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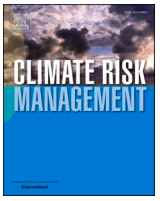

Assessing leverage points for strengthening adaptive capacity in a Global South food system: A psychometric approach

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ABSTRACT

Despite the burgeoning literature on adaptive capacity, there is a lack of psychometric approaches for assessing the determinants of adaptive capacity, particularly in food systems in the Global South. The study addressed this knowledge gap by investigating four determinants, previously identified as leverage points, for strengthening adaptive capacity: access to finance, access to and use of information and knowledge, social learning, and gender equality. Drawing on a survey (n = 1,271) of food system actors in Kisumu County, Kenya, we conducted a confirmatory factor analysis, which yielded factors of moderate-high internal validity and reliability. We then used structural equation modelling to examine the causal effect of food system actors' attitudes and beliefs towards the four leverage points with regards to their perceived adaptive capacity. Two factors, access to finance and social learning, were significant positive predictors of adaptive capacity. A third leverage point factor, gender equality, contributed to the respondents' perceived adaptive capacity through the mediating factor of assets. The results reveal entry points for strategic adaptation planning and raise complexities related to gender norms and values. We discuss the implications of these findings for adaptive capacity and transformative adaptation theory in food systems in the Global South.

1. Introduction

Climate change presents one of the greatest challenges for our planet and its inhabitants (Ripple et al., 2019). Despite progress in the climate policy arena, adaptation to a hotter and drier future with more extreme and erratic weather events is inevitable (Kikstra et al., 2022). Climate change has a particularly devastating impact on food systems in the Global South, where food insecurity is already high (Ericksen et al., 2011; Ziervogel and Ericksen, 2010). Climate change contributes to declining crop yields (Jägermeyr et al., 2021), especially in rainfed subsistence farming systems (Serdeczny et al., 2017).

Adaptive capacity, '*the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences*' (IPCC, 2022), plays a pivotal role in guiding climate change adaptation. Adaptive capacity

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supports adaptation in, for example, people having the knowledge and skills to adapt, people being able to diversify their livelihood in order to adapt, and/or individuals being empowered enough to take adaptation related decisions (Tahiru et al., 2019). Adaptation research has focused on identifying adaptive capacity stocks and deficits linked to natural, physical, financial, human, and social capital, such as financial investment, governance, and climate stressors like drought (Marshall et al., 2010; Mortreux and Barnett, 2017). Social adaptation research has also focused on the preconditions for individuals, communities, organisations, and jurisdictional areas to be able to mobilise adaptive capacity, highlighting the importance of social organisation and agency (Elrick-Barr et al., 2022; Mortreux and Barnett, 2017). A study of residents' adaptive capacity in urban water systems in the United States found that social aspects such as public acceptance, learning opportunities, collaboration, and building trust played an important role in building adaptive capacity (Dilling et al., 2023). A study of the social determinants of the adaptive response of people in Papua New Guinea found that better adaptation outcomes could be achieved by combining investment in financial assets with social organisation, learning, and agency-building activities (Barnes et al., 2020).

A clear understanding of entry points with the potential to strengthen adaptive capacity would make strategic adaptation planning easier, more effective, and adequate. This would benefit stakeholders at all levels, including financial institutions funding adaptation interventions, governments, NGOs, and the people and communities on the ground. Various review studies on adaptive capacity and adaptation have found that the majority of the studies have a geographical focus on countries in the Global North and more studies are needed in the Global South (Mortreux and Barnett, 2017; Nalau and Verrall, 2021; Siders, 2019). The need to find effective ways to strengthen adaptive capacity is of particular importance in Sub-Saharan Africa, the world's most underdeveloped and vulnerable region (UNDP, 2022). Sub-Saharan Africa has the highest percentage of population undernourishment of any region in the world and rapid urbanisation is projected to increase expenditures 2.5-fold by 2050 (FAO, 2023). Food systems are complex and finding solutions has proven challenging (Béné et al., 2016).

The leverage points perspective provides an approach to identify places in complex systems where '*a small shift may lead to a fundamental change in the system as a whole*' (Abson et al., 2017). The leverage point perspective deals with complexity by framing reflection and planning around several system levels, facilitating the identification of points of intervention to create desired change (Fischer and Riechers, 2019). The perspective can serve as a heuristic tool to guide where to intervene in a system, creating efficiency in the planning process (Linnér and Wibeck, 2021). It encompasses justice considerations by addressing social structures and norms, and the values and mental models that underpin a system (Leventon et al., 2021; Riechers et al., 2021). An increased focus on justice considerations has also been singled out as a priority for future adaptive capacity research (Owen, 2020).

Previous scientific works have identified and studied leverage points for strengthening adaptive capacity to climate change in a case study in the Northern Region of Ghana (Rosengren et al., 2020; Rosengren et al., 2023). But whether these leverage points are relevant also in other areas in the Global South remains unstudied. Systemic leverage points have mostly been studied with qualitative methods. Few studies quantitively assess the relationship between the leverage points and the desired outcome. The benefit of a quantitative estimation would provide insight into how easy or difficult it can be to act on a given leverage point. A quantitative estimation would also provide nuanced insights into differences between population sub-groups.

This study examines the causal effects of people's attitudes and beliefs towards the leverage points for strengthening adaptive capacity previously identified in Ghana. For this study we purposely selected Kisumu County in Kenya due its characteristics being different to those of Ghana's Northern Region. Kisumu County is semi-humid (Omondi Omollo, 2016), densely populated, and predominantly Christian and an important agricultural area in Kenya (Apraku et al., 2021). The Northern Region of Ghana is, on the other hand, a semi-arid ecosystem (Mohammed et al., 2021), more scarcely populated and predominantly Muslim (Alhassan, 2013). The study focuses on food system actors because of the vulnerability of food systems to climate change (Fraser, 2006) and the need to find efficient approaches to strengthen the adaptive capacity of food system actors. Different food system actor groups are affected and need to adapt in different ways to climate change. We studied four food system actors groups as depicted by Zurek et al. (2022): producers, processors, distributors, and consumers. Producers in the predominantly rain fed small-scale farming systems in Sub-Saharan Africa in particular are affected by climate change through droughts and irregular precipitation patterns (Alemaw and Simalenga, 2015). Processors, distributors, and consumers are affected through market disruptions and increased food prices (De Winne and Peersman, 2021).

We studied the actors' attitudes and beliefs towards the previously identified leverage points and map the actors' perceived level of adaptive capacity. Self-reported data on how people perceived their adaptive capacity is considered as an appropriate method to measure adaptive capacity and to predict what can lead to actual adaptation (Adger et al., 2013; Grothmann and Patt, 2005; Lam, 2015). Attitudes and beliefs influence intended and actual behaviour (Ajzen and Fishbein, 1977; Glasman and Albarracín, 2006), in this case measures to strengthen actors' adaptive capacity. By understanding actors' attitudes and beliefs towards the previously identified leverage points, it is possible to estimate how much investing and acting on the leverage points would potentially strengthen the actors perceived adaptive capacity. This finding can inform strategic climate change adaptation policy and intervention design as it provides tangible elements for building adaptive capacity. The following objectives guided the research:

1. To empirically identify valid and reliable factors of leverage points and adaptive capacity, drawing on survey results from a sample of food system actors in Kisumu County, Kenya.
2. To estimate the causal effects of respondents' attitudes and beliefs towards the leverage point factors on perceived adaptive capacity factors.

1.1. Conceptual background

This study investigates four previously identified leverage points for strengthening adaptive capacity to climate change. This study aligns its conceptual framework with the two previous studies originally developing the leverage points (Rosengren et al., 2020; Rosengren et al., 2023). Two main concepts form the conceptual background: adaptive capacity and leverage points.

1.1.1. Adaptive capacity

Cinner et al. (2018) present five domains, that are key when building adaptive capacity: assets, flexibility, social organisation, learning, and agency. These five domains are used to form factors in the CFA analysis and are briefly defined below.

