Rethinking agricultural mechanisation for the agroecological transition: Benin's national strategy measured against an ideal type.

Abstract:

Background: Agricultural mechanisation is expected to raise labour productivity in West Africa, yet it may also deepen soil degradation and social inequalities if it is not aligned with the agroecological transition. This study examines the extent to which Benin's policy and institutional framework is consistent with a form of mechanisation compatible with that transition

Methods: An ideal type of an agroecology-compatible mechanisation policy was built from the ten elements of agroecology and the thirteen agroecological principles, and translated into seven operational dimensions. The 2022-2026 national mechanisation strategy and its programme were then described as a policy mix and scored against each dimension, first on the basis of sixteen policy and legal texts and then on the basis of semi-structured interviews with public, private and farmer actors involved in implementation.

Results: The strategy scores six points out of fourteen on paper: it is well equipped for the shared use of equipment, which receives nearly a third of the programme budget, but provides no eligibility criterion, budget line or indicator for input reduction, soil conservation or diversified cropping systems. Implementing actors perceive an even wider gap, describing a model centred on individual ownership of imported tractors, designed without practitioners and communicated from the top down. Three lock-in mechanisms explain this gap: the institutional lineage of the national operator, an import-based supply chain, and distribution-based monitoring indicators.

Conclusion: Aligning mechanisation with the transition requires environmental eligibility criteria, indicators of actual use and territorial consultation bodies.

Key words:-policy mix; policy coherence; institutional lock-in; street-level implementation; mechanisation services; West Africa

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1 Introduction

Agricultural public policies play a central role in steering the development pathways of farming systems, particularly in countries where agriculture is a pillar of the economy and of food security [1]. By structuring intervention frameworks, setting strategic priorities and mobilising financial and human resources, they exert a profound influence on technological progress, innovation and relations between actors within agricultural systems [2], [3], [4]. In this context, agricultural mechanisation is often presented as a lever for modernisation, capable of improving labour productivity, reducing the drudgery of farm work and strengthening the competitiveness of farms [5]. Long neglected in developing countries, it is increasingly regarded as a means of improving the efficiency of agricultural systems [6]. It contributes to the development of food supply chains through improved farming practices [7], alleviates labour shortages and speeds up field operations [8], [9].

The development of mechanisation, however, comes up against a context in which agroecology is gaining ground in policy discourse, owing to concerns about environmental degradation, climate change and the misuse of agricultural land [10]. In Benin, Dugué [11] stresses that the agroecological transition calls for new forms of collective action, and Dorvlo et al. [12] regard a transition towards sustainable mechanisation practices as essential. The challenge is not to replicate the intensive models of industrialised countries but to adopt equipment suited to local agroecological conditions [13]. This ambition has found expression in the rise of the notion of sustainable agricultural mechanisation, understood as an integrated approach that seeks to reconcile economic efficiency, social inclusion and respect for the environment [12], and that makes it possible to replace repetitive and arduous tasks with higher value-added activities at a time when rural labour is becoming scarce [14]. Public policies have gradually incorporated these objectives through institutional reforms and the adoption of international and national strategic frameworks [15], [16], so that in most developing countries mechanisation is now driven by frameworks that pursue productivity and environmental sustainability objectives simultaneously [16].

Nevertheless, many studies point to the poor record of state mechanisation programmes in past decades [8]. These programmes failed because of governance problems such as rent-seeking, difficulties in obtaining spare parts and a shortage of qualified operators and technicians [17], [18]. Mrema et al. [19] and Pingali [20] further note that they were not based on

a rigorous analysis of actual mechanisation needs, which resulted in poorly targeted and short-lived policies. Several studies also show that mechanisation policies suffer from institutional fragmentation, weak coordination between public and private actors and a mismatch between the instruments deployed (subsidies, tax incentives or import programmes) and the needs of small family farms [21], [7], [22]. Added to this are low levels of public investment, a lack of coherence between sectoral strategies and weak appropriation of policy guidelines by implementing actors [15]. According to Amponsah et al. [23], only an endogenous approach, based on the development of local capacities and the adaptation of technologies to their contexts, can guarantee sustainable mechanisation.

This situation raises the question of coherence between mechanisation policies with productivist objectives and the environmental sustainability requirements that the agroecological transition increasingly imposes [23], [10]. The difficulty, for researchers and decision-makers alike, lies in the absence of a tool for assessing whether the concrete instruments of a mechanisation policy are compatible with these requirements or whether, behind a discourse of sustainability, they perpetuate an unquestioned conventional model. This difficulty gives rise to the following research question: to what extent is the existing policy and institutional framework consistent with the development of agricultural mechanisation compatible with the agroecological transition?

The public policy literature encourages sustainability issues to be treated as interdependent [24], which points to the analysis of policy coherence, operationalised through the concept of the policy mix. According to Rogge and Reichardt [25], this concept refers to a policy made up of a strategy carrying objectives and a set of interacting instruments, whose consistency, coherence, credibility and comprehensiveness can be assessed. Such an analysis makes it possible to move beyond a declarative reading of policy texts to assess how they are translated into practice, and to guard against policies that appear to align with environmental objectives while producing the opposite effects through a poorly articulated combination of instruments [25]. A review of the European Common Agricultural Policy has thus shown that its instruments explicitly devoted to climate and the environment could have delivered far greater benefits had their architecture been more coherent [26]. Ignoring the coherence of mechanisation policies therefore entails the risk of committing substantial public resources without any guarantee of alignment with the agroecological transition objectives that the State promotes elsewhere.

The literature has three limitations in this respect. First, the policy mix framework has mainly been used to analyse energy and climate policies in OECD countries, without being applied to agricultural mechanisation or tested against an agroecological normative framework such as the FAO's ten elements [27] or the HLPE's thirteen principles [28]. Second, analyses of agricultural policy coherence most often rely on a reading of documents alone, without comparing it with the appropriation of instruments by implementing actors, a dimension that is nonetheless decisive in contexts of low administrative capacity [29]. Third, the actual alignment between mechanisation policy instruments and local agroecological transition dynamics remains poorly documented in West Africa.

In view of these shortcomings, this study aims, first, to measure the gap between Benin's mechanisation policy and a policy genuinely compatible with the agroecological transition, using an ideal type built from international agroecological frameworks [27], [28], and, second, to explain this gap in the light of institutional lock-in mechanisms [30] and of the appropriation of instruments by actors. Theoretically, it proposes a combined application of the Weberian ideal-type method and the policy mix framework to a West African agricultural policy. Empirically, it provides a documented diagnosis of this alignment at a time when public investment in mechanisation is reaching a significant scale. Operationally, it offers decision-makers evidence for readjusting the design of future support instruments. Section 2 presents the analytical framework and the methodology, Section 3 the results, which Section 4 discusses before the conclusion.

2 Materials and methods

2.1 Analytical framework

The analytical framework of the study operates at two levels. The first is that of the normative ideal type of a mechanisation policy compatible with the agroecological transition, built from international agroecology frameworks, which serves as the benchmark for measuring the coherence of the existing policy. The second brings together the factors that help to explain the observed gap between this ideal type and reality: the composition of the policy mix, institutional lock-in and the appropriation of instruments by implementing actors.

