al., 2019).

Overall, the accelerated economic growth and poverty reduction estimated by macro-economic models suggest a general improvement in food security.

It should be noted that for ethanol, the two papers using general equilibrium models (Arndt et al., 2009; Hartley et al., 2019) estimate that the land areas needed for sugarcane are slightly larger than the area we estimated to produce the ethanol for E10 in 2026 (48 - 96 thousand hectares). This means that where these two studies estimated no effect on food security due to the replacement of food crops, a similar conclusion could probably be expanded to estimations based on smaller areas needed. However, the estimated impacts of the 4th scenario in Hartley et al. (2019), assuming that needed additional sugarcane cultivation occurs in areas previously occupied by food crops, consist of welfare losses and a reduction in household consumption for rural households as food production decreases.

The general equilibrium model used for biodiesel (Arndt et al., 2009) suggests that welfare and food security broadly increase due to enhanced purchasing power. However, the authors also highlight that certain households may be adversely affected. It should be noted that the authors estimate a quantity of land area needed for jatropha that is much lower than the area we estimated for soy and cotton for B3. So their conclusion cannot be expanded to the effects of B3 in 2026 (where needed land is much higher).

All macroeconomic models considered assume that all ethanol and biodiesel production is exported. In general equilibrium models, this causes an appreciation of the national currency exchange rate. This is the reason why, in one of the two studies of Arndt et al. (2011), biofuels expansion results in a reduction of traditional export crop cultivated area[26] rather than non-exported food crops. Blending biofuels with gasoline or diesel fuel for use in the domestic market would not have such an effect.

At the household level, two different mechanisms have an effect on food security. On one side, smallholder feedstock production or employed work in plantations provides income, which can be used to buy food or agricultural inputs. In this way, household involvement in biofuel activities can potentially have a positive impact on household food security. On the other side, feedstock production competes for labor, land, and agricultural inputs on smallholder land, while employment in plantations can divert labor away from subsistence agricultural activities. This diversion of labor, land, and agricultural inputs can have a negative effect on household food security (Gasparatos et al., 2015). The final result for food security depends on which of these two mechanisms is stronger.

While the studies discussed above estimated the impact at the national level of modeled investments, a different set of studies tried to assess which of the two mechanisms has a stronger effect on food security at the local level by comparing certain food security and poverty indicators for households involved in sugarcane or jatropha production with those of a control group. The latter was made up of households not involved in feedstock production (either in the same zone or in a more far-away zone, which was still similar to the areas where the feedstock was cultivated). To the best of the authors' knowledge, in southern Africa, such an approach was used in five papers, whose results are included in Table 6.

Table 6: Main results of models estimating impacts of biofuels at local level

Authors	Outcome variables	Sites	Production models	Main results
Gasparatos et	- Food consumption	Dwanga (Malawi)	- Sugarcane plantation	Involvement in feedstock production improves food security, while involvement

[26] An appreciation of the exchange rate makes exported products less competitive on price

Authors	Outcome variables	Sites	Production models	Main results
al. (2022)	score[27]		- Small-scale sugarcane out-growers	in plantation work does not seem to have a strong effect on food security. Irrigation use significantly improves food security Households involved as plantation workers or sugarcane growers had lower poverty levels than control groups
Mudombi et al. (2018)	- Household food insecurity access scale[28] - Multidimensional poverty index[29]			
		Mangochi (Malawi)	Smallholder farmers growing jatropha in hedgerows	No statistically significant difference on food security and poverty indicators
		Buzi (Mozambique)	Jatropha estate	No statistically significant difference on food security between households having employees at the estate and control group. Jatropha plantation workers had lower poverty than farmers in the control groups
		Tshaneni (Swaziland)	- Commercial sugarcane estate - Community owned sugarcane plantations	Strong positive effect on food security for involvement in sugarcane production. Lowest level of poverty among plantation workers. Workers and owners of community owned plantations are less poor than control group.
Herrmann et al. (2018)	- food crop land area changes - food crop input purchase - farms asset investments - staple food production - staple food yields	Dwanga (Malawi)	Small-scale sugarcane out-growers	Participation in sugarcane outgrowing production is associated with statistically significant increase in farm asset investments and staple crop input purchase. A statistically increase in staple food production and in staple food yields is found with the use of a specific econometric model (ESR) but not with another (PSM).
Chamdimba et al. (2019)	Average consumption expenditure per adult equivalent unit[30]	Mangochi (Malawi)	Smallholder farmers growing jatropha in hedgerows	Depending on the econometric model used, jatropha farmers had statistically significant lower welfare outcomes (PSM) or their welfare benefits were at best zero (ESR)
Thornhill et al. (2016)	Household nutrient deficient gap[31]	Bilene (Mozambique)	Jatropha plantation	No statistically significant difference
		Panda	Jatropha plantation	No statistically significant difference

[27] It is a measure of dietary diversity and it is calculated using the frequency of consumption of different food groups by a household during the seven days before the survey

[28] It assesses household perception of food insecurity and responses to it using progressively more severe questions about prevalence of lack of food in the four weeks before the survey

[29] The index identifies the poor by counting the number of people suffering deprivation in various dimensions, as well as the number of dimensions in which they fall below the threshold. The dimensions used are health, education and living standards (they all have an equal weight)

[30] The choice of consumption expenditure over income draws from well-documented merits of its reliability and relative ease in capturing the data

[31] It uses the individual household nutrient deficit gaps (the percentage difference between reported household consumption of each nutrient and the calculated household requirement of each nutrient) to create a weighted average deficit score for

Authors	Outcome variables	Sites	Production models	Main results
		(Mozambique)		
		Dombe (Mozambique)	Sugarcane plantation	No statistically significant difference

Overall, sugarcane workers and smallholders tend to be significantly better off in terms of food security indicators than their control groups with an exception in the Illovo sugarcane plantation workers in Dwanga (Malawi). This was attributed to the low salary received by the plantation workers. On the other hand, even though jatropha plantation workers experience some economic benefits in Buzi, these benefits do not necessarily cause an improvement in food security (Gasparatos et al., 2015).