Assets in this context refers to household income (Lemos et al., 2013), access to credit, crop insurance (Panda et al., 2013), land tenure (Antwi-Agyei et al., 2015), tools, and vehicles (Cinner et al., 2018). **Flexibility** refers to the ability to switch livelihood strategy (Cinner et al., 2018), which again depends on access to networks and **learning** opportunities (Bullock et al., 2022), including both formal training and informal. **Social organisation** refers to the ability to network and self-organise (Cinner et al., 2018; Mutebi et al., 2020), which depends on the level of **agency.** Here, agency refers to the level of empowerment, ability, and freedom of individuals and communities to pursue their goals (Amartya, 1985; Hanmer and Klugman, 2016).

1.1.2. Leverage points

Access to finance refers to access to banks, microcredits (Caretta, 2014), savings groups, or borrowing money from a neighbour, friend, or relative (Marsden et al., 2020). Several studies have indicated the importance of access to finance in building adaptive capacity regarding assets, flexibility, and agency (Azad and Pritchard, 2022). A study of the determinants of farmers' adaptation to climate change in agricultural production in central Vietnam found that access to credit significantly influenced adaptive capacity (Trinh et al., 2018). A study of household vulnerability to floods in India found that borrowing cash increased adaptive capacity (Bhattacharjee and Behera, 2018).

Access to and use of **information and knowledge** are considered an important determinant of adaptive capacity (Williams et al., 2015). We consider knowledge to be the ability to understand, organise, and use information; for example, access to weather and climate hazard information is key for planning and making adaptation decisions (Eakin et al., 2014), and including indigenous knowledge is crucial for guiding decisions (Mapfumo et al., 2016; Nkomwa et al., 2014; Nyong et al., 2007). Access to and use of information and knowledge are also relevant for learning and agency (Panday and Baroi, 2015; Silici et al., 2021).

Social learning is strongly linked to information and knowledge. It has been described as a learning process including multiple societal stakeholders that come together iteratively to facilitate co-creation and joint learning (Bos et al., 2013; Ensor and Harvey, 2015; Pahl-Wostl et al., 2008). It can play an important role in building adaptive capacity by facilitating learning and social organisation (Thi Hong Phuong et al., 2017). Social learning can enhance especially bridging social capital (Dressel et al., 2020). Bridging social capital refers to when individuals from different social backgrounds establish relations (Harrison et al., 2016).

For decades, **gender equality** has been a key concern of development work, and a range of gendered barriers and challenges have been identified, both general and context-specific. Dev and Manalo (2023) investigated research trends related to gender and adaptive

Fig. 1. Map of the study area. Kisumu County by Lake Victoria is marked in dark orange.

capacity in the Global South. They found that women are 'disproportionately affected by climate change impacts in male-dominant social structures', and that social norms, control of assets, and decision-making power affect women's adaptive capacity in developing countries (Dev and Manalo, 2023). We include three different aspects of equality in our factor which we argue cover the core elements of equality relevant for gender and adaptive capacity. First, we consider the importance of schooling children of both genders to be at the core of any gender equality effort (Anyanwu, 2016; Mbodji, 2023). Second, we consider access to information and knowledge. (Jost et al., 2016). Third, we consider the opportunity of women earning an income outside the household (Haley and Marsh, 2021; Sell and Minot, 2018).

For clarity, we explain here the use of the following terms: domain, factor, and construct. When adaptive capacity is discussed from a theoretical perspective, we use the term adaptive capacity "domains" to align with theoretical language in existing literature (Cinner et al., 2018). We use the term "factor" when we discuss the statistical analysis. We set out to form a factor of each of the five adaptive capacity domains. A "construct" includes all the factors related to a given concept, in the case of this study 1) adaptive capacity and 2) leverage points.

2. Material and methods

2.1. Study area

The data were collected in Kisumu County in western Kenya by Lake Victoria, the world's largest tropical lake (Fig. 1). Its capital is Kisumu, Kenya's third largest city, after Nairobi and Mombasa. The county is known for its rich cultural heritage, especially of the Luo, the region's dominant ethnic group. Agriculture, fishing, and trade drive its economy. The region is also home to several industries, including manufacturing, construction, and tourism. Kisumu is a major transport hub, with a busy port on Lake Victoria connecting the region to Tanzania and Uganda.

2.2. Sample

A sample (n = 1,271) of Kisumu County's local food system actors was formed. The total sample contained groups (producers, processors, distributors, and consumers) to give nuanced results. The division into the four subgroups applied the division of food system actors by Zurek et al (2022). The respondents could have overlapping roles. For example, they could be both producers and distributors, but each respondent is classified in the analysis as belonging to only one food system actor group.

The Kisumu food system's existing gender roles meant more men were included in the producer sub-sample, and more women in the distributor and consumer sub-sample (Medard et al., 2002; Musuva et al., 2022; Odhone et al., 2020). Therefore, we examine possible gender bias in the results and present the results for each sub-sample. Producers, processors, and distributors worked with two specific value chains: fish and vegetables.

The **producer** group consisted of 200 respondents, 155 men and 45 women, including farmers, fisher folk, and people producing fish in ponds. According to existing gender norms, men dominate fishing while both men and women are involved in vegetable farming (Medard et al., 2002; Mireri, 2013; Odhone et al., 2020). We sampled producers using a snowball sampling technique, starting with research team visits to areas locally known for their numerous fisher folk and extensive vegetable production. The persons surveyed were asked to suggest other producers and provide their contact information. Those the respondents suggested were then approached and interviewed if prior and informed consent was freely given.

The **processor** group included 61 respondents, 5 men and 56 women. Processors included individuals who add value to food commodities. According to existing gender norms, women dominate fish processing (Medard et al., 2002; Odhone et al., 2020). The sub-sample size was small, as the number of fish and vegetable processors is limited in Kisumu County. It was therefore not considered in the sub-group analysis. The processor sub-sample was created using purposive sampling due to the lack of a comprehensive list of fish and vegetable processors in Kisumu County.

The **distributor** sub-group included 500 respondents, 78 men and 422 women. The distributor sub-group included both wholesalers – middlemen selling commodities in bulk – and retailers – people like street and market vendors selling products directly to consumers. According to existing gender norms, women dominate fish and vegetable distribution (Medard et al., 2002; Odhone et al., 2020; Weinberg et al., 2011). First, a mapping was made of all retailers in four informal settlements in Kisumu: Bandani; Obunga; Manyatta A; and Manyatta B. Based on this list, stratified random sampling was done to cover an equal number of retailers from each settlement. Likewise, a list of fish and vegetable wholesalers in Kisumu County was prepared. All the wholesalers were interviewed, and the sub-sample was then increased, using snowball sampling to ask the wholesalers already interviewed to suggest additional wholesalers.

The **consumer** group included 510 respondents, with only 8 men and 502 women. According to existing gender norms, women have the main responsibility for purchasing and preparing food (Musuva et al., 2022). The sampling used a list maintained by the local authorities of households in the same four informal settlements of Kisumu mentioned above. Based on this list, we conducted stratified random sampling to cover an equal number of households from each settlement.

2.3. Survey technique

The data were collected in two instances. The first batch was collected in February to April 2022, and the second in October 2022. Trained enumerators collected the data in person. We used guides to introduce our data collection teams to the survey's various areas

and to assist in building trust. The guides ranged from lead farmers, the chairpersons of market groups, community health volunteers, and government officials within the survey location.

The survey consisted of two main parts: statements related to the four hypothesised leverage point factors; and statements related to the five hypothesised adaptive capacity factors. Each of the nine hypothesised factors contained two to five statements. These statements were designed to capture the essence of each hypothesised factor (Table 1). Five responses for each statement were provided to choose from according to a 5-point Likert scale: 1 = strongly disagree; 2 = disagree; 3 = do not know; 4 = agree; 5 = strongly agree. The adaptive capacity statements drew on similar surveys from the literature on adaptive capacity (Lockwood et al., 2015; Seara et al., 2016). The adaptive capacity statements were formulated in first person pronominal starting "I have the capacity to…". These statements were designed to measure the interviewed person's level of perceived adaptive capacity. The leverage point statements were designed to capture the respondents' attitudes and beliefs towards the four leverage points.

Table 1
The descriptive values and Cronbach alpha of the improved constructs.