2.1.1 The ideal type of an agroecology-compatible mechanisation policy

The ideal type, as theorised by Weber [31], does not describe reality: it is an analytical construct used in three steps, namely the selection of an object that is relevant in terms of values, the construction of an idealised synthesis, and concrete imputation, which consists in confronting this construct with empirical cases [32]. It is this third step that structures the empirical approach of the study: the mechanisation policy is analysed not in absolute terms but in terms of the distance that separates it from the constructed ideal type. The approach is enjoying renewed use in comparative public policy analysis. It has been used to quantify qualitative data in the comparative analysis of social protection regimes [32], a logic that can be

transposed to the comparison of agricultural policies; its heuristic function in comparative political economy has been reaffirmed, provided that its analytical rather than descriptive character is acknowledged [33]; and the conditions for its rigorous use in a qualitative case study have also been specified [34].

The ideal type adopted here transposes two consolidated normative frameworks into design criteria for a public policy. The FAO's ten elements of agroecology [27] are a tool intended to help countries operationalise agroecology; they cover diversity, co-creation and sharing of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy. These elements have been consolidated into thirteen principles, which include recycling, input reduction, soil health, biodiversity, synergy, economic diversification, co-creation of knowledge, fairness, connectivity, land and natural resource governance, and participation [28], [10]. Applied to mechanisation, the translation of these two frameworks into seven operational dimensions provides the normative grid of the study (Table 1).

Table 1: Grid of the seven dimensions of the ideal type of an agroecology-compatible mechanisation policy

Dimension	Source principles	Operational criterion applied to mechanisation policy	Summary indicator
D1. Input reduction and recycling	Recycling; input reduction [28]	Instruments support equipment that limits dependence on synthetic inputs (direct seeding, biomass management) rather than equipment calibrated for intensification	Dedicated budget lines or eligibility criteria; types of equipment promoted
D2. Diversity and economic diversification	Diversity; economic diversification [27], [28]	The mix covers a range of equipment scales (manual, animal traction, small-scale motorisation) and is not centred on a single technological model	Budget allocation across equipment categories; types of equipment promoted
D3. Knowledge co-creation	Co-creation and sharing of knowledge [27], [28]	Research and advisory mechanisms formally involve local manufacturers and farmers in equipment design	Existence of formal consultation or co-design mechanisms
D4. Equity and participation	Fairness; participation [28]	Eligibility criteria do not structurally exclude smallholders, women and young people	Differentiated measures; effective access rate by category
D5. Responsible governance of resources	Land and natural resource governance; soil health [27], [28]	Instruments explicitly link mechanisation with soil and water conservation	Environmental conditionalities attached to support
D6. Connectivity and circular economy	Connectivity; circular and solidarity economy [27], [28]	Instruments support the shared use of equipment (cooperatives, service providers)	Dedicated mechanism for shared mechanisation services
D7. Resilience and synergies	Resilience; synergies [27], [28]	Equipment and advisory services are designed for diversified systems (intercropping, rotations) rather than for monoculture alone	Explicit reference to complementarity between supported equipment and diversified practices

Source: grid constructed by the authors from [27] and [28].

2.1.2 The policy mix as the second term of the comparison

The second term of the comparison is established through the policy mix framework, which breaks a policy down into a strategy carrying objectives and plans and a set of interacting instruments, assessed in terms of the consistency of its elements, the coherence of its processes, its credibility and its comprehensiveness [25]. Widely used in the analysis of energy and climate transitions, this framework makes it possible to document, instrument by instrument, how the mechanisation policy is positioned with respect to each of the seven dimensions of the ideal type.

2.1.3 Two explanatory bodies of literature: institutional lock-in and appropriation

Two complementary bodies of literature are drawn upon to explain the measured gap. The first is the literature on path dependency and lock-in [30]. Instruments inherited from an earlier trajectory generate institutionalised interests, such as an import channel for motorised equipment, historical funding from partners or administrative habits, which make any reorientation costly, even when it is formally announced in policy texts [30]. This phenomenon has been documented in Europe, where the OECD observes that the Common Agricultural Policy struggles to overcome its path dependency and that its successive reforms have produced only incremental progress [35]. The second body of literature concerns the appropriation of instruments by the actors responsible for implementing them. The coherence of a policy is not settled at the design stage alone: it is reshaped during implementation through the discretion exercised by street-level agents, which is particularly decisive in institutional contexts of low administrative capacity [29]. The gap measured in the texts may therefore differ markedly from the gap perceived by actors, since the credibility of an instrument is socially constructed between stated intentions and actual practices.

The resulting analytical model combines three components (Figure 1). The seven-dimension ideal type serves as the reference; the description of the policy mix actually in place constitutes the second term of the comparison and yields a gap that can be measured dimension by dimension; and institutional lock-in and appropriation by actors are used to explain this gap, complementing a descriptive reading with a dynamic and institutional reading of its causes.

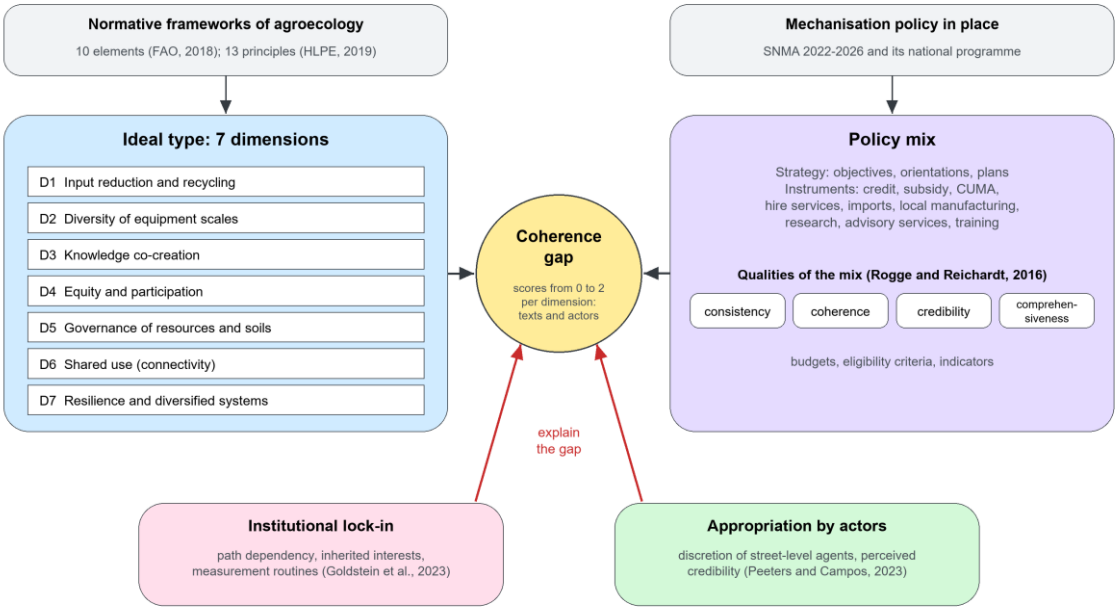

Fig. 1. Analytical framework of the study.
Source: research data, 2026

2.2 Overall approach and documentary corpus

The study adopts a qualitative case study approach based on comparison with an ideal type. This choice reflects the nature of the object: the aim is to characterise the coherence between a normative framework and a complex institutional object, namely the instruments in place, and then to explain the underlying mechanisms on the basis of the meaning that actors attribute to them. The approach combines two sources of data. The first is documentary and consisted in identifying the relevant policy and legal texts (Table 2), together with the scientific literature on agricultural policy analysis.