Regarding poverty, the results of the studies considered suggest that in the sugarcane-growing areas (Dwangwa in Malawi and Tshaneni, Swaziland), those who participated in sugarcane activities, such as plantation workers and sugarcane farmers, consistently had a lower poverty level than those who were not involved. On the other hand, in jatropha-growing areas, the results were mixed. There were no clearly defined differences between control groups and jatropha farmers in Mangochi (Malawi) where multidimensional poverty was measured (Mudombi et al., 2018). In the more robust research design[32] of Chamdimba et al. (2019), jatropha farmers had a worse welfare outcome than the control group or their welfare benefits were at best zero. The workers of the jatropha plantation in Buzi had slightly lower poverty than their respective control groups (but food security indicators were not statistically higher than those of the control group). This suggests that the poverty alleviation outcomes of involvement in feedstock crop production can vary between different crops and modes of engagement.

Overall, none of the studies done at the household level found a negative effect on food security. The results also indicate that various factors affect food security, having a different effect and depending on the site. As a result, adopting a "one size fits all" approach can possibly have a counterproductive effect.

All groups across all sites were deprived in terms of access to electricity and clean cooking fuels, which is somewhat ironic for areas that host energy (Johnson et al., 2018). This obviously raises “energy justice” considerations.

7.2 IMPACT ON IMPORT SUBSTITUTION

As stated among the objectives of Measure 10 of the PAE, the biofuel blending mandates that the government has introduced are meant to substitute oil products (gasoline and diesel fuel). So the analysis proposed here focuses on oil products only.

The International Energy Agency (IEA) dataset shows that the total energy consumption of Mozambique was 340,024 terajoules (TJ) in 2020. Of this, 69% was from biomass sources, 18% was from oil products, 13% was

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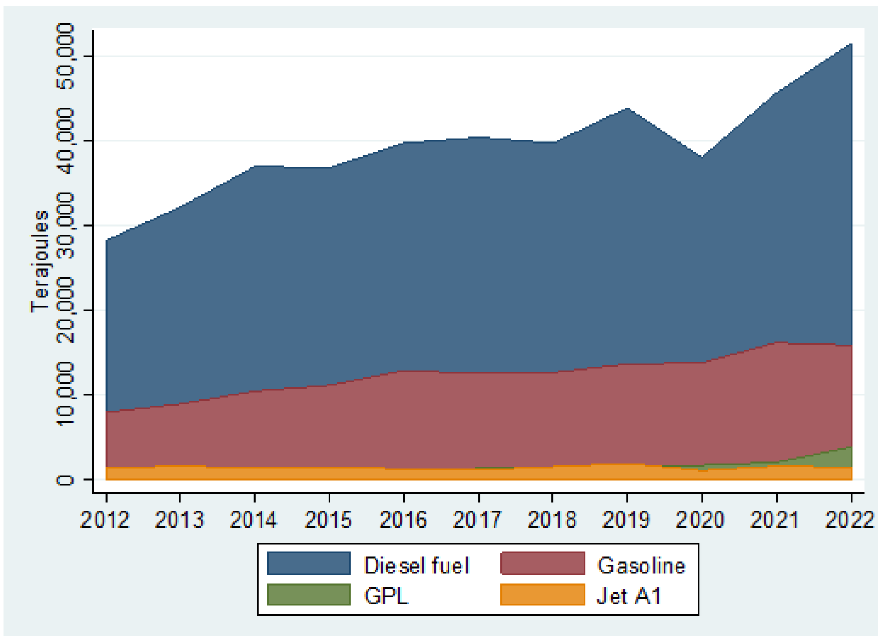
the macro and micronutrients included in the calculation.

[32] While the research design of Gasparatos et al. (2015) and Mudombi et al. (2018) consists in a simple comparison of the chosen variables for households involved with those not involved in feedstock production or in plantation work, Chamdimba et al. (2019) and Herrmann et al. (2018) addresses selection bias by using a propensity score matching (PSM) technique or endogenous switching regression (ESR). Indeed, Gasparatos et al. (2015) and Mudombi et al. (2018) explicitly caution the reader that their study cannot establish a causal relationship between the involvement in biofuels and the observed detected differences in the chosen outcome variables. More than establishing causality Gasparatos et al. (2015) and Mudombi et al. (2018) allude to poverty reduction or food security effects.

from electricity generation, and the rest was from natural gas and coal. Oil products used for electricity generation are heavy fuel oils, and their quantity is minimal (less than 1%).[33]The largest majority of oil products consumption (74%) is caused by the transport sector.

Figure 1 shows the domestic sales of oil products during the last ten years. Both the sales of gasoline and diesel fuel have doubled between 2012 and 2022. Once the sales volume of the different oil products is converted into the same energy metric (joules), it results in the sales of diesel fuel and gasoline being 71% and 22%, respectively, in 2022.

Figure 1: Oil products sales in Mozambique



Source: NDH[34]

Biodiesel has approximately the same energy content as diesel fuel. So, the energy security effect of a certain level of substitution of diesel fuel with biodiesel can be quantified as the same quantity of biodiesel introduced in the blend. The B3 target has a very modest energy security effect, since it replaces only 3% of diesel fuel. The contribution of B10 for energy security would obviously be greater.

The blending ratios set for ethanol are higher than those of biodiesel. So ethanol could contribute to energy security for private vehicles (which mainly run on gasoline). However, gasoline represents only 22% of the total sales of oil products. Also, the energy yield of one liter of ethanol is roughly 68% of the energy yield of gasoline.[35] So the import substitution effect of a certain blending ratio (e.g. 10%) obtained using domestically produced biofuel is 32% lower than the blending ratio. As a result, the substitution of 20% of gasoline with ethanol (the highest blending rate set in the regulation) is equivalent to 3% of the energy content of the oil products sold in

[33] Source: MIREME (2022)

[34] The following conversion factors were used: GPL: 42.5 MJ/Kg, gasoline: 32.5 MJ/L, diesel fuel: 36.1 MJ/L, Jet-A1: 34.7 MJ/L

[35] More precisely, the energy density of gasoline is 32.5 MJ/Lt and the energy content of sugarcane ethanol is 22 MJ/Lt

2022.