Latent variables	Statement code	Statements/ Observed variables	Stand. reg. estimates	Item mean	Stand. dev.	Cron. alpha
Leverage point statements						
Access to finance	Accfin_1	Being able to borrow money is crucial to improving my way to earn my living	0.581	4.12	1.027	0.689
	Accfin_4	Having more clear information about the terms of a loan would increase the chances that I would take a loan in the future.	0.596	4.08	0.914	
	Accfin_5	Being able to borrow money from for example a savings group, micro credit scheme or other can solve problems.	0.784	3.94	1.059	
Information & knowledge	Info_2	My ancestors have had ways to deal with difficult weather, like drought and floods.	0.782	3.58	1.268	0.606
	Info_3	I get the most important information about risks related to the weather and climate from others in my community.	0.557	3.01	1.212	
Social learning	Soc-Learn_1	Discussing and sharing ideas with others is a good way to learn.	0.64	4.36	0.674	0.643
	Soc-Learn_3	Discussing ideas and learning new things together with others helps me adapt to future challenges.	0.718	4.13	0.783	
	Soc-Learn_4	It is easier to change my practices in my livelihood and daily life if people around me do it as well.	0.54	3.97	0.948	
Gender equality	Gender_1	When a mother has access to information and knowledge, she has better possibilities to adapt to changing circumstances.	0.884	4.25	0.974	0.0.784
	Gender_2	In order to cope with future challenges, it is important for both boys and girls to attend school.	0.912	4.33	1.035	
	Gender_3	It is good for the family when women also earn money outside of the household.	0.453	4.44	0.722	
Adaptive capacity statements						
Assets	Assets_1	I have the equipment and funds needed to manage my way to earn my living	0.801	2.42	1.234	0.683
	Assets_2	I have sufficient financial resources to manage my livelihood.	0.646	2.08	1.142	
Flexibility	Flex_3	I am already trying to find ways to deal with the changing climate.	0.844	3.12	1.284	0.837
	Flex_4	I know what to do to deal with the changing climate.	0.853	2.95	1.299	
Social organisation	SocOrg_1	There are groups, associations and networks in my community that I can turn to for information related to my livelihood.	1.082	3.23	1.221	0.454
	SocOrg_2	Through connections with local groups, associations and networks I am better able to diversify my way to earn my living.	0.290	3.92	0.848	
Agency	Agency_1	I have the capacity to learn new skills and gain new knowledge.	0.416	3.82	1.074	0.730
	Agency_2	I have the capacity to influence decisions taken about the community.	0.809	3.76	1.153	
	Agency_3	I feel my views and experience are valued in our community.	0.880	3.78	1.157	
Removed statements						
Latent variables	**Statement code**	**Statements/ Observed variables**		**Item mean**	**Stand. dev.**	
Access to finance	Accfin_2	I have the information about how to get a loan from for example a savings group, micro credit scheme or other if I need it.		3.48	1.267	
	Accfin_3	Fear of not being able to pay back a loan makes me hesitant to borrow money.		3.33	1.394	
Information & knowledge	Info_1	Radio is one of the most important sources of information regarding the weather and climate.		4.02	0.926	
Social learning	Soc-learn_2	Interest groups and associations in my community are good places to learn new things.		3.98	0.869	
Assets	Assets_3	Climate change negatively impacts my current way to earn a living.		4.14	0.880	
Flexibility	Flex_1	Having an additional way to earn my living would improve my possibility to deal with risks.		4.10	1.016	
	Flex_2	I need more information and knowledge to find new ways to earn a living.		4.19	0.811	
Learning	Learn_1	I am interested in learning new skills and gain new knowledge.		4.39	0.648	
	Learn_2	I know where I can learn new skills.		3.32	1.172	
Agency	Agency_4	I feel I can decide about most aspects in my life.		3.48	1.267	

2.4. Statistical analysis

Confirmatory factor analysis (CFA): the objective of the CFA was to develop internally valid and reliable factors forming two constructs, one for adaptive capacity and another for leverage points, with good model fit. We used confirmatory factor analysis (CFA) in Amos software to test the leverage point and the adaptive capacity constructs' internal validity. The following fit indices and related thresholds for a good model fit were used: the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI), with a threshold of > 0.90 as a reasonable model fit and ≥ 0.95 as a good model fit. We also used the Root Mean Square Residual (RMR) and Root Mean Square Error of Variance Approximation (RMSEA), where < 0.08 can be considered a reasonable model fit, and ≤ 0.05 a good model fit (Hu and Bentler, 1999). Moreover, we represented the model's chi-square value, although it is known to be problematic with large sample sizes (Vandenberg, 2006). Chi-square divided by degrees of freedom can also be used as a measure of model fit; although there is no universally agreed limit for this value, many have used a limit of 5 or less. For each factor, we constrained one of the loadings between a statement and its factors to one, while the other loadings remained free. The same construct's factors were allowed to correlate. To achieve a good model fit for each construct, we made one edit at a time, guided by the statements' factor loadings. Each factor's internal consistency and reliability were tested using SPSS. We applied a Cronbach alpha threshold above 0.7 by removing the statements weakening the factor's internal consistency.

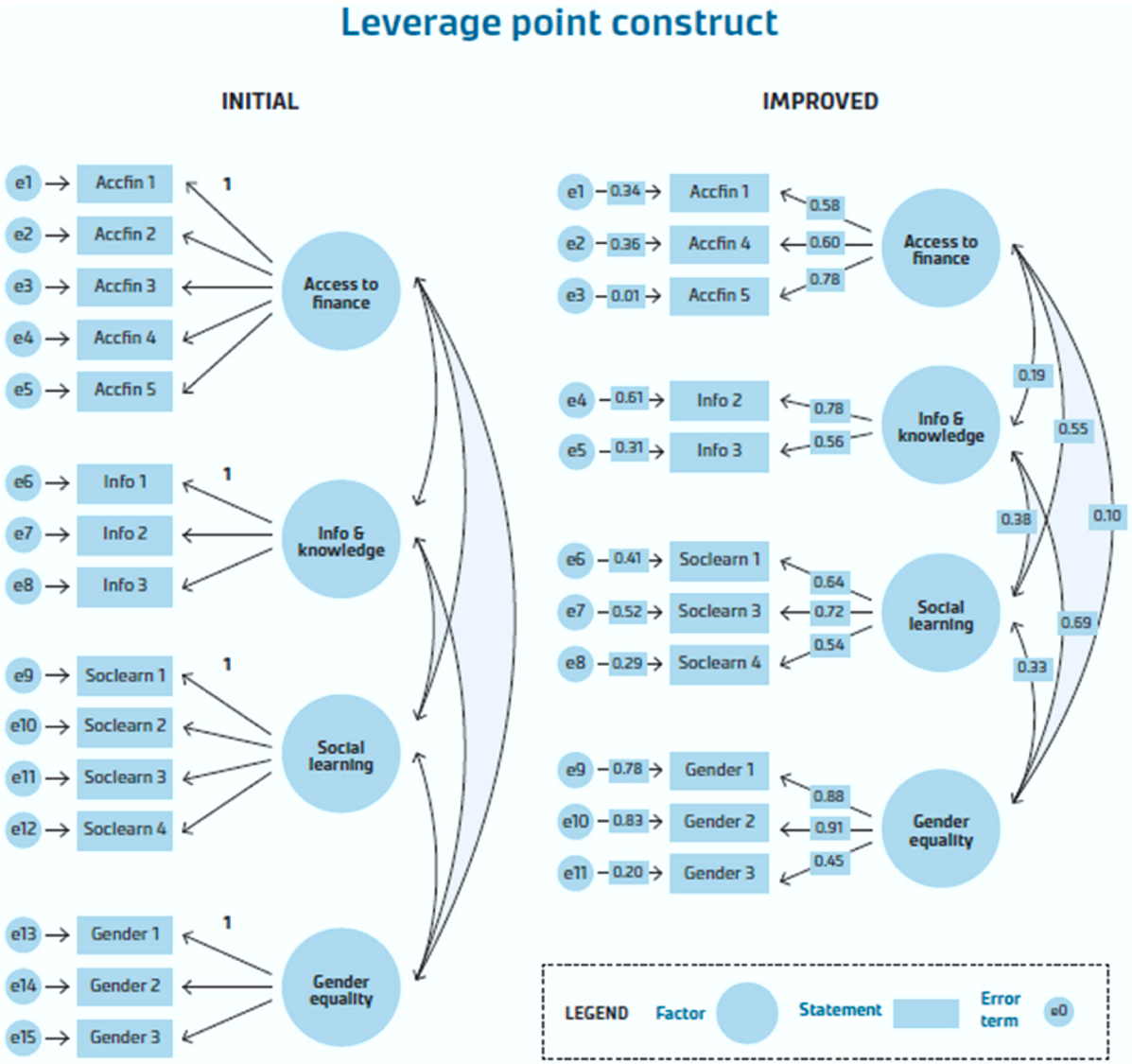

Fig. 2. The initial (left) and improved (right) leverage point constructs. Single-headed arrows from the factors to the statements indicate factor loadings, while single-headed arrows from the error terms to the statements indicate the error variances of the statements. Double-headed arrows connecting the factors indicate the allowed correlations between the factors.