Table 2: Policy documents and legal texts consulted

Year	Title
2022	Law No. 2022-14 of 9 July 2022 on agricultural orientation and food and nutrition security in the Republic of Benin [36]
2017	Law No. 2013-01 on the Land and State Property Code, amended in 2017
2007	Decree No. 2007-090 of 28 February 2007 on the establishment, powers, composition and functioning of the National Council for Agricultural Mechanisation
2016	Decree No. 2016-65 of 10 March 2016 approving the statutes of the Agricultural Mechanisation Development Agency (ADMA-SA)
2019	Decree No. 2019-123 of 10 April 2019 approving the statutes of the National Agricultural Mechanisation Agency
2005	National Agricultural Mechanisation Strategy (SNMA 2006-2015)
2021	National Agricultural Mechanisation Strategy (SNMA) of Benin 2022-2026 [37]
2017	Strategic Plan for Agricultural Sector Development (PSDSA) 2025 and National Agricultural Investment and Food and Nutrition Security Plan (PNIASAN) 2017-2021 [38]
2017	Second-generation National Agricultural Investment and Food and Nutrition Security Plan
2011	Strategic Plan for the Revitalisation of the Agricultural Sector (PSRSA)
2010	Agricultural Investment Plan 2010-2015
2017	Agricultural Sector Programming Framework
2021	Government Action Programme 2021-2026
2022	National Strategy for the Development of Ecological and Organic Agriculture in Benin (SNDAEB-Bénin) [39]
2017	Land Degradation Neutrality: policy brief on targets and measures
2025	National Policy for the Promotion and Development of Small and Medium-sized Enterprises (PNPDPME) 2025-2034

Source: documentary research, 2026

2.3 Study area and selected case

Benin is a West African country where farm mechanisation remains limited: according to the 2019 National Agricultural

Census, 12.41 per cent of farms engaged in crop production mechanise their tillage, animal traction included, with wide disparities between the cotton-growing north and the rest of the country [40]. To make its agricultural sector more competitive, the country has adopted a National Agricultural Mechanisation Strategy (SNMA) [37]. At the same time, in response to declining soil fertility, policy ambitions show growing interest in the agroecological transition, as evidenced by the adoption of a National Strategy for the Development of Ecological and Organic Agriculture (SNDAEB) [39]. The Beninese context thus offers a relevant setting for understanding how mechanisation policy and the imperatives of the transition fit together, beyond the tensions between these two notions highlighted in the literature. The policy case selected is the SNMA 2022-2026 and its National Agricultural Mechanisation Development Programme, whose instruments are deployed in an environment marked by agroecological transition initiatives led by the State and its partners.

2.4 Data collection methods and tools

Two types of data were collected. Documentary data were extracted from the corpus using a reading grid structured around the seven dimensions in Table 1; they cover the history of mechanisation policies, the instruments deployed by the strategy, their budgets and indicators, and their fit with the dimensions of the ideal type. Additional data were then gathered through semi-structured interviews, conducted with an interview guide, with the actors involved in implementation: officials from the Ministry of Agriculture, Livestock and Fisheries (MAEP), the departmental directorates (DDAEP), the Territorial Agencies for Agricultural Development (ATDA) and the municipal units; officials from the National Agricultural Mechanisation Company (SoNaMA); advisory and training organisations; financial services; and beneficiaries, whether farmers, mechanisation service providers or local manufacturers. Sampling was purposive and guided by the principle of information saturation [41]. The interviews covered actors' knowledge of the strategy's guidelines, their appropriation of them, the inconsistencies perceived in implementation and general perceptions of the policy. They were supplemented by testimonies collected during the workshops of the innovation platform of Agricultural Development Pole 2 (PDA 2), in particular the February 2025 workshop. The recorded interviews were transcribed, then reread and corrected before analysis. The interview excerpts quoted in this article were translated from French by the authors.

2.5 Data analysis methods

The data were analysed through content analysis. Each dimension in Table 1 was coded deductively on a three-level scale, applied separately to the documentary data and to the interview data in accordance with the principles of thematic analysis [41]. For the texts, a score of 0 indicates that the dimension is absent, a score of 1 that it is mentioned without any instrument, budget, criterion or indicator to make it operational, and a score of 2 that it is supported by an identifiable instrument accompanied by a budget or an indicator. For the interviews, a score of 0 indicates that actors describe the absence of the dimension or a contrary practice, a score of 1 partial consideration, and a score of 2 consideration that they regard as effective. The gap relative to the ideal type corresponds to the difference between the maximum score of 2 and the score obtained. The content analysis of the interviews was also used to identify institutional lock-in mechanisms and forms of discretionary appropriation of the instruments.

3 Results

3.1 Historical trajectory of mechanisation in agricultural policies

Beninese public action on mechanisation starts from an agriculture dominated by human energy: across sub-Saharan Africa, Side and Havard [42] estimate that 65 per cent of the energy used in agricultural production comes from humans, 25 per cent from animals and 10 per cent from engines. For Benin, the SNMA indicates that 76 per cent of tillage is done manually, 23 per cent with animal traction and only 1 per cent with motorised equipment, attributing these figures at times to the 2011 agricultural strategic plan and at others to the 2006 mechanisation policy document [37]. Animal traction expanded in the 1980s thanks to COBEMAG and the Boko animal traction centre, while motorisation remained marginal. The late 1990s were marked by the omission of mechanisation from policies and the termination of research and training programmes; farmer initiatives then took over, foremost among them the cooperatives for the shared use of agricultural equipment (CUMA), launched in 1997 in Ina, which make it possible to pool the economic risk of investment [43].

Between 2005 and 2015, public intervention returned through the supply side. The first SNMA (2006-2015), drawn up with FAO support, was barely implemented, for lack of steering tools and of a monitoring and evaluation system. The Agricultural Mechanisation Promotion Programme (PPMA) organised the import of more than one thousand tractors and implements and then gave rise to the Agricultural Mechanisation Development Agency (ADMA), which was liquidated in 2017 [37]. The record of the decade combines low adoption, underuse of equipment, recurrent breakdowns, the absence of after-sales service, the politicisation of interventions and competition from the State that private importers regarded as unfair, with quantitative progress: the SNMA reports that the rate of motorisation of activities rose from 2 to 20 per cent and that the number of CUMA increased by more than 500 per cent over the period [37].

Since 2016, the State has refocused implementation on a national operator, the National Agricultural Mechanisation Agency (ANaMA), established in 2019 and converted into the National Agricultural Mechanisation Company (SoNaMA S.A.) in 2021. The SNMA 2022-2026 sets out a 2030 vision of mechanisation that is 'sufficient, sustainable, adapted to the socio-economic context of actors and to environmental (or agroecological) conditions' [37]. This trajectory reveals a shift towards operational sustainability, built on the structuring of services, credit and maintenance, whose agroecological dimension has yet to be established. This is the subject of the following sections.