In case Mozambique cannot produce the required quantity of ethanol and biodiesel to meet the blending mandates, a possible alternative is importing biofuels and blending them. Such an approach could enable the country to develop the needed logistical infrastructure. However, importing biofuels would not contribute to the energy security of the country. Also, importing biofuels would aggravate the balance of payments deficits. By comparing the CIF price of biodiesel importing countries like the Netherlands (reported by COMTRADE) with the unit expenditures of the Mozambican diesel fuel imports reported by the DNH, it results that the price of biodiesel is at least twice the price of diesel fuel. Also, the price of imported soybean oil in Mozambique is higher than the price of imported diesel fuel.

7.3 IMPACT OF BIOFUELS LARGE-SCALE INVESTMENTS

Overall, land-based investments in agriculture can be classified under four basic models: i) smallholders (also called family farming), ii) outgrowing or contract farming, iii) large-scale commercial farming; and iv) hybrid models (combining large-scale farming and smallholder farming) (Ntauzi, 2022). This section includes considerations on large-scale investment farming.

The Mozambican government has adopted a dualistic approach to developing the agricultural sector, simultaneously supporting the growth of large-scale commercial agriculture and offering support to smallholder farmers. The former strategy has been advanced through a range of policy initiatives, such as the promotion of agricultural corridors and the provision of tax incentives to corporations (Tostão et al., 2016).

Mozambique is generally recognized to have one of the most progressive land laws in Africa (Vermeulen and Cotula, 2010). Although all land legally belongs to the state, the Land Law 19/97 safeguards the rights of citizens to land and natural resources by providing them the right to use and benefit from land with or without formal documentation. The national law also accommodates customary law over land, leaving decisions on matters of inheritance and land use to community-level institutions (Tostão et al., 2016).

However, numerous development practitioners, civil society organizations, and scholars have raised serious concerns that community land is at risk from large-scale acquisitions. Both the government and donors have supported efforts to increase the formal registration of landholdings and improve land information systems (Locke, 2014).

The Land Law establishes three means of acquiring land, namely, i) through existing occupation established by customary norms and practices (this includes used and unused lands that a rural household needs to have access to and control over for a certain period of time), ii) through existing occupation "in good faith" (when people have occupied the land for at least ten years without challenge, which aims to protect the rights of displaced persons that settled in lands during the civil war that were formerly owned by colonial powers), and iii) through a formal request to the State (Schut et al., 2010).

The same Land Law states that formal requests to the State must be accompanied by a community consultation, which seeks to ensure that community rights are taken into account and provides an opportunity for communities to negotiate some element of compensation or benefit with investors, including employment opportunities and other social benefits. The literature review and interviews found that consultations for large-scale agricultural investments are characterized by significant variation in practices.

A long list of criticisms was found in the literature review on the way consultations have been actually conducted. These include: consultations limited to village elders, elites, and officials, with no sign that efforts were made to include significant social groups such as women and pastoralists; community-level meetings dominated by local community leaders who often previously participated in preliminary meetings to promote the investments, with no clear mechanisms to resolve different priorities among community members; information provided to communities often incomplete; consultations consisting of one single event with communities rather than ongoing interactions; records of meetings that are vague about timeframe and targets; agreements on social investments guaranteeing resource access and benefit sharing often not documented in informal documents or legally binding contracts; women are seldom included in consultations and they almost never sign the respective reports/documents despite women representing the majority of the rural workforce (Bussotti, 2020; Nhantumbo and Salomão, 2010; Ntauzi, 2022; Tostão et al., 2016; Vermeulen and Cotula, 2010).

The outcome of a consultation process is the minutes of the community meeting. The minutes are not a legally binding contract, and no sanctions are in place in the event that private investors do not respect the promises made to the community (Nhantumbo and Salomão, 2010).

While large-scale investments may create new opportunities for local livelihoods and national economies, a large number of people are vulnerable to dispossession as a result of changes in land use. Therefore, compensation is foreseen in Decree 31/2012 and in the Land Law. However, different studies have highlighted that compensations for improvements and non-land assets may not be enough to provide access to alternative land (Vermeulen and Cotula, 2010). For instance, Ntauzi (2022)'s analysis of a large investment for soybean production in Gurué revealed that not all affected small-scale farmers were compensated. The same study also shows that, on average, the land extension that displaced households farmed at the time of the study was much smaller than the area they had before the arrival of the company. In a study assessing six large-scale agricultural investments (which took place from 2009 to 2012) in the Nacala corridor, Zaehringer et al. (2018) found that not even half of the households who lost land for one of the assessed investments received any kind of compensation. Tostão et al. (2016) also reported other cases of large farms planting 10,000 hectares of soybean with no compensation provided for displaced families. The study of Dal Belo Leite et al. (2020) on sugarcane investment and outgrowing arrangements in Xinavane reports that compensation measures included irrigation infrastructure for food crop production. However, irrigation areas for food production remained very limited and much lower than the envisaged target. After the famous failure of Pro-cana investment for ethanol production in Massingir, [36] displaced families were not able to return to their land (Tostão et al., 2016). Interviews with one informant also revealed that similar cases occurred in Buzi, where people resettled after establishing a jatropha plantation by a private company (Niqel) could not return to their field after the jatropha plantation failed.

Interviews with representatives of farmer organizations reported several cases of land conflicts due to large-scale investments. In this regard, the study team had access to a document drafted by the União de Camponeses de Nampula reporting a long list of land conflicts where compensations were not provided and community consultations were not conducted.