Structural equation modelling (SEM): The objective of the SEM was to test and estimate the causal effects of the leverage points factors on the adaptive capacity factors i.e. to examine the interviewed persons' attitudes and beliefs on the leverage points value on their perceived adaptive capacity. Based on the CFA structure with the improved factors containing statements with high loadings, low cross-loadings, and good reliability, we built a theoretical structural equation model. SEM includes CFA and a structural regression analysis of complex relationships among multiple variables simultaneously to examine the interrelationships and interdependencies between the independent and dependent variables (Byrne, 2016). This makes SEM particularly suitable for capturing the multidimensional nature of adaptive capacity (Afkhami et al., 2022). Another benefit of SEM is that the method accounts for measurement errors, meaning it only uses the variance explained by the tested model in the statistical analysis (Dressel et al., 2020). We used the same fit indices in the SEM as in the CFA listed above.

The model's leverage point factors represented the independent and exogenous variables, and the adaptive capacity factors the dependent and endogenous variables. After a parsimonious model with a good model fit was identified for the total sample, the same model was conducted for the sub-groups. For the food system actor group processor (n = 61), the sample size was too small for SEM analysis and was therefore excluded from the sub-sample analysis. The maximum likelihood (ML) estimation method was used in all statistical models.

Checking for gender bias: As the overall sample contained substantially more women than men, we made two additional analyses to check whether the results contained a gender bias. First, the largest possible stratified sample was taken and weighted so that an equal number of women and men (n = 136 both) was selected from each actor group. The standardised estimates of SEM were compared to the model for the total sample. Second, the effect of gender was added as a control variable to the model for the total sample, allowing us to test whether gender had a statistically significant effect on the endogenous factors.

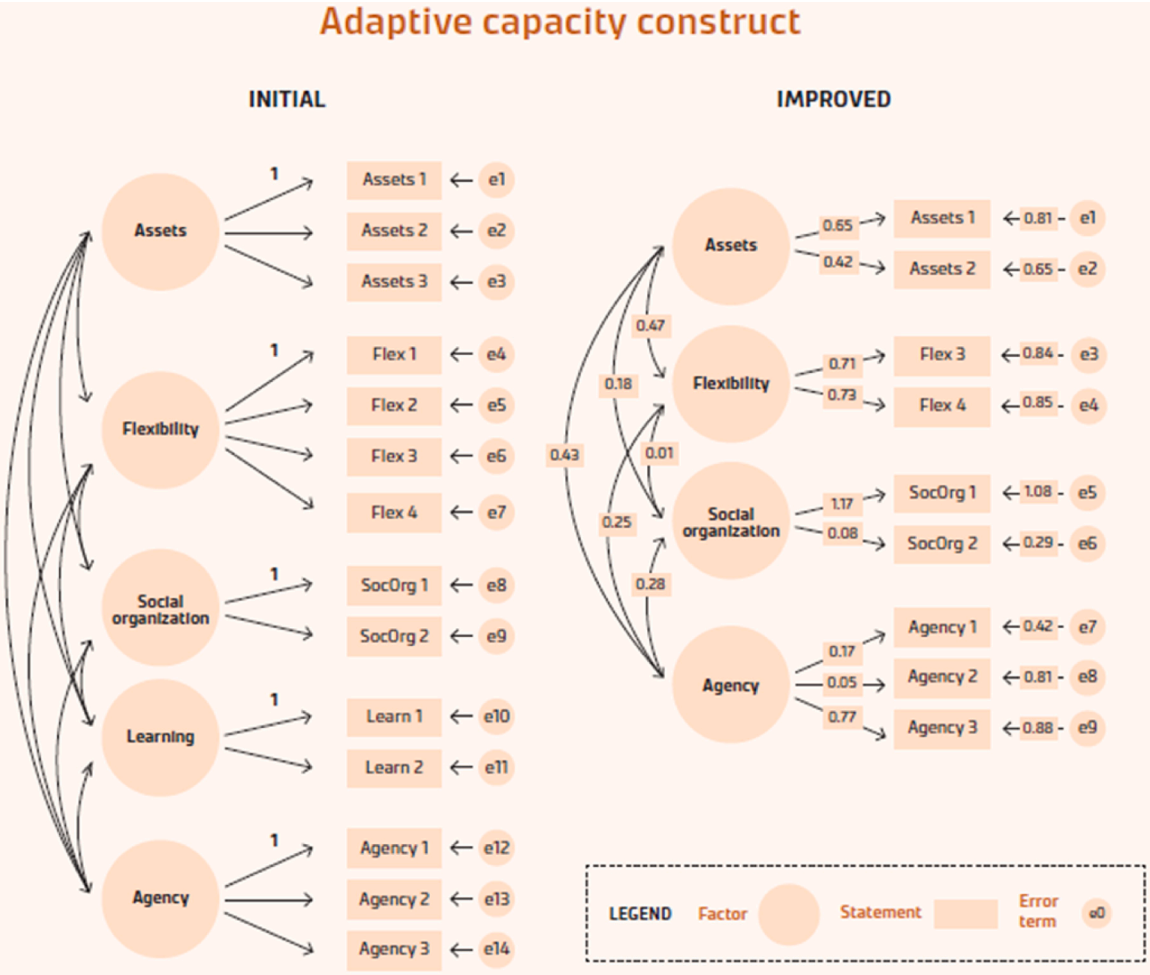

Fig. 3. The initial (left) and improved (right) adaptive capacity constructs. Single-headed arrows from the factors to the statements indicate factor loadings, while single-headed arrows from the error terms to the statements indicate the error variances of the statements. Double-headed arrows connecting the factors indicate the allowed correlations between the factors.

3. Results

3.1. Confirmatory factor analysis

Leverage points construct: Based on the CFA of the initial leverage point construct (Fig. 2), the model fit indices were already quite good (CFI 0.901, TLI 0.876, RMR: 0.062 and RMSEA 0.066), but efforts were made to improve them. Statements with low standardised regression estimates were therefore removed. The statements *Accfin_2* (β = -0.313) and *Accfin_3* (β = 0.167) were removed, resulting in α = 0.689 for the *Access to finance* factor. The statement *Info_1* (β = 0.102) was removed from the factor *Information and knowledge*, resulting in α = 0.606, and the statement *Soclearn_2* (β = 0.540) was removed from the factor *Social learning*, resulting in α = 0.643. The final leverage point factor – *Gender equality* – was left with all three initial statements (α = 0.784). With these changes, the already initially good model fit further improved: chi^2: 273, DF: 38, CFI: 0.942. TLI: 0.916, RMR: 0.048, and RMSEA: 0.070. Full statements are listed in Table 1.