3.2 Characterisation of the policy mix of the SNMA 2022-2026

The SNMA is implemented through a single programme, the National Agricultural Mechanisation Development Programme, whose overall objective is 'to develop environmentally friendly agricultural mechanisation' [37]. The programme is organised into two orientations, five axes and fourteen actions, at an estimated cost of 22.085 billion CFA francs (Table 3). The first orientation, which concerns access to equipment 'for the benefit of the different categories of farmers, including women and young people', accounts for 58.8 per cent of the budget; the second, which concerns equipment use practices and human capital, accounts for 41.2 per cent.

Table 3: Policy mix of the National Agricultural Mechanisation Development Programme

Axis	Actions (instruments)	Cost (FCFA billion)	Share (%)	Dimensions concerned
1.1. Farmer investment	Adapted credit system (1.1.1); 'smart' subsidy system (1.1.2)	0.310	1.4	D1, D4
1.2. Service access models	Strengthening of the CUMA network (1.2.1); organisation of hire service providers (1.2.2)	6.905	31.3	D6, D4
1.3. Private supply sector	Promotion of imports and digitalisation (1.3.1); promotion of local manufacturing (1.3.2); network of maintenance technicians (1.3.3); revaluation of idle assets (1.3.4)	5.780	26.2	D3, D2
2.1. Techniques adapted to the local context	Research and development in crop and post-harvest (2.1.1), livestock (2.1.2) and fisheries (2.1.3) production; advisory programme on equipment use (2.1.4)	6.500	29.4	D3, D1
2.2. Training	Training programmes (2.2.1); strengthening of training institutions (2.2.2)	2.590	11.7	D3
Total	14 actions	22.085	100	

Source: compiled from the action sheets and budget annex of the SNMA [37].

Three features stand out in this mix. First, the two financial instruments that determine the type of equipment acquired, credit and subsidies, account for only 1.4 per cent of the costed budget, because their main envelope is referred to the National Agricultural Development Fund (FNDA) and is not budgeted in the strategy. The subsidy is presented as a means of steering investment towards activities 'with no negative social or environmental effects', and the strategy cites equipment for conservation agriculture as an example of what should be prioritised, yet its indicators are limited to the 'percentage of farmers who have received a subsidy' and the 'rate of consumption of the allocated budget' [37]. Second, shared use is the largest item in the programme, with nearly a third of the budget allocated to CUMA and hire service providers. Finally, supply relies on a dual arrangement of imports and local manufacturing, the former backed by technical specifications and a planned certification centre, the latter by capacity building for artisans and access to credit; in both cases, a shortlist of suppliers is to be selected to access the programme's incentives [37].

3.3 Measuring the gap between the ideal type and the SNMA

Scoring the seven dimensions reveals a substantial gap between the ideal type and the strategy (Table 4; Figure 2). At the documentary level, the SNMA scores 6 points out of 14. Only one dimension, the shared use of equipment (D6), is fully backed by instruments; four are mentioned without an operational instrument (D1, D3, D4, D5); and two are absent (D2, D7).

Table 4: Scores for the seven dimensions in the texts and in the interviews (0 to 2)

Dimension	Score (texts)	Evidence from the texts	Score (actors)	Evidence from the interviews
D1. Input reduction	1	Subsidy directed towards equipment 'contributing to environmental protection', with conservation agriculture as an example; no budget line, eligibility criterion or indicator	0	Kits centred on ploughing; seed drill mentioned as an unmet need; no mention of support for direct seeding equipment
D2. Diversity of scales	0	Programme targeted at 'modern agricultural equipment'; animal	1	Power tillers offered alongside tractors; 'mechanisation is not

Dimension	Score (texts)	Evidence from the texts	Score (actors)	Evidence from the interviews
		traction and hand tools mentioned in the diagnosis but absent from the actions		just the tractor', a territorial official points out; animal traction maintained by default
D3. Co-creation	1	Manufacturers, artisans and farmers listed among the bodies involved in research and development; indicators limited to the number of prototypes and publications	0	'Intellectualised' strategy, drawn up without practitioners; manufacturers and CUMA consulted on an ad hoc basis
D4. Equity and participation	1	Orientation 1 open to women and young people; 'particular interest' in cooperatives, women and young people in the credit criteria; indicators not disaggregated	0	Farmer representatives chosen from among those with large landholdings or who speak French; logic of individual satisfaction
D5. Resources and soils	1	Vision 'adapted to environmental conditions'; no environmental conditionality attached to credit or subsidies	0	No conditionality known to actors; erosion and deforestation cited among the effects of mechanisation
D6. Shared use	2	Actions 1.2.1 and 1.2.2: FCFA 6.905 billion, indicators on the creation of cooperatives and service enterprises	1	Services tracked by geolocation, local clusters; but a model perceived as geared towards individual ownership
D7. Diversified systems	0	No mention of intercropping or rotations; research organised by agroecological zone and by value chain	0	Equipment row spacings unsuited to crop diversity; specialisation by value chain rather than by system
Total	6 / 14		2 / 14	

Source: content analysis of the SNMA 2022-2026 [37] and of the interviews, 2026.