Failure to comply with promised compensation is a common concern reported both in the literature review and during consultations conducted by the study team. Some interesting data on compensations are provided in a report developed by Centro Terra Viva (Cesar et al., 2020). The report includes annual data obtained from DINOTER from 2014 to May 2020 on the number of households that were forced to move as a result of third-party investment and the number of households that were formally resettled, meaning that they obtained a new house. While at the beginning of the time series, almost all affected households were formally resettled, the percentage of resettled households constantly decreased over time. In 2020, only 25% of the affected households

[36] Procana, wsa London based company that acquired 30,000 hectares close to the dam (in the red area closest to the Massingir minor town), was approved in 2007 as an investment project aiming to accommodate a sugarcane/ethanol plantation and to create 7000 direct jobs, and engage in a scheme of sugarcane out-growers (Bruna, 2019). After two years, the company lost its right to use the land because the company failed to comply with its contractual obligations.

were formally resettled.

Over time, large-scale investments in agriculture will have a deep impact on the local and national economy, including economic growth and a more skewed land distribution (Vermeulen and Cotula, 2010). Also, large-scale investments will have differentiated effects on rural people. In this regard, Ntauzi's (2022) study shows how some households managed to acquire more land once dispossessed while others acquired much less (although, on average, farmed land by smallholders after resettlement was smaller). Some farmers started farming a new profitable crop (soy), received training, and used the same modern agricultural techniques of the incoming company, while for others, their social and economic situation clearly worsened. In a similar way, Zaehringer et al. (2018) found that following large-scale investments, more than 60% of the households who lost land managed to acquire new cropland. However, households who lost land still ended up with an average of 1.8 hectares less than before losing the land. Additionally, as explained by Ntauzi (2022) in his analysis on a large-scale soybean investment in Gurué, land-dispossessed villages lack employment and land opportunities, compelling some people, predominantly the young, to migrate to urban areas in pursuit of fresh employment prospects. This also affects gender roles within the household, with women often taking on tasks traditionally assigned to men. As men head to towns or cities in search of employment, women remain in charge of land preparation for farming. The combined effect of the current land rights system and land dispossession may further disempower women. In areas governed by a patrilineal system, land belongs to men, while in areas governed by matrilineal norms (in the North), land rights belong to women's male relatives. For women, this ensures a high chance of co-titling or inheriting in the event of the husband's death. Conversely, in the event of land dispossession, even in these areas, women are no longer land right-holders, and the chances of co-titling and inheriting land are small if they move to the husband's family or other areas (Ibid.).

Mechanisms for addressing differences in needs and priorities between investors and local communities and within the rural population are very difficult to develop. Different authors have acknowledged how the national and local governments have a very ambiguous role. On the one hand, they actively promote conditions for commercial expansions and for assigning land to investors, and on the other hand, they spearhead the defense of local interests. In this regard, both Vermeulen and Cotula (2010) and Bussotti (2020) conclude that government agencies invariably align with the investor rather than the local land users.

In this context, the claim that feedstock for biofuel crops can be commercially grown on marginal land should be taken with serious caution. Indeed, crops like jatropha, sugarcane, and soy can grow in poor soils and with no irrigation. However, in these conditions, productivity is low. So investors naturally will look for good soils to reach profitable yields. As a result, land allocations for biofuel production are likely to affect areas with high suitability for crops or forest areas.

7.4 ENVIRONMENTAL IMPACTS

Environmental impacts are scale-specific. Greenhouse gas (GHG) emissions are a global-level problem. Other impacts, such as environmental pollution and water consumption, loss of biodiversity, and land use changes, manifest at lower scales.

Land use changes and GHG emissions

One main argument for the promotion of biofuels is their potential reduction in greenhouse gas (GHG) emissions when fossil fuels are displaced. In this regard, the last line of the definition of Economic Acceleration Package Measure 10 mentions the potential mitigation effects of biofuels. A similar statement appears also in the regulation approved in September 2023. Although both the regulation and the text of Measure 10 do not clearly refer to a specific effect to mitigate, the authors understand that GHG emissions are to be mitigated. Potential GHG emissions reductions primarily depend on the type of land cover converted for biofuel production. If areas with high carbon stock, such as forests, are cleared for cultivating biofuel feedstocks, significant carbon liabilities may arise. This is the result of alterations in both the aboveground and below-ground biomass and soil organic carbon, which may potentially outweigh any greenhouse gas emission reductions achieved over the entire life cycle of biofuels. Fargione et al. (2008) refer to these land conversion emissions as "carbon debt". For instance, Fargione et al. (2008) calculate that the emissions per hectare caused by deforestation would require from 17 to 37 years to repay the carbon debt with soybean biodiesel if forest clearing occurs in the Cerrado biome.

A study conducted by Romeu-Dalmau et al. (2018) and assessing the land use changes caused by biofuels in five case studies in Malawi, Mozambique and Swaziland found that a jatropha plantation in Mozambique caused a significant carbon debt due to direct land conversion, while the sugarcane investments in Malawi and Swaziland gave rise to carbon stock gains. These positive gains were the results of growing sugarcane in areas covered by low-density forest agriculture (which are land uses that store less carbon than sugarcane).

In addition to direct land use change (i.e. clearing of land for the purpose of cultivating a certain crop), indirect land use change is a further risk. This happens when land displaced from a given location are reallocated to another location. Direct land use changes can easily be assessed through remote sensing or other techniques, while indirect land use changes are much more difficult to assess. Zaehringer et al. (2018) combined remote sensing techniques with farmers' interviews to confirm causal links between selected land use changes in the Nacala corridor and six large-scale agricultural investments to produce soybeans for the poultry industry, bananas and macadamia nuts for exports, and vegetables for local markets. Their results show that investments had partially been established on land previously farmed by smallholders. Also, in their analysis, a great part of the newly farmed land (90%) by displaced farmers was established at the expense of forests. The authors attribute this additional deforestation to the large-scale investments since displaced farmers were left with little other choice than to clear new land in forested areas. Similarly, von Maltitz et al. (2016) found that the abovementioned jatropha plantation in Sofala caused indirect land use changes in addition to direct woodland clearing. Indeed, displaced farmers cleared new farms in the surrounding woodland.