Adaptive capacity construct: Based on the CFA of the initial adaptive capacity construct (Fig. 3), the model fit indices were poor: CFI: 0.736, TLI: 0.642, RMR: 0.090 and RMSEA: 0.12 (Hu and Bentler, 1999), and the construct therefore needed improvement. We removed statement *Assets_3* (β = 0.086) from the factor *Assets*, thus increasing the Cronbach alpha to good (α = 0.683). From the factor *Flexibility*, we removed statement *Flex_1* (β = 0.259) and *Flex_2* (β = 0.164). With these changes, the Cronbach alpha increased to good (α = 0.837). The statements designed for the factors *Social organisation* (α = 0.454) and *Learning* (α = -0.017) did not create cohesive factors. We decided to keep the factor *Social organisation* as the factor was nearly acceptable, but we removed the factor *Learning*. The factor *Agency* was left with all three initial statements, as the Cronbach alpha was already good (α = 0.730). With these changes, a good

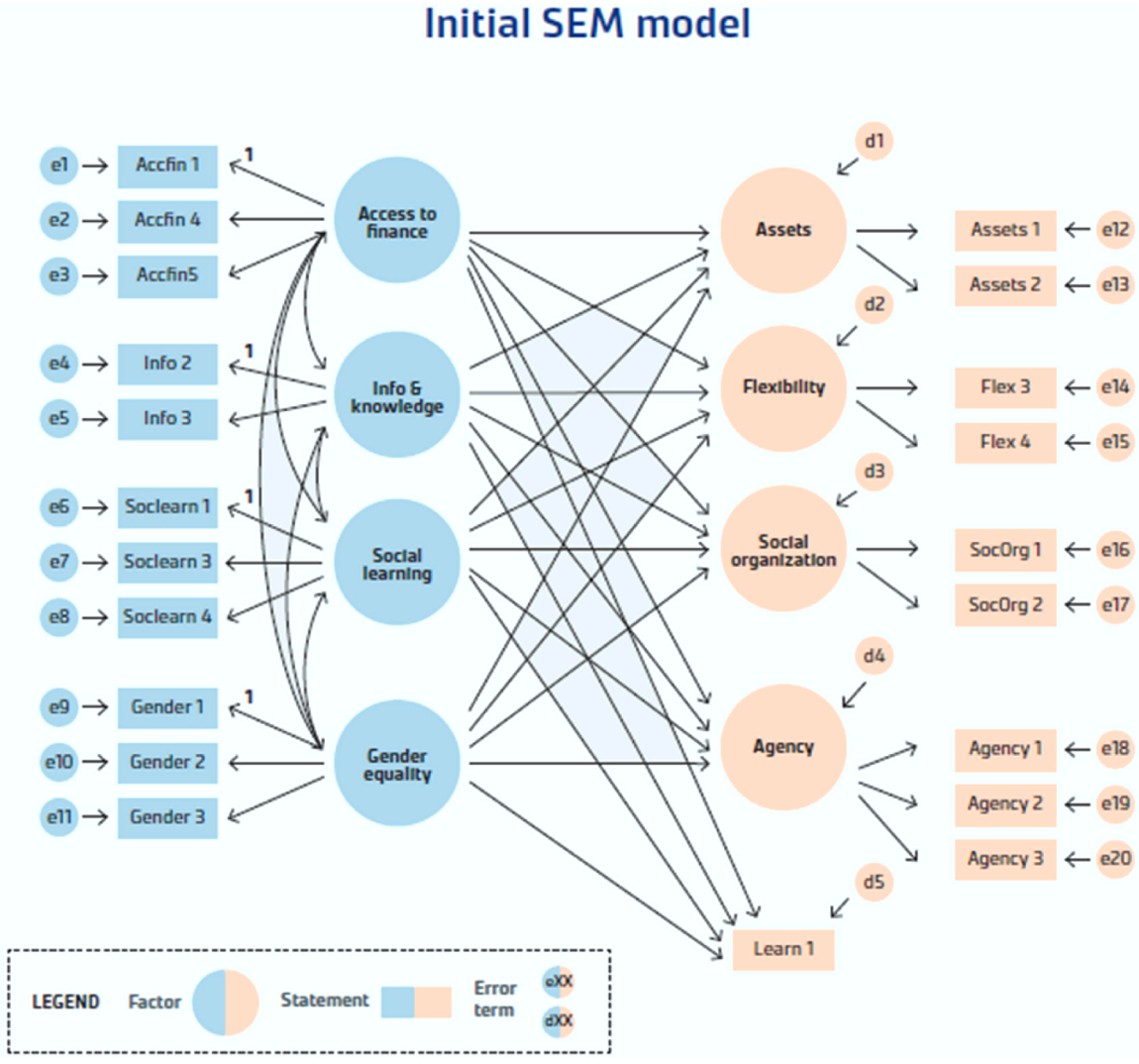

Fig. 4. Initial SEM model. Leverage point factors (blue colour) to the left and adaptive capacity factors (light orange colour) to the right.

model fit was achieved: chi^2: 123, DF: 21, CFI: 0.967, RMR: 0.050, TLI: 0.944 and RMSEA: 0.062.

3.2. SEM model

We created a structural equation model, with the formed leverage point factors as the independent variables and the formed adaptive capacity factors as the dependent variables. To keep all five domains of adaptive capacity aligned with theory even though the learning domain did not create a factor, we added the statement of *Learn_1* to represent the *learning* domain. In the initial SEM model (Fig. 4), paths were drawn from each leverage point factor to each adaptive capacity factor, including to the statement of *Learn_1*. The model fit indices for the initial model were not sufficiently good: CFI: 0.882, RMR: 0.088, TLI: 0.849, and RMSEA: 0.070, and efforts were therefore made to improve them. We removed (sequentially) associations with problematic standard regression estimates, associations that were not statistically significant based on modification indices provided by the Amos software, and items with low factor loadings. Associations with a standard regression estimate that exceeded one indicated a multicollinearity problem, and these associations were therefore investigated first: *Information and knowledge -> Assets*, *Information and knowledge -> Social organisation*, *Gender equality -> Social organisation*, *Social learning -> Assets*. Associations that were not statistically significant were *Access to finance -> Flexibility*, *Access to finance -> Assets*, and *Social learning -> Agency*. To achieve an acceptable model fit, we also removed the leverage point factor of *Information and knowledge* and the adaptive capacity factor of *Social organisation*. Finally, we tested mediating associations of adaptive capacity factors.

The final optimised model (Fig. 5) had a good model fit: chi^2: 2417, DF: 756, CFI: 0.924, TLI: 0.903, RMR: 0.069, RMSEA: 0.024. The final model contained seven paths between the leverage point factors and the adaptive capacity factors. In addition, the final model contained two mediating regression lines connecting the adaptive capacity factor *Assets* with the adaptive capacity factor *Flexibility* and *Agency*. All nine paths were statistically significant for the total sample.

Finally, we fitted the final SEM model construct for five sub-groups including gender: men/women and food system actor groups: producer/distributor/consumer (Table 2.). Below, we describe the model's nine causal effects. Standardised regression estimates are shown in parentheses.