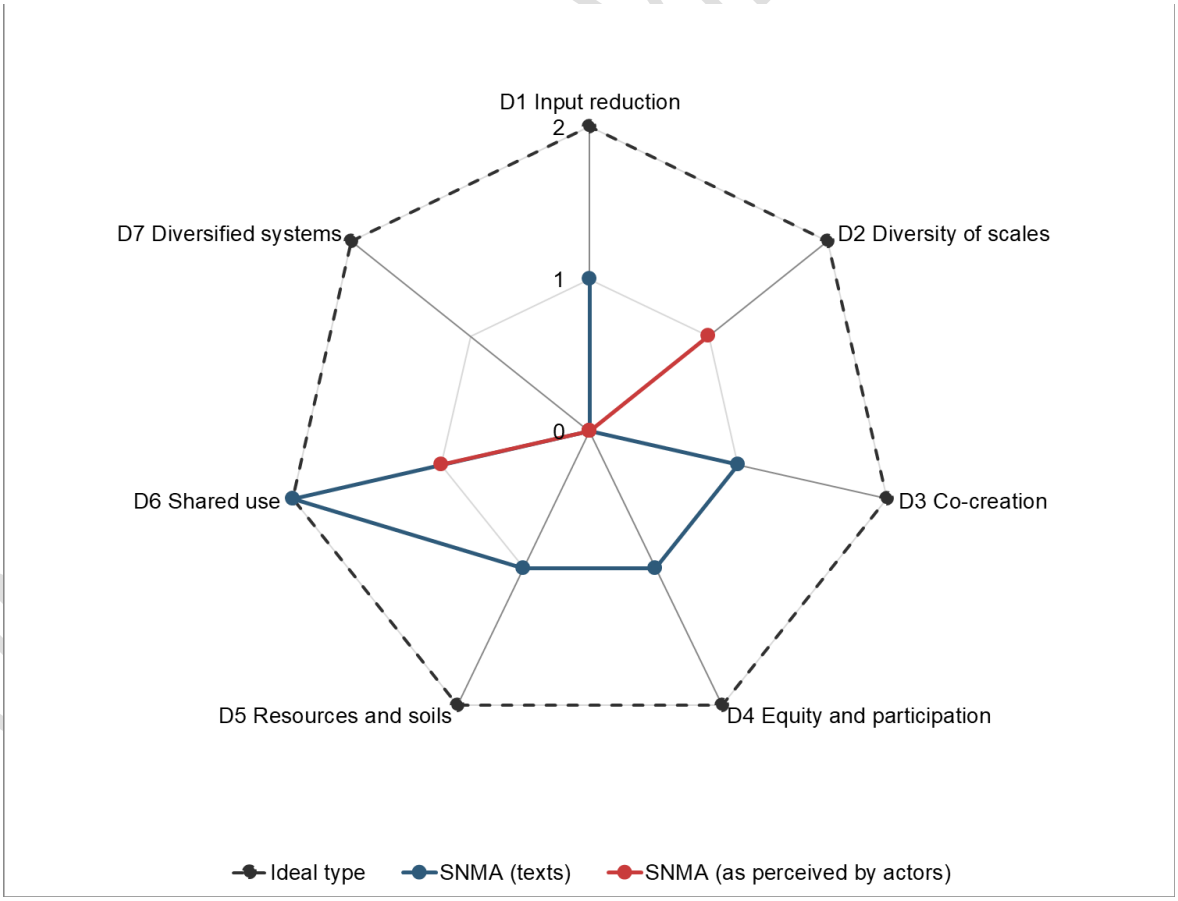

Fig. 2. Gap between the ideal type, the SNMA as written and the SNMA as perceived by actors.

Source: research data, 2026

Read through the four qualities identified by Rogge and Reichardt [25], this profile sheds light on the composition of the mix. Consistency is weak, because the overall objective of 'environmentally friendly' mechanisation is not carried through by any instrument that would make it a condition of access. Coherence with other policies is one-sided: the SNDAEB, adopted in November 2022, declares itself consistent with the mechanisation component of the PSDSA and provides for the development of production technologies including mechanisation, but the SNMA, finalised in August 2021, could not refer to it, and no mechanism is foreseen to link the two strategies [39], [37]. Credibility is undermined by the strategy itself, which lists among its risks the 'weak appropriation of the Policy by stakeholders', the 'spontaneous change of strategic option by the authorities' and the 'heavy dependence of the system on external funding' [37]. Comprehensiveness, finally, is real as regards access and human capital, but the mix covers neither environmental conditionality, nor fuel supply, nor the monitoring of the actual use of equipment.

3.4 Credibility as perceived by implementing actors

3.4.1 Organisational framework of mechanisation actors

The SNMA organises implementation around SoNaMA, which resulted from the conversion of ANaMA in 2021 (Figure 3). This public limited company combines responsibilities for coordinating, monitoring and implementing national policy with commercial and industrial tasks of assembly, distribution and maintenance, which places it in the position of both delegated regulator and market operator. The Directorate of Rural Engineering (DGR) retains responsibility for design and for monitoring and evaluation, the ATDA are in charge of transferring know-how, the FNDA manages subsidies and credit in partnership with financial institutions, and research and training fall to the National Institute of Agricultural Research of Benin (INRAB) and to university and technical institutions. Lastly, the strategy recognises CUMA as the reference structure for the collective use of equipment and calls on the private sector (importers, distributors, manufacturers and service providers) to build a viable market [37].

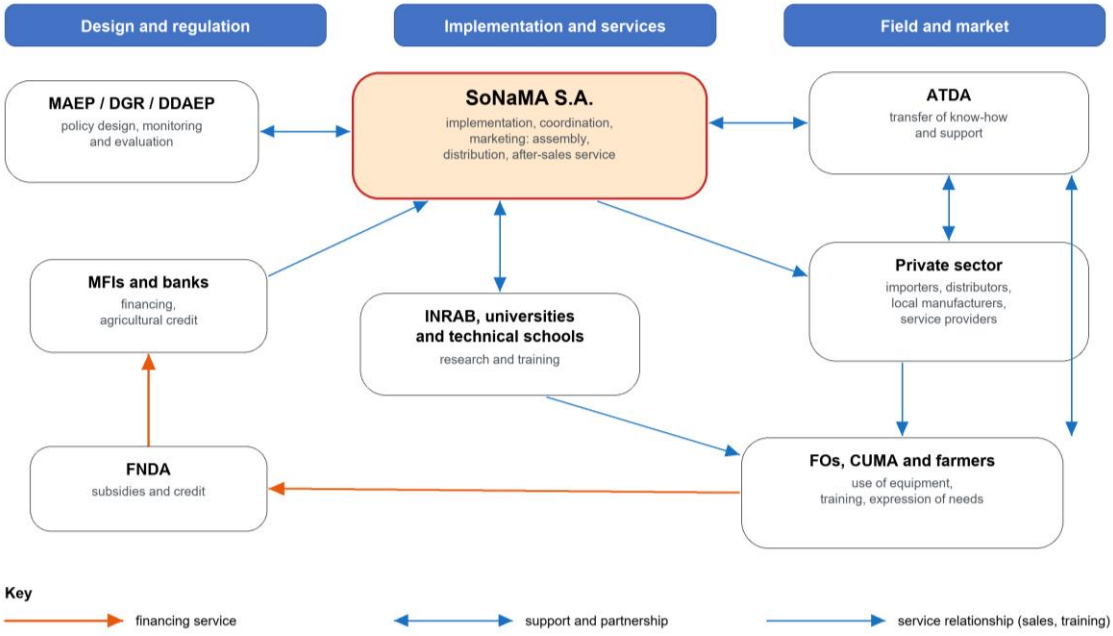

Fig. 3. Overview of the actors in the organisational framework of agricultural mechanisation in Benin.
Source: research data, 2026

The strategy itself notes that competition from the State is an obstacle to the emergence of an autonomous private supply [37]. On the ground, collaboration between SoNaMA and other actors appears limited and transactional. A local manufacturer and a CUMA facilitator describe it in identical terms:

> *'We have no formal partnership with SoNaMA; we are only called upon when they need us. Once the job is done, the relationship ends, keeping us in a vicious circle of discontinuity.'*
>
> Excerpt from an interview with O. W., Kandi, 26 April 2025

3.4.2 Comparison with credibility as perceived by field actors

Comparing documentary and perceived scores shows that the gap widens from design to implementation, from 8 to 12 points out of 14. Four findings account for this.

The first concerns the dimension best provided for on paper, shared use. Although nearly a third of the programme budget is devoted to it, an official from a public body describes an implementation geared towards the individual satisfaction of farmers:

> *'Today, we are in a logic of trying to satisfy farmers individually. […] It is difficult to sell a tractor to an individual and think that this is how mechanisation is being developed.'*

The official contrasts this model with the equipping of farmer groups, which would have made it possible to reach the objectives more quickly, and anticipates its cost, the risk being, in the official's words, that of

> *'sending it all for scrap'.*

Shared services do exist, but they stem from local initiatives, such as farmer clusters run by an advisory NGO, where service providers charge members a reduced rate, rather than from the instruments of the strategy.

The second finding concerns co-creation. The same official describes the strategy as 'intellectualised':

> *'We did not want to listen to those who are not graduates […] but who acquired their knowledge through practice',*

citing the repair artisan in Kérou as

> *'the best placed to tell you how the equipment should be sized'.*

Testimonies gathered at the innovation platform workshop in February 2025 illustrate the consequences of this lack of dialogue. One farmer reports that in the village 'nobody uses the mouldboard plough' because it breaks on roots, and the representative of the mechanics' network immediately generalises:

> *'I know several farmers who contacted me after buying their tractor to help them find a disc plough to replace the mouldboard plough they were sold at SoNaMA.'*

The third finding relates to equity and participation. The consultation frameworks organised by the operator bring together farmers whose selection, according to the ATDA, favours those farming large areas, those who have faced many difficulties and those who speak French. The criterion of 'particular interest' in women and young people set out in the strategy does not appear in any of the interviews. As a point of reference, the 2019 census indicates that 7.34 per cent of the farms that mechanise their tillage in the Alibori Sud-Borgou Nord-2KP pole are headed by women [40].