The government is committed to increasing agricultural productivity. The recently approved Plano Estratégico Para o Desenvolvimento Agrário (PEDSA) 2030 intends to double soybean and cotton yields by 2030. However, considering that agricultural area expansion has been the main factor driving an increase in crop production since the end of Mozambique's civil war (WB, 2020), the risk of an expansion of feedstock cultivation for biofuel production at the expense of areas with high carbon stock (i.e. forests) remains a serious possibility. This risk is particularly important in Mozambique since land use changes are the main source of GHG emissions. In this regard, as per data included in the Second National Communication to the United Nations Framework Convention on Climate Change, in 2016 land use and land use changes caused 61% of the country's GHG emissions.

Impact on water quantity and quality

Feedstock production can impact both the amount and quality of water available. Water consumption depends on factors such as plant physiology and the specific agricultural methods employed, such as whether irrigation or rainfed farming is used. Water quality is predominantly influenced by the release of harmful contaminants linked to feedstock production, processing, and biofuel manufacturing, including substances like fertilizers, pesticides, and industrial wastewater.

The main determinant of water consumption is the choice of agricultural practices (rain-fed versus irrigation) rather than the specific feedstock. This is because all potential feedstocks (sugarcane, cotton, soybean, jatropha) do not possess the capability to access deep water sources, nor do they harm soils as observed in tree species like Eucalyptus (Gasparatos et al., 2015).

The impact on water consumption of soybean and cotton cultivation is currently null since these two crops are rainfed in Mozambique. For sugarcane, a comparison of data reported on AQUASTAT with that on FAOSTAT shows that approximately half of the sugarcane harvested area was irrigated in 2020.

The extraction and transmission of water from rivers, underground sources, or artificially created reservoirs has the potential to influence the flow patterns of water bodies and underground water sources in more distant areas. Similar to any form of irrigated agriculture, the consequences on the availability of downstream water depend on several factors, including the production site's position within the watershed, the specific soil and topographical characteristics of the area, farming practices, and the prevailing local climate conditions (Hess et al., 2016). When the failed ProCana sugarcane/ethanol project was designed, van der Zaag et al. (2010) conducted simulation models for the Lower Limpopo River Basin and concluded that the Limpopo River did not carry sufficient water for all planned irrigation (73,000 hectares), which was largely driven by sugarcane development for the planned ethanol production.

Regarding water quality, to the best of the authors' knowledge, there are no studies quantifying the water pollution effects of soybean, cotton, or sugarcane in Mozambique. However, no fertilizers are currently used for cotton or soybean in Mozambique. Also, plant protection chemicals (PPC) are generally not used for soybean production, while cotton requires an important amount of PPC. However, given that cotton is not irrigated, the discharge of PPC residues into aquatic environments is probably very low. One source of risk is the management and cleaning of spraying equipment. In this regard, a study conducted by ILO (2016) on decent work in the cotton sector observed that equipment used for spraying cotton fields was regularly washed near river wells, which was probably a source of water pollution.

Water contamination risks are covered in scientific literature on sugarcane production in other countries. Evidence indicates that the use of agrochemicals in sugarcane farming in Brazil has had adverse effects on water quality, subsequently impacting ecosystem functionality (Martinelli and Filoso, 2008). Water monitoring studies conducted in Swaziland have identified elevated concentrations of total dissolved solids, sodium, and magnesium stemming from sugarcane plantations, surpassing Swaziland's guidelines for drinking water and South African standards for irrigation water (Mhlanga et al., 2006). In the Nzoia sugarcane belt of Kenya, the extensive historical and current use of pesticides and herbicides (e.g., DDT, aldrin, dieldrin, and endrin) has resulted in some cases of concentration levels exceeding the European Union's limits for drinking water, potentially posing risks to both humans and livestock if left untreated (Muendo et al., 2012).

The effects of sugarcane production on water quality are also closely tied to the operations of sugar mills and refineries. Vinasse is the wastewater generated by ethanol distilleries. In Brazil and in Malawi, vinasse finds widespread use as a natural fertilizer in sugarcane fields. However, in many other countries, additional processing is necessary to lower the organic pollutant levels (Ecoenergy, 2008).

The main byproduct of biodiesel production is glycerol. More precisely, about 10 kg of biodiesel production produces 1.1 kg of glycerol. In principle, glycerol could be an additional source of revenue from biodiesel production, since it is a three-valent alcohol extensively utilized in the pharmaceutical, food, cosmetic, and chemical sectors. However, with no market to sell it, increasing amounts of crude glycerol could also lead to serious waste disposal issues.

Impact on Biodiversity

Quantifying the potential effects of biofuels on biodiversity is very difficult. The Millennium Ecosystem Assessment (MA) has identified six main drivers of biodiversity losses. Biofuel expansion has been linked directly to four of these, namely land use change, invasiveness, pollution, and climate change (Gasparatos et al., 2011). Based on the above reported considerations and the fact that none of the targeted crops will be newly introduced in the country as a result of biofuel expansion, the main impact of biofuel expansion on biodiversity could come from land use changes.

Changes in land use can also exert indirect impacts on biodiversity. It is widely recognized that poor communities in Africa rely on the essential services provided by ecosystems, such as wild food, fuelwood or charcoal, timber, and non-timber forest products. When natural vegetation is transformed into feedstock production areas, it may concentrate resource harvesting in the remaining forested regions. If resource harvesting becomes restricted to progressively diminishing forested areas, it can result in the overexploitation of commercially valuable species. In this context, overexploitation (rather than habitat loss) is the primary mechanism leading to biodiversity depletion (Gasparatos et al., 2015).

Impacts on Health

Impacts on health mainly depend on agricultural practices. In Mozambique, traditional preharvest burning is the predominant method in sugarcane farming. Pre-harvest burning is a primary source of health issues. This practice has adverse effects on the respiratory system and lung function, and there have also been documented concerns related to urinary functions and chronic kidney-related symptoms in the literature on sugarcane production (El Chami et al., 2020).

The impact of sugarcane socio-economics on health was analyzed by Richardson (2010). His study found that labor migration in Zambia contributed to 16-22% of HIV/AIDS infections.