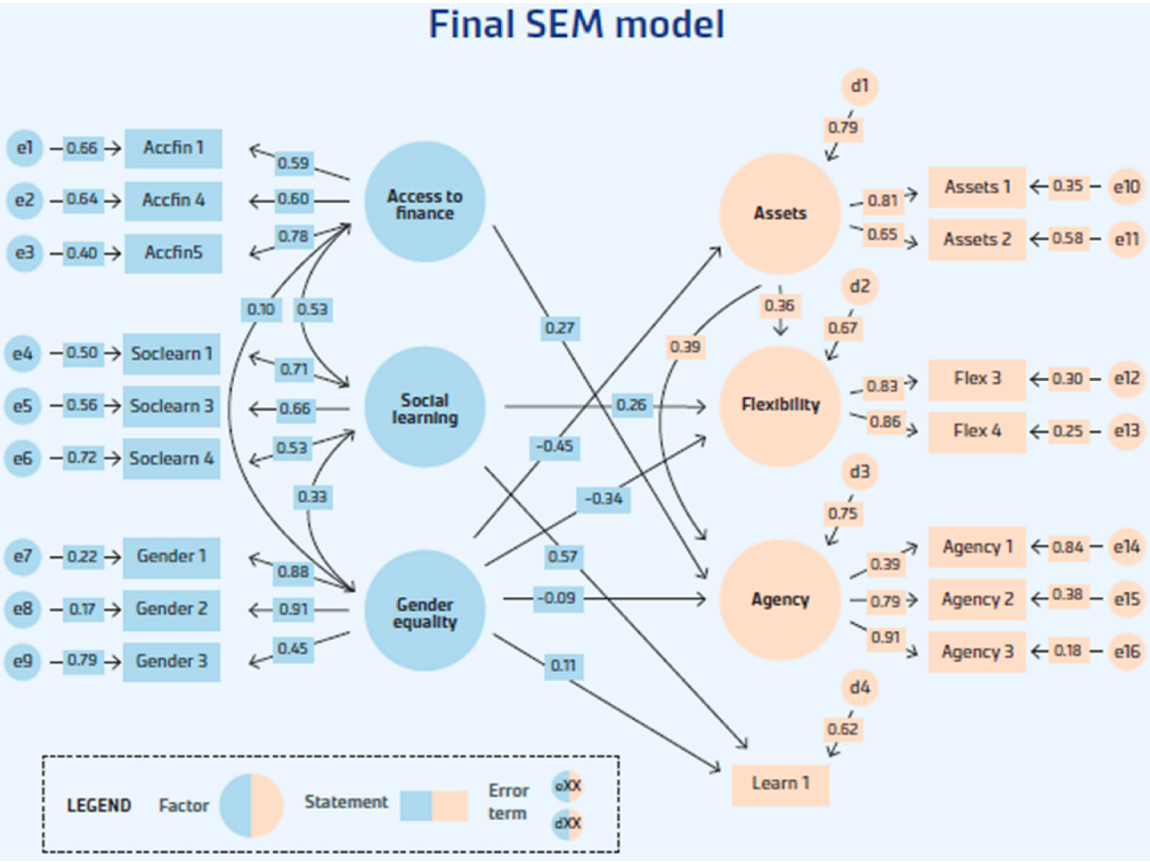

Fig. 5. The final SEM model. Single-headed arrows from the leverage point factors (blue colour) to the adaptive capacity factors (light orange colour) indicate standardised regression estimates, while single-headed arrows from the error terms to the statements indicate the error variances of the statements. Double-headed arrows connecting the leverage point factors indicate the allowed correlations between the factors.

Table 2
Summary of the paths included in the final model and their standardised regression estimate estimates. The table includes results for both the total sample and the sub-groups. The standardised regression estimates that are not statistically significant (above the significance level 0.05) are marked with ns.

Standardised regression estimates								
#	Independent variable	Dependent variable	All n = 1271	Gender		Food system actor		
				Male n = 246	Female n = 1,025	Producer n = 200	Distributor n = 500	Consumer n = 510
1.	Access finance	Agency	0.270	0.511	0.204	0.302	0.430	−0.003 ns
2.	Social learning	Flexibility	0.255	0.142 ns	0.281	0.035 ns	0.115	0.297
3.	Social learning	Learn_1	0.575	0.576	0.578	0.596	0.522	0.365
4.	Gender equality	Assets	−0.455	−0.446	−0.460	−0.304	−0.498	−0.380
5.	Gender equality	Flexibility	−0.335	−0.345	−0.321	0.134 ns	−0.380	0.011 ns
6.	Gender equality	Agency	−0.095	−0.060 ns	−0.104	0.277	−0.257	−0.073 ns
7.	Gender equality	Learn_1	0.112	0.187	0.085	0.094	0.105	0.365
8.	Assets	Flexibility	0.360	0.382	0.368	0.398	0.513	0.263
9.	Assets	Agency	0.392	0.315	0.401	0.298	0.367	0.402
Model fit								
Chi square			567	298	482	219	334	398
Degrees of freedom			108	108	108	108	108	108
RMR			0.069	0.079	0.053	0.065	0.080	0.074
CFI			0.924	0.837	0.933	0.912	0.936	0.907
TLI			0.903	0.870	0.916	0.889	0.907	0.883
RMSEA			0.024	0.085	0.058	0.055	0.064	0.073

Access to finance -> Agency: *Access to finance* was a positive predictor of the adaptive capacity factor *Agency* when considering both the total sample (β = 0.270) and for all sub-groups except consumers. *Access to finance* improved men's agency (β = 0.511) more than twice as much as for women (β = 0.204). *Access to finance* also benefited distributors substantially (β = 0.430) and producers slightly less (β = 0.302) but had hardly any effect on consumers (β = -0.003). The association was statistically significant for the total sample and all sub-groups except consumers.

Social learning -> **Flexibility:** *Social learning* was a positive predictor of the adaptive capacity factor *Flexibility* for the total sample (β = 0.255), as well as for all sub-groups. *Social learning* benefited the flexibility of both men (β = 0.142) and women, but women's nearly twice as much (β = 0.281). *Social learning* benefited all three food system sub-groups of food system actors: consumers the most (β = 0.297), distributors only half as much (β = 0.115) and producers hardly any (β = 0.035). The association was statistically significant for the total sample, and all sub-groups except for men and producers.

Social learning -> **Learning** *Social learning* was a strong positive predictor of the adaptive capacity statement related to learning when considering the total sample (β = 0.575). *Social learning* also enhanced both men's (β = 0.576) and women's (β = 0.578) learning opportunities. Likewise, all the food system's three sub-groups benefited: producers (β = 0.596); distributors (β = 0.522); and consumers (β = 0.365). The association was statistically significant for the total sample and all sub-groups.

Gender equality -> Assets: *Gender equality* was a strong negative predictor (β = -0.455) of the adaptive capacity factor *Assets*. *Gender equality* weakened both men's (β = -0.446) and women's (β = -0.460) perceived level of assets. *Gender equality* was also a strong negative predictor of *Assets* for all three sub-groups of food system actors, mostly for distributors (β = -0.498) and slightly less for consumers (β = -0.380) and producers (β = -0.304). The association was statistically significant for the total sample and all sub-groups.

Gender equality -> Flexibility: *Gender equality* was a mixed predictor of the adaptive capacity factor *Flexibility*, and its relationship varied between sub-groups. *Gender equality* was a negative predictor when considering the total sample (β = -0.335), as well as for the two gender sub-groups: men (β = -0.345); and women (β = -0.321). *Gender equality* was also a strong negative predictor of distributors (β = -0.380) but had hardly any impact on consumers (β = 0.011) and a slight positive effect on producers (β = 0.134). The association was statistically significant for the total sample and all sub-groups except producers and consumers. The adaptive capacity factor of *Assets* also significantly mediated the relationship between *Gender equality* and *Flexibility*. We divided the effects into direct and indirect. The direct effect (*Gender equality* -> *Flexibility*) represented 67 % of the total effect, while the indirect effect (*Gender equality* -> *Assets* -> *Flexibility*) represented only 33 %.

Gender equality -> Agency: *Gender equality* was a mixed predictor of the adaptive capacity factor *Agency*, and its relationship varied between sub-groups. *Gender equality* was a weak negative predictor when considering the total sample (β = -0.095), as well as when considering the two gender sub-groups. The negative effect of *Gender equality* was stronger for women (β = -0.104) than for men (β = -0.060). For distributors (β = -0.257) and consumers (β = -0.073), the factor *Gender equality* was also a negative predictor, but for producers (β = 0.277), a positive. The association was statistically significant for the total sample and for all sub-groups except men and consumers. The adaptive capacity factor of *Assets* also significantly mediated the relationship between *Gender equality* and *Agency*. The direct effect (*Gender equality* -> *Agency*) represented only 35 % of the total effect, while the indirect effect (*Gender equality* -> *Assets* -> *Agency*) represented 65 %.

Gender equality –> Learning: *Gender equality* was a positive predictor of the adaptive capacity statement *Learn_1* for the total sample (β = 0.112) and all sub-groups. *Gender equality* improved both men's (β = 0.187) and women's (β = 0.085) learning

opportunities but benefited men more. *Gender equality* also improved all three food system actor sub-groups' learning opportunities, but consumers benefited more (β = 0.365) than producers (β = 0.094) and distributors (0.105). The association was statistically significant for the total sample and for all sub-groups except men.