The fourth finding concerns appropriation itself. The territorial level learns of policy orientations after they have been adopted: 'Perhaps it is because I am not at the level of the decision-makers. It is when the information comes here that we find out about it.' Actors also acknowledge changes of direction introduced by the national operator, such as the introduction of soil preparation equipment other than tractors and ploughs, staggered payments backed by the FNDA and the specialisation of supply by value chain, which explains the partial scores assigned to dimensions D2 and D6. These changes are, however, attributed to the operator rather than to the strategy, which shows that the credibility of the policy is built through the action of a single actor more than through its instruments.

3.5 Institutional lock-in mechanisms identified

Three lock-in mechanisms explain the persistence of the gap (Table 5).

Table 5: Institutional lock-in mechanisms in mechanisation policy

Mechanism	Manifestation in the SNMA	Manifestation in implementation	Dimensions affected
Lineage of the national operator	PPMA, ADMA, ANaMA, SoNaMA chain; revaluation of the assets inherited from the former PPMA/ADMA-SA; combination of regulatory and commercial functions	Operator perceived as unavoidable, organiser of consultations and main source of information	D3, D4, D6
Import-based supply chain	Import promotion action and shortlist of approved suppliers; local manufacturing mainly oriented towards post-harvest equipment	'You go and see your Indian friend, your Chinese friend, your Japanese friend, and you import the equipment'; standardised kit composition	D1, D2, D7

Mechanism	Manifestation in the SNMA	Manifestation in implementation	Dimensions affected
Distribution indicators	Indicators expressed as percentage of beneficiaries, budget consumption rate, 50 per cent increase in demand for equipment	Monitoring of tractors delivered and hectares worked; no monitoring of unused implements or of effects on soils	D1, D5, D7

Source: content analysis of the SNMA [37] and of the interviews.

The first mechanism is the lineage of the national operator. SoNaMA inherits an institutional chain running from the PPMA to ADMA and then to ANaMA, and the strategy entrusts it with revaluing the stock of equipment inherited from these structures, which, the strategy recalls, left some 3.5 billion CFA francs in unpaid debts for the equipment supplied between 2008 and 2011 alone [37]. This legacy weighs on the design of instruments: the operator must both settle the past and develop a commercial offer, which encourages it to favour the equipment it already knows.

The second mechanism is a supply chain built on imports. The strategy provides for the selection of a shortlist of importers eligible for incentives [37], and actors describe a decision-making process in which equipment is chosen on the basis of relations with supplier countries rather than of soils and crops. The same territorial official calls for a break with this logic: 'We must now say no, we are developing our own model in the light of our realities, in the light of our soils, in the light of our crops.'

The third mechanism relates to indicators. Those adopted by the strategy measure access, budget consumption and increased demand, and the most advanced monitoring system, the geolocation of SoNaMA tractors, provides information on the hectares worked. No indicator covers equipment that has been acquired but remains unused, or the effects of mechanised cropping practices on soils. A policy evaluated against these indicators cannot detect the gap relative to the ideal type, since that gap shows up precisely in what is not measured.

4 Discussion

4.1 A gap relative to the ideal type concentrated on environmental dimensions

The scoring reveals a clear asymmetry: the SNMA has instruments for the economic and organisational dimensions of agroecology, in particular shared use, but remains declaratory or silent on its environmental and agronomic dimensions, namely input reduction, soil conservation and diversified systems. This profile is consistent with the finding of Daum [8], for whom mechanisation contributes to sustainability only if coherent policies steer it towards compatible practices, and with that of Baudron et al. [21], who link appropriate mechanisation to conservation agriculture and private sector involvement. It also extends the observation made by Guyomard et al. [26] on the Common Agricultural Policy: stated environmental objectives have an effect only if the architecture of instruments makes them binding. In the Beninese case, conservation agriculture is cited only as an example in the strategy's approach to implementing the subsidy, without any criterion that would make it enforceable. The ideal type thus makes it possible to pinpoint the deficit: it stems not from a lack of intention but from the failure to translate that intention into instruments.

4.2 Implementation as the stage at which the gap widens

The widening of the gap between texts and perceptions, from 8 to 12 points, confirms the value of systematically comparing documentary analysis with appropriation by actors. Peeters and Campos [29] show that, in contexts of low administrative capacity, street-level agents reshape policies according to the resources available to them. The case studied provides an illustration: the territorial level, which did not take part in drawing up the strategy and learns of its orientations after the fact, defers to the national operator, whose action becomes the concrete form of the policy. This de facto delegation explains why positive changes are attributed to SoNaMA rather than to the SNMA, and why the strategy's written commitments on equity remain unknown to actors. It echoes the analyses of Daum and Birner [17] on the governance challenges of mechanisation in Ghana, where the concentration of functions within public actors facilitated the capture of programmes.

4.3 Lock-in as an explanation for the persistence of the model

The three mechanisms identified correspond to the forms of path dependency described by Goldstein et al. [30]: inherited infrastructure and organisations, economic interests built around a supply channel, and measurement routines that render alternatives invisible. Their combination explains why a strategy that explicitly breaks with past failures nevertheless reproduces the core of its model, that of imported motorised equipment acquired individually. This finding qualifies the opposition often drawn between distribution policies and systemic policies [5], [22]. The SNMA includes genuine systemic components, namely shared use, training and research, but their scope is limited by financial instruments and indicators that remain those of distribution. The lesson echoes that drawn by the OECD from the Common Agricultural Policy: without action on lock-in mechanisms, reforms produce only incremental progress [35].

4.4 Methodological contribution

The combined application of the ideal type and the policy mix framework offers two advantages for the analysis of agricultural policies. First, it makes the notion of coherence measurable, dimension by dimension, without claiming a degree of quantification that qualitative data do not allow, in keeping with the heuristic use of the ideal type advocated by Swedberg [34] and by Mulé and Walzenbach [33]. Second, it distinguishes the design gap, visible in the texts, from the implementation gap, visible in practices, which makes it possible to address differentiated recommendations to designers and to operators. The seven-dimension grid can be applied to other mechanisation policies in the subregion, provided that its scoring rules are specified and each score is documented with a verifiable excerpt, as in Table 4.

4.5 Limitations of the study

Several limitations circumscribe the scope of these results. The perceived scoring rests on a small number of in-depth interviews whose transcription required corrections, and it will need to be consolidated by coding the full interview corpus. Budget amounts are those of programming and not of execution, on which the documents consulted provide no information. The subsidy and credit envelope, referred to the FNDA, could not be examined, although it largely determines the type of equipment acquired. The position of the authors, one of whom serves as secretary of the PDA 2 innovation platform, facilitated access to actors but is not neutral with respect to the object of study, which is why each score was systematically documented with excerpts from texts and interviews.