VIII. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

Measure 10 of the Economic Acceleration Package is not the first country's attempt to develop a biofuel industry. Indeed, from 2002 to 2008, the oil price has continually increased, and this stimulated the search for alternative liquid fuels. A first wave of biofuel investment took place in the 2007-2013 period, with important legal acts developed at that time. This also included an ambitious biofuel strategy and policy and relevant regulation. However, the biofuel sector never took off. The main reasons included excessive reliance on a crop (i.e., jatropha) with very limited scientific research to support production, the international financial crisis, a decrease in oil prices, a shift of the Mozambican government's attention from biofuels to the exploration of gas fields, and excessive red tape to authorize investments. Also, the civil society raised important concerns over the negative effects of biofuels. As a result, the government delayed approvals of investments to wait for the results of new studies, which further demotivated investors.

The newly endorsed regulation has established time-bound blending targets that must be achieved using domestic production of biofuels. Nevertheless, a policy gap persists since the 2009 National Biofuel Strategy was not updated. Moreover, discussions on sustainability criteria are blatantly missing from the policy debate. Also, the current regulatory framework creates significant uncertainty for biofuel producers regarding future biofuel prices. This may easily undermine investments.

Feedstocks that have the higher potential to be used immediately for ethanol are sugar molasses and juice, and for biodiesel are soybean and cottonseed oils. Other feedstocks might be considered if production potential is proved.

Regarding ethanol, the quantity of molasses currently produced can only yield 34% of the envisaged quantity for E10 in 2026. Including expansion plans from sugar mills and assuming that part of the Buzi district could resume sugarcane production the molasses production could satisfy only 44% of the 2026 ethanol demand for E10.

One possible solution is to expand sugarcane cultivation in order to produce more sugar and more molasses. Based on 10-15 years old data on land availability, it seems that land is available for further expansion of sugarcane. Important risks associated with sugarcane expansion are further marginalization of women (who face very strong barriers to engage in contract farming) and more migration of male workers to work in plantations (with women taking on more tasks traditionally assigned to men). Also, special attention should be paid to empower smallholder sugarcane farmers versus mills since sugarcane smallholders in Mozambique are price-takers and the monopsony structure of the sugar milling sector puts smallholders in a very weak position when negotiating with mills. Another technological solution is the use of sugarcane syrup to produce ethanol. This alternative does not necessarily require an expansion of sugarcane planted areas. However, it entails foregoing sugar production. Given the current high price of sugar, this second option does not seem to be viable for mills.

Concerning biodiesel production, the volume of vegetable oil achievable at the current extraction rate of existing mills, and using the current soybean and cottonseed production, would be adequate to cover only 4.6% of the country's oil demand which includes substituting imported soybean and cottonseed oils and generating the necessary biodiesel for B3 in 2026.

In order to meet the required quantity of biodiesel and to substitute imported soybean oil, the area needed to produce soybean and cotton should be expanded enormously. The quantity of land needed was estimated based on different assumptions. For best-case scenarios, where yields are doubled from the current level and mills invest to improve oil extraction efficiency, the additional area needed is approximately 1.1 million hectares. However, with no improvement in yields and oil extraction efficiency, the additional land area needed is 3.7 million hectares. Such a large expansion of cultivated area would most likely cause the displacement of existing crops and forest areas.

The implementation of B3 in 2024-2026 and B10 in 2033 (to recall the timeframe set in the recently approved regulation), with biodiesel obtained through domestically produced feedstocks, looks definitely overly ambitious, if not unattainable.

A country that successfully managed to replace 10% of diesel fuel with biodiesel (mainly produced using soybean oil) in a relatively short period of time is Brazil. However, Brazil took a considerably longer timeframe to achieve blending rates comparable to those stipulated by Mozambican regulations. [37] Brazil could achieve the biodiesel blending targets because it is a country where soybean production has always been very high. Indeed, when the biodiesel program was approved in 2005, soybean yields[38] were 2.2 Tons/ha, which is 3.6 times the current soybean yield in Mozambique. Brazil was the second-largest soybean oil exporter[39] and the second-largest soybean producer in the world. The soybean sector in Mozambique is still at an infant stage, and, most importantly, Mozambique is a net soybean oil importer.

Given the considerations reported above, the implementation of a blending mandate for ethanol seems more feasible than a blending mandate for biodiesel. But even for ethanol, E10 would probably require a longer time than the timeline currently envisaged in the regulation.

A feasible method for achieving the targeted biodiesel blends would involve importing biodiesel or vegetable oils. However, this alternative would not align with the objectives outlined in Measure 10 of the PAE, such as generating employment and reducing reliance on imported fuels. Instead, it would worsen the country's balance of payments deficit.

If achieving large-scale biodiesel and ethanol production in the near future is unattainable, an alternative approach involves adopting a niche strategy, which focuses on developing biofuel production and consumption at a local scale instead of a national one. This strategy includes producing biofuels to blend them with fuels for captive fleets and utilizing local biomass in isolated areas. Another niche approach involves capitalizing on the presence of specific conditions and companies providing complementary processes and products in certain areas (e.g. in Sofala[40]). Employing a strategic management approach would also facilitate the creation of necessary networks,

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[37] The Brazilin Biodiesel Program was launched in 2005 and a 3% blending ratio was enforced three years after (while in Mozambique the envisaged 3% blending rate is 11 months after the approval of the relevant regulation), the B7 became effective in 2014, which was 9 years after the launch of the program (while in Mozambique B7.5 is scheduled to be enforced only after five years and few months after the approval of the regulation) and B10 was achieved in March 2018, that is, 13 year after the approval of the regulation (while the planned period in Mozambique for B10 is 9 years)

[38] Source: FAOSTAT

[39] Source: COMTRADE

[40] In this area three are sugarcane mills that generate substantial amount of molasses, an idle ethanol distillery, and a good transport infrastructure (i.e. railways, paved roads, electricity).

among relevant stakeholders and promote learning processes.