Assets - > Flexibility: *Assets* was a positive predictor of the adaptive capacity factor *Flexibility* for the total sample (β = 0.360) and all sub-groups. Both men (β = 0.382) and women (β = 0.368) benefited equally. *Assets* was a particularly strong predictor for distributors (β = 0.513) and slightly less for producers (β = 0.398) and consumers (β = 0.263). The association was statistically significant for the total sample and all sub-groups.

Assets -> Agency: *Assets* was a positive predictor of the adaptive capacity factor *Agency* for the total sample (β = 0.392) and all sub-groups. Both women (β = 0.401) and men (β = 0.315) benefited. *Asset* was a stronger predictor of *Agency* for consumers (β = 0.402), while producers (β = 0.289) and distributors (β = 0.367) benefited less. The association was statistically significant for the total sample and all sub-groups.

Checking for gender bias: Due to gender imbalance, SEM analysis was conducted for an altered sample containing an equal number of men and women, stratified by actor role, to check for possible gender bias. The differences in the standardised estimates were mostly minor (less than β=±0.06), but the strength of the path from the leverage point factor *Access to finance* to the adaptive capacity factor *Agency* increased by 0.19. Furthermore, the path from the leverage point factor *Gender equality* to *Learn_1* increased (β =+0.13), while the strength of the paths from the leverage point factor *Social learning* to the adaptive capacity factor *Flexibility* and from *Gender equality* to *Agency* decreased by 0.14. Alternatively, the effect of gender was added as a control variable to the model for the total sample. A statistically significant effect of gender was found only for the factor *Agency* ($p < 0.0001$). The paths from *Access to finance* and *Gender equality* to *Agency* would both have been weaker (β = 0.242 and β = -0.088) in this model.

4. Discussion

The study set out to 1. empirically identify valid and reliable factors of leverage points and adaptive capacity, drawing on survey results from a sample of food system actors in Kisumu County, Kenya and, 2. estimate the causal effects of respondents' attitudes and beliefs towards the leverage point factors on perceived adaptive capacity factors. The following three key messages emerged from the findings. First, we developed and tested a new psychometric scale of leverage points, finding that it was both a valid and reliable measure of all four tested leverage point factors. Second, 47 of the total 54 causal effects estimated of attitudes and beliefs towards the leverage points on perceived adaptive capacity were statistically significant. This finding indicates that targeting a given leverage point has the potential to strengthen adaptive capacity in specific cases. Measuring people's attitudes and beliefs towards the leverage points could also determine their level of perceived adaptive capacity. Third, the study provided two determinants for advancing transformative adaptation, named *Social learning* and *Gender equality*. We discuss each key message in detail below.

4.1. New psychometric scales

Our first objective was to empirically identify valid and reliable factors of leverage points and adaptive capacity. The factors formed two constructs, one construct formed by the leverage points and another by the adaptive capacity factors. The psychometric scales therefore provide a valid and reliable means of assessing individual differences of respondent's attitudes and beliefs towards the four leverage points and measuring the respondent's perceived adaptive capacity. To our knowledge, no self-reporting scale for the four leverage points has previously been developed. However, scales do exist for assessing perceived adaptive capacity. The existing scales are designed for a Global North context (Gardezi and Arbuckle, 2019; Lockwood et al., 2015; Seara et al., 2016), and to our knowledge, no scale has been designed for a Global South context. To accommodate the socio-cultural features of a Sub-Saharan context we included reference to people's community in the statements. For example, a statement for the adaptive capacity factor Agency: *I have the capacity to influence decisions taken about the community*. Further work on the scientific development of the adaptive capacity scale is however needed. Only three out of the total five adaptive capacity factors were valid and reliable. *Flexibility*, containing two statements, scored highest in the reliability test (α = 0.837), followed by *Agency* (α = 0.730) and *Assets* (α = 0.683), but the reliability of *Social organisation* scored barely below the acceptable threshold of α = 0.5 (α = 0.454), and the hypothesised factor *Learning* could not be formed at all. We analyse why in the section Limits and future research.

All the factors of the leverage point scale were valid and reliable based on the CFA. The factor *Gender equality*, containing three statements, formed the most reliable factor (α = 0.784), followed by *Access to finance* (α = 0.689), *Social learning* (α = 0.643), and *Information and knowledge* (α = 0.606). Like the adaptive capacity statements, the leverage point statements were formulated to be relevant in a Sub-Saharan context. In the factor *Information and knowledge* one of the statements relates to local, indigenous, and traditional knowledge, an aspect considered important in climate change adaptation in the Global South (Mapfumo et al., 2016): *My ancestors have had ways to deal with difficult weather, like drought and floods.* A statement part of the factor *Access to finance* asks about savings groups and micro credit, also relevant mainly in the Global South: *Being able to borrow money from for example a savings group, micro credit scheme, or other can solve problems.*

Due to the abstract and elusive nature of adaptive capacity, a psychometric scale can provide a tangible tool to measure adaptive capacity. From a policy and strategic planning perspective, psychometric scales provide tools for mapping and quantifying needs to tailor targeted interventions, for impact evaluation, and the long-term monitoring of the benefits or absence of benefits provided by a given intervention.

4.2. Predictors of adaptive capacity

There is currently a lack of knowledge of tangible entry points for enhancing adaptive capacity (Fila et al., 2023; Siders, 2019). More generally, the empirical relationships between leverage points and adaptive capacity remain unclear in the literature. We addressed this knowledge gap by analysing the causal effect of attitudes and beliefs towards the leverage point factors on perceived adaptive capacity factors using structural equation modelling. We found strong evidence that the attitudes and beliefs toward the leverage points had a causal effect concerning the food system actors' perceived adaptive capacity. The final SEM model had a good model fit, meaning the data supported the variables' and factors' hypothesised relationships and patterns. Nearly all, 47 of a total 54, relationships were statistically significant. Below, we discuss the results of the three leverage points' causal effect on adaptive capacity in the final SEM model *Access to finance*, *Social learning*, and *Gender equality*.

Social learning: The existing literature suggests that social learning plays a critical role in strengthening adaptive capacity (Bullock et al., 2022; Pahl-Wostl et al., 2007; Thi Hong Phuong et al., 2017). The outcomes of social learning include both newly acquired knowledge and skills and deeper change, including enhanced cooperation and trust-building, and interestingly even changed attitudes and power structures, values, and social norms (Baird et al., 2014; Bullock et al., 2022; Suškevičs et al., 2018). In our study, social learning presented the strongest causal effect of the final SEM model, more precisely on the adaptive capacity statement on learning. This effect was observed in the total sample ($\beta = 0.575$) and in all sub-groups: men ($\beta = 0.573$), women ($\beta = 0.578$), producers ($\beta = 0.595$), distributors ($\beta = 0.522$), and consumers ($\beta = 0.365$). *Social learning* also enhanced the adaptive capacity factor *Flexibility* for the total sample and all sub-groups. The finding is in line with the existing literature on the importance of social learning in building adaptive capacity (Ensor and Harvey, 2015; Thi Hong Phuong et al., 2017) and provides further support that social learning is indeed an adequate and effective way to build adaptive capacity and should be included in strategic adaptation plans and policies in the Global South.

Access to finance through microcredit schemes and savings groups has been studied in the Global South in the past, mainly in relation to women's empowerment. These studies show positive outcomes, including increased bargaining power and increased well-being in the household economy (Caretta, 2014; de Haan and Lakwo, 2010; Rokhim et al., 2016). Our study's results concur with previous studies. *Access to finance* was a positive predictor of the factor *Agency* for the total sample and all sub-groups except consumers. *Access to finance* had limited effect on consumers but substantially effected the perceived adaptive capacity of producers and distributors. This may be explained by producers' and distributors' ability to invest in and develop their livelihoods. Overall, the producers' and distributors' results contained more similarities while the results of the consumers differed from the other sub-groups. This may be because a producer can also assume a distributor's role. Especially for men, *Access to finance* predicted an increase in *Agency* ($\beta = 0.511$ vs $\beta = 0.204$ for women). The role of access to finance in empowering and building women's agency has previously been widely established in the literature (Andriamahery and Qamruzzaman, 2022; Mukendi and Manda, 2022) and our results support these studies. A possible explanation of the stronger predictive effect of *Access to finance* increasing men's agency is related to the expectations placed on men as breadwinners (Stoebenau et al., 2022). Our study confirms and extends the knowledge base on the striking importance of access to finance in building agency and adaptive capacity, particularly of men.