5 Conclusion

This study sought to determine the extent to which Benin's policy and institutional framework is consistent with mechanisation compatible with the agroecological transition. Measured against a seven-dimension ideal type, the SNMA 2022-2026 scores 6 points out of 14 in its texts and 2 points out of 14 in the perception of the actors responsible for its implementation. It has instruments for the shared use of equipment but none that make input reduction, soil conservation or adaptation to diversified systems operational. The gap widens during implementation, where actors describe a model centred on individual ownership of imported tractors, designed without practitioners and communicated from the top down. The lineage of the national operator, an import-based supply chain and distribution indicators explain the persistence of this model.

Three implications follow for public action. The first is to attach environmental and agronomic eligibility criteria to credit and subsidy instruments, for example by reserving part of the FNDA envelope for direct seeding, biomass management and reduced tillage equipment. The second is to replace or supplement distribution indicators with indicators of actual use, of access disaggregated by category of farmer and of effects on soils. The third is to formally involve artisans, mechanics, CUMA and farmers in defining the content of equipment kits, through territorial consultation bodies with a recognised mandate. Two avenues for further research emerge: extending the scoring to all the interviews and to the budget execution of the strategy, and applying the grid to other national mechanisation policies in West Africa in order to establish whether the profile observed in Benin is a particular case or a regional configuration.

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REFERENCES

[1] M. Adugna, A. Gela, K. Jembere and E. Negesse, "Willingness-to-Pay for 4-Wheel Drive Tractor Hiring Services by Smallholder Farmers in the Central Highlands of Amhara Region, Ethiopia," Advances in Agriculture, vol. 2025, art. 5022645, 2025. https://doi.org/10.1155/aia/5022645

[2] C. Edquist, Systems of innovation: perspectives and challenges, In: J. Fagerberg, D. C. Mowery and R. R. Nelson (Eds.), The Oxford Handbook of Innovation, Oxford: Oxford University Press, pp. 181-208, 2005. https://doi.org/10.1093/oxfordhb/9780199286805.003.0007

[3] A. Hall, V. Rasheed Sulaiman, N. Clark and B. Yoganand, "From measuring impact to learning institutional lessons: an innovation systems perspective on improving the management of international agricultural research," Agricultural Systems, vol. 78, no. 2, pp. 213–241, 2003. https://doi.org/10.1016/S0308-521X(03)00127-6

[4] D. C. North, Institutions, Institutional Change and Economic Performance, Cambridge: Cambridge University Press, 1990.

[5] T. Daum and R. Birner, "Agricultural mechanization in Africa: Myths, realities and an emerging research agenda," Global Food Security, vol. 26, art. 100393, 2020. https://doi.org/10.1016/j.gfs.2020.100393

[6] K. Houmy, M. Flores Rojas and C. Side, Agri-location en Afrique subsaharienne : modèles économiques pour investir dans la mécanisation durable [Agricultural hire services in sub-Saharan Africa: business models for investing in sustainable mechanisation], Rome: FAO, 2021. [Online] Available: https://www.fao.org/3/cb5071fr/cb5071fr.pdf
[7] B. Sims and J. Kienzle, "Sustainable Agricultural Mechanization for Smallholders: What Is It and How Can We Implement It?," Agriculture, vol. 7, no. 6, art. 50, 2017. https://doi.org/10.3390/agriculture7060050
[8] T. Daum, "Mechanization and sustainable agri-food system transformation in the Global South. A review," Agronomy for Sustainable Development, vol. 43, no. 1, art. 16, 2023. https://doi.org/10.1007/s13593-023-00868-x
[9] Z. Li, M. Zhu, H. Huang, Y. Yi and J. Fu, "Influencing Factors and Path Analysis of Sustainable Agricultural Mechanization: Econometric Evidence from Hubei, China," Sustainability, vol. 14, no. 8, art. 4518, 2022. https://doi.org/10.3390/su14084518
[10] A. Wezel, B. G. Herren, R. B. Kerr, E. Barrios, A. L. R. Gonçalves and F. Sinclair, "Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review," Agronomy for Sustainable Development, vol. 40, no. 6, art. 40, 2020. https://doi.org/10.1007/s13593-020-00646-z
[11] P. Dugué, Rapport de la mission d'expertise du CIRAD « Transition agroécologique et changement d'échelle », 19 au 27 mars 2018, Bénin [Report of the CIRAD expert mission 'Agroecological transition and scaling up', 19-27 March 2018, Benin], Technical report, CIRAD, 2018.
[12] S. Y. Dorvlo, G. Baffoe, E. K. K. Jew, E. Mkandawire and A. J. Dougill, "Improving stakeholder collaboration for sustainable agricultural mechanisation in rice production: a case study from Asutsuare, Ghana," Discover Applied Sciences, vol. 7, no. 9, art. 970, 2025. https://doi.org/10.1007/s42452-025-07542-9
[13] M. Gibigaye, "Politique de mécanisation et production agricole dans la commune de Glazoué au centre du Bénin [Mechanisation policy and agricultural production in the commune of Glazoué, central Benin]," Revue de Géographie Tropicale et d'Environnement (GEOTROPE), no. 2, pp. 56–64, 2013.
[14] S. Y. Dorvlo, E. Mkandawire, K. Roelich and C. B. Jumbe, "Pathways and Interactions for Integrating Mechanisation into Sustainable Agricultural Production: The Case of Rice Production in Asutsuare, Ghana," Sustainability, vol. 15, no. 22, art. 15888, 2023. https://doi.org/10.3390/su152215888
[15] L. M. Bastidas-Orrego, N. Jaramillo, J. A. Castillo-Grisales and Y. F. Ceballos, "A systematic review of the evaluation of agricultural policies: Using PRISMA," Heliyon, vol. 9, no. 10, art. e20292, 2023. https://doi.org/10.1016/j.heliyon.2023.e20292
[16] FAO and AUC, Sustainable Agricultural Mechanization: A Framework for Africa, Addis Ababa: FAO and African Union Commission, 2018.
[17] T. Daum and R. Birner, "The neglected governance challenges of agricultural mechanisation in Africa: insights from Ghana," Food Security, vol. 9, no. 5, pp. 959–979, 2017. https://doi.org/10.1007/s12571-017-0716-9
[18] J. K. M. Kuwornu, E. K. Apiors and G. T.-M. Kwadzo, "Access and Intensity of Mechanization: Empirical Evidence of Rice Farmers in Southern Ghana," Brazilian Archives of Biology and Technology, vol. 60, art. e17160396, 2017. https://doi.org/10.1590/1678-4324-2017160396
[19] G. C. Mrema, D. Baker and D. Kahan, Agricultural mechanization in sub-Saharan Africa: time for a new look, Agricultural Management, Marketing and Finance Occasional Paper 22, Rome: FAO, 2008.
[20] P. Pingali, Agricultural mechanization: adoption patterns and economic impact, In: R. Evenson and P. Pingali (Eds.), Handbook of Agricultural Economics, vol. 3, Amsterdam: Elsevier, pp. 2779-2805, 2007. https://doi.org/10.1016/S1574-0072(06)03054-4
[21] F. Baudron, B. Sims, S. Justice, D. G. Kahan, R. Rose, S. Mkomwa et al., "Re-examining appropriate mechanization in Eastern and Southern Africa: two-wheel tractors, conservation agriculture, and private sector involvement," Food Security, vol. 7, no. 4, pp. 889–904, 2015. https://doi.org/10.1007/s12571-015-0476-3
[22] X. Diao, H. Takeshima and X. Zhang (Eds.), An evolving paradigm of agricultural mechanization development: How much can Africa learn from Asia?, Washington, DC: International Food Policy Research Institute, 2020. https://doi.org/10.2499/9780896293809
[23] S. K. Amponsah, F. Kumi, G. Akolgo and D. D. Azumah, "A Review of Transforming Rice Harvesting in Sub-Saharan Africa: Addressing Constraints, Leveraging Mechanization, and Enhancing Productivity," Advances in Agriculture, vol. 2025, art. 5523207, 2025. https://doi.org/10.1155/aia/5523207
[24] N. Di Santo, T. Del Giudice and R. Sisto, "Policy mixes in rural areas: a scoping literature review," Rivista di Economia Agraria / Italian Review of Agricultural Economics, vol. 79, no. 3, pp. 83–99, 2024. https://doi.org/10.36253/rea-15149
[25] K. S. Rogge and K. Reichardt, "Policy mixes for sustainability transitions: An extended concept and framework for analysis," Research Policy, vol. 45, no. 8, pp. 1620–1635, 2016. https://doi.org/10.1016/j.respol.2016.04.004
[26] H. Guyomard, C. Détang-Dessendre, P. Dupraz, L. Delaby, C. Huyghe, J.-L. Peyraud et al., "How the Green Architecture of the 2023–2027 Common Agricultural Policy could have been greener," Ambio, vol. 52, no. 8, pp. 1327–1338, 2023. https://doi.org/10.1007/s13280-023-01861-0
[27] FAO, The 10 Elements of Agroecology: Guiding the Transition to Sustainable Food and Agricultural Systems, Rome: FAO, 2018. [Online] Available: https://www.fao.org/3/i9037en/i9037en.pdf