Assessing the likely economic and food security impacts of investments that have not yet materialized presents significant challenges. Nevertheless, due to the heightened interest in biofuels between 2007 and 2013, various studies attempted to evaluate the food security and economic consequences of investments planned during that time. The use of their results should be taken cautiously since the baseline input data is different from what scholars have available for contemporary Mozambique. Moreover, studies modeling biodiesel investments were based on jatropha, which at that time was assumed to have much higher yields than those considered nowadays (soybean and cotton). The macro-economic models reviewed yielded positive economic results and an overall GDP growth with an increase in jobs generated. Overall, they did not suggest negative effects on food security. The exception to this general conclusion was the case of an expansion of sugarcane cultivation in areas previously occupied by food crops. In this case, according to these models, households experienced welfare losses and a reduction of household consumption. For biodiesel, given the higher extension of area needed, more displacement of food crops was estimated in models, with a stronger trade-off between food and biodiesel feedstock production where female labor is used intensively.

The studies conducted at the local level did not find a deterioration of food security conditions. They also found that farmers engaged in sugarcane feedstock production and in outgrowing arrangements experienced greater benefits than those involved in jatropha cultivation (either planted by plantations or by smallholders) or those working in plantations. Still, given that various factors affect food security and these depend on the specific sites and conditions, adopting a "one size fits all" approach is not recommended.

While part of the needed feedstock can be produced by smallholders, the typology of investments that took place in 2007-2013 also included large-scale investments. Certainly, large-scale investments have a significant advantage in that they provide the necessary capital for substantial greenfield projects. However, they also pose important social risks that should not be underestimated. Large-scale investments easily cause land dispossession for rural communities with all related social consequences: more skewed land distribution, more migration to urban centers (especially for the youth), disempowerment of women in areas where the matrilineal system predominates,[41] and a redistribution of gender roles as women take tasks traditionally assigned to men when men migrate.

When large-scale investments take place, it is crucial to ensure that affected communities receive appropriate compensation and that meaningful consultations are conducted. The Mozambican law makes adequate provisions for consultations and compensations. Nevertheless, consultations are characterized by a wide variety of practices (when they are conducted). Also, a lack of adequate compensation is a common concern.

Outgrowing schemes are widely practiced for sugarcane and cotton production. With the recent change in the regulation of seed oils, they might also be used for soybean cultivation in the near future. While common concerns reported in contract farming include a lack of transparency, overall outgrowing schemes cause fewer social disruptions than large-scale investments. However, outgrowing schemes tend to favor men's participation

[41] In these areas the land rights belong to the women's male relative, ensuring a better chance for co-titling or inheriting in the event of the death of the husband; however, chances of co-titling and inheriting land are small if women move to the husband's family or other areas due to land dispossession

over women's participation.

Import substitution is an important driver of biofuel development. Nonetheless, it is crucial to recognize that the expected blending ratios are likely to have a limited impact on reducing imports. When considering biodiesel, the proposed blending ratios are relatively modest (ranging from 3% to 10%), and achieving the upper end of this range appears to be impractical today. For ethanol, blending ratios are higher. However, gasoline represents only 22% of the current sale of oil products, and the energy content of ethanol is substantially lower than the energy density of gasoline. So, in energy terms, replacing 20% of gasoline (the highest blending ratio set in the regulation) is equivalent to just 3% of the oil needs of the transport sector.

The assessment presented in this work also includes an analysis of potential environmental impacts. Potential GHG emissions reductions primarily depend on the type of land cover converted for biofuel production. When areas with a high carbon stock, like forests, are cleared for cultivating biofuel feedstocks, there is a significant risk of incurring carbon liabilities. Indirect land use change poses additional risks. The assessment of land areas needed for biodiesel reported in this study shows that large expanses of land will be needed to achieve the biodiesel blending target. Direct and indirect land use changes may easily be provoked. Rather than a carbon credit, biofuels may cause significant carbon debt.

At the local level, none of the considered crops are expected to have a dramatic effect on water consumption. However, such a risk cannot be excluded for very large-scale sugarcane plantations. In this regard, it will be important to improve the water efficiency of sugarcane irrigation systems. Contamination of water resources is expected to be low for rainfed soybean and cotton production, but attention should be paid to ensure proper management and cleaning of spraying equipment for cotton. In other countries, a significant amount of water contaminant was found in sugarcane areas, and that risk should be taken into account also in Mozambique. Also, some impacts on human health will be unavoidable as long as pre-harvest burning is used.

While at this stage, predicting the location of future investments is highly speculative, a reconstruction of the location of investments (and project expressions of interest) from the 2006-2008 period suggests that the main interests of commercial projects will understandably be in areas with good infrastructure, which may exacerbate geographic differences. The Beira-Tete corridor looks particularly attractive for biodiesel projects.

8.2. RECOMMENDATIONS

1) The Biofuel Policy and Strategy should be updated.

It is important that country priorities are clarified through a dedicated policy design process. The biofuel policy and strategy need to be updated. The policy development process would enable the government to clarify certain priorities like import substitution of vegetable oil, the role of sustainability criteria, and the use of multiple feedstocks.

2) The government should review the implementation timeline for blending mandates, extending it over a longer period of time. The government should also consider canceling the introduction of blending mandates for biodiesel, or, at least, blending mandated for biodiesel should be phased in over a much longer period of time than the mandates for ethanol. For ethanol, an initial lower than 10% blending mandate could represent a more realist signal or companies willing to invest in pilot projects.

Biofuel mandates are powerful mechanisms for establishing biofuel markets, since they create a steady biofuel demand. However, the blending ratios and the timeframe for their implementation should be realistic and in line with the availability of raw material. In case the established blending mandates cannot be achieved, the government would be forced to postpone and relax the implementation of the mandates. This would signal to biofuel producers that the biofuel demand may not be eventually established. The implementation of the blending mandates in August 2024 is not realistic, neither for ethanol nor for biodiesel. The feasibility analysis provided in this assessment shows that while for ethanol, the country has a good amount of molasses (whose production still needs to be substantially increased to meet the E10 demand), the gap between the amount of feedstock available for biodiesel and the quantity needed for B3 is extremely wide. Also, a longer period of time would allow producers to increase production capacity, and the government to develop the needed supporting institutional capacities (see below).