Gender equality: Somewhat surprisingly, the direct effect of *Gender equality* on *Assets*, *Flexibility*, and *Agency* was negative. While the statements related to *Gender equality* received quite high arithmetic means (above 4 in the 1–5 Likert scale), the negative regression estimates for the association between *Gender equality* and the adaptive capacity factors *Assets*, *Flexibility*, and *Agency* revealed conservative and traditional values. This is in line with numerous studies reporting on patriarchal gender norms in Kisumu, Kenya (Jewitt and Ryley, 2014; Muthengi et al., 2016; Mutisya et al., 2018; Njue et al., 2009). At the same time there is considerable agreement in the scientific literature that promoting gender equality to strengthen adaptive capacity is linked with effective adaptation strategies (Dev and Manalo, 2023). Within the leverage point literature, it is known that especially powerful leverage points typically addressing values, social norms, worldviews, and power structures are usually difficult to address and act on (Meadows, 1999). These "deep leverage points" that address values, social structures, and power relations are also the ones where the most desired gains can be attained (Abson et al., 2017). The leverage point literature highlights the need to create "chains of leverage" where a less powerful leverage point can work as a facilitator to be able to act on the deeper and more powerful leverage points (Fischer and Riechers, 2019). Our study is an example of a path of a "chain of leverage" where *Assets* played a key role in strengthening adaptive capacity as a mediator. The mediating relationship linking *Gender equality* to *Agency* through *Assets* was significant, accounting for 65 % of the total effect, while the mediating effect of *Gender equality* on *Flexibility* was slightly less, 33 %. The finding on the mediation effect of Assets also provides further support that different domains of adaptive capacity are tightly interconnected (Cinner et al., 2018), and harnessing the synergies between the domains is important for strengthening it (Thapa et al., 2016).

Another consideration in interpreting the results is time. This study's results present a snapshot of a single timepoint of the views of food system actors in Kisumu, Kenya. As we know, views and perceptions can change, and facilitating such changes in beliefs and attitudes will be key to strengthening adaptive capacity (Cinner et al., 2015).

4.3. Towards transformative adaptation

The transformative adaptation field studies processes that bring about deep, fast, and broad adaptation. Adaptive capacity can play an important role in instigating transformative adaptation by providing the necessary preconditions (Dilling et al., 2023). Existing literature suggest that values, justice, power structures, and interactions play a fundamentally important role in transformative adaptation (Dilling et al., 2023; Scoones et al., 2020; Shi and Moser, 2021). In particular, two leverage points included in this study, *Social learning* and *Gender equality*, can be considered entry points for operationalising transformative adaptation.

From a leverage point perspective, gender equality can be considered "deep", addressing values, worldviews, and social norms and structures (Manlosa et al., 2019). It is indeed these deep leverage points that offer most potential for advancing desired change (Abson et al., 2017). However, our results indicate that respondents' attitudes and beliefs towards gender equality is complex and the direct effects on the adaptive capacity factors were negative while the mediating effect connecting Gender equality with Flexibility and Agency through the factor Assets was positive. This supports existing leverage point literature arguing that deep leverage points are hard to move (Fischer and Riechers, 2019).

Social learning presented the strongest causal effect of the final SEM model, connecting the Social learning factor with learning ($\beta = 0.575$) and Agency ($\beta = 0.255$). This can be seen as an encouraging results and useful entry point for adaptation policy and strategic intervention planning. Our results further underline the benefits of social learning on adaptation including providing opportunities for actors operating at multiple systems to interact and co-create even in some instances leading to changes in entrenched attitudes and beliefs (Baird et al., 2014; Bullock et al., 2022).

5. Limitations and future research

Our study used stratified random sampling for two sub-samples of consumers and distributors. For the other two sub-samples – producers and processors – a list of farmers and processors was unavailable, leading us to use the snowball technique and purposive sampling. Despite the use of snowball and purposive sampling in two of the sub-samples, stratified sampling including four food actor groups still improved the total sample's representativeness. We recommend random sampling be used in future studies. Due to challenges in identifying enough processors the sub-sample remained too small to conduct sub-sample analysis for the SEM. Further qualitative research on food system actor groups' adaptive capacity and underlying reasons for potential differences would also be useful.

Only three out of a total five factors of the adaptive capacity construct proved valid and reliable. This may be because only two statements were designed and included in the survey for these hypothesised factors, and we therefore encourage researchers to include a minimum of three statements in a questionnaire for each hypothesised factor to increase the probability of creating a reliable factor. We consider the results of the psychometric scales for the leverage points and adaptive capacity a foundation of future research.

Adaptive capacity needs are relatively context-specific (Armah et al., 2015; Siders, 2019), and the study's replication in another Global South location is recommended to gain a further insight into the results' generalisability. Our findings related to the predictive power of gender equality on different adaptive capacity domains merit further investigation on how patriarchal gender norms influences advancing climate change adaptation.

6. Conclusion

This article developed, tested, and validated two psychometric scales: one that measures people's attitudes and beliefs towards four leverage points and one that measures respondent's perceived adaptive capacity. The psychometric scales provide an objective and quantitative way to measure abstract matters like adaptive capacity and the four leverage points: access to finance; access to and use of information and knowledge; social learning; and gender equality. The novelty of both these adaptive capacity related scales is that they are tailored for a Global South context. From the standpoint of policy and strategic planning, psychometric scales offer a valuable instrument for needs assessments and can serve as a means for monitoring and evaluation the impact of a specific intervention over time.

As people's attitudes and beliefs influence intended and actual behaviour, the study estimated the causal effects of attitudes and beliefs towards four leverage points on the respondent's perceived adaptive capacity. The results reveal two useful entry points for strategic adaptation planning: *Access to finance* and *Social learning*. We found that these leverage point factors were significant and positive predictors of adaptive capacity. *Access to finance* was a particularly strong predictor of men's agency. *Social learning* strongly benefited all sub-groups, both men and women, as well as producers, distributors, and consumers. A third leverage point factor, *Gender equality*, was also important to achieve a parsimonious model. The direct effect linking *Gender equality* to the adaptive capacity factors *Assets*, *Flexibility*, and *Agency* were negative predictors in all three cases. The model also contained mediation connecting *Gender equality* to *Agency* and *Flexibility* through the factor *Assets*. We conclude that the five adaptive capacity domains are highly intertwined and complex and that particularly the mediating effect linking *Gender equality* with *Assets* and *Agency* is important to be mindful of in policy and strategic intervention planning.

The leverage points this study presents are quite abstract, and context-specific interventions need tailoring to local needs when operationalising and putting the leverage points into practice through policy and strategic adaptation planning. From a policy and practitioner perspective, the results for access to finance and social learning present two useful adaptation planning entry points. Tangibly, access to finance could mean supporting the establishment of savings groups in communities, access to micro credit schemes or revolving funds, and social learning could be operationalised by establishing, for example, farmers' associations, online communities, multistakeholder platforms for locally led adaptation, or women's groups around a given cause. While there is a high level of agreement in the academic literature that gender equality strengthens adaptive capacity, our results reveal conservative gender norms, underlining the importance of acknowledging local values in adaptation planning. Nevertheless, we encourage the inclusion of gender equality aspects in policy and intervention planning. Social learning can play a key role in facilitating discussions around deeply rooted gender role beliefs.

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Ethical considerations

Ethical clearance (ESRC P1063/2021) was provided by AMREF Health Africa in Kenya. The study also complied with the General Data Protection Regulation (GDPR) of the European Union.

CRediT authorship contribution statement

Linda M. Rosengren: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Janne Kaseva:** Methodology, Software, Supervision, Validation, Writing – review & editing. **Mila Sell:** Funding acquisition, Project administration, Resources. **Christopher M. Raymond:** Conceptualization, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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