[28] HLPE, Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition, Report 14 of the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome, 2019.
[29] R. Peeters and S. A. Campos, "Street-level bureaucracy in weak state institutions: a systematic review of the literature," International Review of Administrative Sciences, vol. 89, no. 4, pp. 977–995, 2023. https://doi.org/10.1177/00208523221103196
[30] J. E. Goldstein, B. Neimark, B. Garvey and J. Phelps, "Unlocking "lock-in" and path dependency: A review across disciplines and socio-environmental contexts," World Development, vol. 161, art. 106116, 2023. https://doi.org/10.1016/j.worlddev.2022.106116
[31] M. Weber, The Methodology of the Social Sciences, E. A. Shils and H. A. Finch (Eds. and trans.), Glencoe, IL: Free Press, 1949.
[32] Y. Sun, "Recontextualizing Max Weber's Ideal Type: Lessons from Idealization in the Philosophy of Natural Science and Economics," Innovation in the Social Sciences, vol. 2, no. 2, pp. 194–234, 2024. https://doi.org/10.1163/27730611-bja10021
[33] R. Mulé and G. Walzenbach, "The Weberian ideal type in political economy: obsolete match or fruitful encounter?," New Political Economy, vol. 29, no. 6, pp. 914–926, 2024. https://doi.org/10.1080/13563467.2024.2356536
[34] R. Swedberg, "How to use Max Weber's ideal type in sociological analysis," Journal of Classical Sociology, vol. 18, no. 3, pp. 181–196, 2018. https://doi.org/10.1177/1468795X17743643
[35] OECD, Policies for the Future of Farming and Food in the European Union, OECD Agriculture and Food Policy Reviews, Paris: OECD Publishing, 2023. https://doi.org/10.1787/32810cf6-en
[36] République du Bénin, Loi n° 2022-14 du 09 juillet 2022 portant orientation agricole, sécurité alimentaire et nutritionnelle en République du Bénin [Law No. 2022-14 of 9 July 2022 on agricultural orientation and food and nutrition security in the Republic of Benin], Cotonou: Secrétariat général du Gouvernement, 2022. [Online] Available: https://sgg.gouv.bj/doc/loi-2022-14/
[37] MAEP and FAO, Stratégie nationale de mécanisation agricole (SNMA) au Bénin 2022-2026 [National Agricultural Mechanisation Strategy (SNMA) of Benin 2022-2026], final version, Technical Cooperation Programme TCP/BEN/3707/C2, Cotonou: Ministry of Agriculture, Livestock and Fisheries, August 2021. [Online] Available: https://faolex.fao.org/docs/pdf/ben210366.pdf
[38] MAEP, Plan stratégique de développement du secteur agricole (PSDSA) 2025 et Plan national d'investissements agricoles et de sécurité alimentaire et nutritionnelle (PNIASAN) 2017-2021 [Strategic Plan for Agricultural Sector Development (PSDSA) 2025 and National Agricultural Investment and Food and Nutrition Security Plan (PNIASAN) 2017-2021], final version, Cotonou: Ministry of Agriculture, Livestock and Fisheries, November 2017. [Online] Available: https://ecowap.ecowas.int/media/ecowap/naip/files/BENIN_SIM6akD.pdf
[39] MAEP, Stratégie nationale de développement de l'agriculture écologique et biologique au Bénin (SNDAEB-Bénin) [National Strategy for the Development of Ecological and Organic Agriculture in Benin], Cotonou: Ministry of Agriculture, Livestock and Fisheries, November 2022. [Online] Available: https://eoai-africa.org/wp-content/uploads/2023/11/Strateigie-Agriculture-_Ecologique-Biologique_VF.pdf
[40] Direction de la Statistique Agricole (DSA-Bénin), Recensement National de l'Agriculture 2019, volume 2 : principaux résultats du module de base [2019 National Agricultural Census, volume 2: main results of the core module], Cotonou: Ministry of Agriculture, Livestock and Fisheries, October 2021. [Online] Available: https://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/WCA_2020/WCA_2020_new_doc/WCA_2020_doc2/BEN_REP_FRE_2019_2020.pdf
[41] M. Naeem, W. Ozuem, K. Howell and S. Ranfagni, "Demystification and Actualisation of Data Saturation in Qualitative Research Through Thematic Analysis," International Journal of Qualitative Methods, vol. 23, art. 16094069241229777, 2024. https://doi.org/10.1177/16094069241229777
[42] C. S. Side and M. Havard, Mécanisation en Afrique de l'Ouest et du Centre. Bilan des tentatives passées, état actuel et contraintes [Mechanisation in West and Central Africa: review of past attempts, current situation and constraints], In: 6th Géocoton Seminar « Le coton africain : évolution des principaux facteurs de production en zone cotonnière » [African cotton: changes in the main production factors in the cotton zone], Paris, France, 29 September-3 October 2014, 23 pp., 2014. [Online] Available: http://agritrop.cirad.fr/574346/
[43] M. Balse, C. Ferrier, P. Girard, M. Havard, D. Herbel and F. Larue, Une expérience originale de mécanisation partagée en Afrique. Les Coopératives d'utilisation de matériel agricole au Bénin [An original experience of shared mechanisation in Africa: cooperatives for the shared use of agricultural equipment in Benin], Collection Champs d'acteurs no. 3, Rome: FAO, 2015. [Online] Available: https://agritrop.cirad.fr/575878/
[44]