3) An active promotion of strategic niches for biofuel production and use should be considered. This involves developing biofuel production and usage projects at a local scale, in areas where feedstock is abundant. Strategic niches also include the production of biofuels in isolated areas so biofuels can be blended and used in captive fleets in same areas.

Focusing on strategic niches would facilitate essential learning processes and the formation of networks among stakeholders with complementary interests. An example of such an approach is the promotion of ethanol production and use in Sofala. Here, three sugarcane produce substantial quantities of molasses, an established ethanol distillery currently sits unused, transport infrastructure is adequate and a previous sugarcane estate has vast tracts of unused land. Other niche opportunities lie in establishing oil extraction units and transesterification plants in remote areas to produce biodiesel for captive fleets.

4) **National capacities of relevant institutions to review project investment proposals should be strengthened. These include the Direcção Nacional das Terras, the Direcção Provincial das Terras in all provinces, the Agência Nacional para o Controlo da Qualidade Ambiental and Direcção Nacional de Hidrocarbonetos e Combustíveis**

During the 2007-2013 period, a very high number of project proposals were submitted by investors, thus overwhelming the capacity of relevant agencies to assess projects. The country needs to develop adequate human and technical capacities to assess project proposals, ensuring proper permitting processes and even adequate laboratory capacity.

The permitting process could even include contemplating more favorable conditions for projects sourcing feedstock from outgrowing arrangements since sourcing feedstock from smallholders would cause less social disruption than large scale investments.

5) **Community land rights need to be appropriately protected when considering large-scale investments. Special attentions should be paid to ensure that proper consultations and compensations take place**

Investments in large-scale commercial operations may easily give rise to land dispossessions. Community land rights need to be protected, ensuring that consultations are properly conducted, fair compensation is provided, investors are held accountable for promises made, and land is regained in case a project fails. All this requires dedicated government investments for monitoring large-scale investment design proposals and implementation.

6) **Specific Social and environmental Biofuels sustainability framework (including criteria and indicators) for biofuel projects should be developed/updated in coordination with the MTA to authorize projects. These should include food security and women empowerment criteria.**

This report has shed light on a broad range of environmental and social risks associated with large-scale biofuel development. The use of environmental and social criteria should be articulated in the biofuel policy implementation. These should include measures to enhance local food security and empower women. A good starting point for the development of a sustainability governance framework is the work already conducted until 2012. The most recent version included seven principles (legality, social responsibility, energy security, economic and financial viability, food security, agricultural and industrial productivity, and environmental protection), 15 criteria and 24 indicators. In any case, the credibility of the sustainability framework will come from the involvement of multiple actors during different stages of the framework development to ensure the relevance and legitimacy of the framework.

7) **The government should consider reactivating the inter-ministerial biofuels commission and creating a biofuels task force involving the public and private sector, academia and civil society organizations to develop the needed sustainability framework (see recommendation 5)**

To facilitate the establishment of a competitive and sustainable biofuels sector and to develop a sustainability governance framework, an inter-ministerial biofuels commission was initially established but it was later abolished when the biofuel sector lost interest. Now that the government intends to promote biofuels production again, the role of an inter-ministerial commission becomes increasingly important. The work of the inter-ministerial commission should be complemented by a task force that includes academia, the private sector, and civil society to ensure that all legitimate concerns are taken into account.

8) **The development of an updated agro-ecological zoning should be seriously considered for the evaluation of investment proposal**

Agro-ecological zoning is needed to ensure that the investment proposals are in line with the available land and potential. It would also facilitate the project authorization process. Eventually, it would make it possible for more precise estimations of achievable blending targets with respect to the available land.

9) Crops with proven potential (agricultural yield, energy yield), and possibly multiple uses should be promoted, but the choice of feedstocks for biofuel production should not be restricted to certain crops. In any case, the government should not promote the use of crops with unproved potential. Also the use of staple food crops as a feedstock for biofuel production should be avoided.

While most ethanol-producing countries typically rely on a single primary crop for ethanol production, biodiesel often utilizes a mixture of different feedstocks. This study specifically focused on soybean and cottonseed oil because they show significant promise for an immediate use for large-scale biofuel production. Nonetheless, other potential feedstocks, such as animal fat, could be considered, as long as they are not staple food crops and have been proven viable in Mozambique. Past failures with jatropha serve as a valuable lesson, highlighting the risks associated with investing in wild and unimproved crop varieties.

The exploration of alternative crops should only occur after their potential has been rigorously verified, a process that demands significant research and development efforts. Using staple food crops like cassava or maize for biofuel production could lead to a substantial increase in food prices, making it imperative to avoid such practices.

10) Agricultural production for biofuel development should be promoted through land-use intensification and the production of second-generation biofuels rather than through land-use expansion.

Traditionally, agricultural production increase in Mozambique has relied on land-use expansion. However, this approach brings significant environmental and social risks, including deforestation and the displacement of rural households. A fundamental shift is necessary if agriculture is to contribute to fuel production. Key strategies for land-use intensification involve implementing crop rotations (that alternate food crops with agrofuel crops) and establishing agro-forestry modules. Additionally, utilizing lignocellulosic biomass for biofuel production (e.g., using sugarcane bagasse) can reduce the amount of land required to meet a certain quantity of biofuel demand. Therefore, promoting technological transfer for second generation biofuel is crucial.

11) Improvements in water use efficiency should be promoted in sugarcane planted areas

Expansions in the sugarcane planted area and desired improvements in sugarcane yield areas will require additional irrigation water. Improvements in water use efficiency will reduce water consumption.

12) The Mozambican industrialization policy should further promote the establishment of processing units for vegetable oil seed extraction to add value to the oil seed sub-sector.

Groundnut, sunflower seeds and sesame seeds are commonly exported as grains. With the establishment of the biofuels industry in the country, there is an opportunity to add value to the oil seed sub-sector by extracting vegetable oils. Additionally, investments in oil seed processing units are synergic with those needed for the development of a biodiesel sector.

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X. ANNEXES

ANNEX I: ASSUMPTIONS FOR LAND AREA AND PRODUCTION CALCULATIONS

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estimations_3.xlsx