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Talking about trees: the territorial classification of native forests in the Argentinian Chaco

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Abstract

Deforestation represents an important contributor to climate change. For this reason, identifying conditions that enable the adoption of policies halting or reversing this process is crucial to avoid catastrophic climate change. The Argentinian Gran Chaco is a hotspot of deforestation, mainly due to the expansion of capital-intensive agriculture. In Argentina, the introduction of the national forest law (NFL) represents an important step to protect the remaining forests. However, in the Chaco ecoregion, the implementation of the NFL by the different provinces is extremely heterogeneous. Previous research has provided rich descriptions of the dynamics behind the implementation of the NFL. Yet this research, mainly based on qualitative approaches, does not allow for a systematic analysis of the conditions leading to more or less stringent implementations of the NFL. To address this gap, we first combine the socio-ecological systems framework with historical materialism to generate a plausible hypothesis for the heterogeneous implementation of the NFL across the 12 different provinces of the Argentinian Chaco. Specifically, we hypothesise that it is the differences in contextual factors (i.e. differences in forest cover), material/economic conditions (i.e. presence and extent of capital-intensive agriculture) and the strength of pro- and anti-deforestation coalitions, which lead to a heterogeneous territorial classification of native forests across the various provinces. Subsequently, we test the hypothesis by developing thorough case studies via qualitative comparative analysis. This approach allows us to study in a more systematic way the reasons for the observed institutional heterogeneity. The results show that the proportion of native forests characterised as of low conservation value reflects both the environmental context (i.e. the extent of native forests) as well as the material/economic conditions (i.e. the extent of capital-intensive agriculture) and the presence of strong pro-deforestation cultures, expressed via pro-deforestation coalitions.

1. Introduction

The Gran Chaco is an important agricultural frontier and has experienced very high rates of deforestation (Hansen *et al* 2013) following the expansion of soybean production first, and feedlots for intensive livestock rearing more recently (Piquer-Rodríguez *et al* 2018). It is the second largest forest biome in South America, it extends for about one million Km^2, mainly situated in Argentina, where it spans across 12 different provinces: Catamarca, Chaco, Cordoba, Corrientes, Formosa, Jujuy, La Rioja, Salta, San Luis, Santa Fe, Santiago del Estero and Tucuman.

Given the importance of land use cover change in terms of greenhouse gas emissions (IPCC 2014), reducing and possibly reversing deforestation is a crucial target for mitigation efforts (Rogelj *et al* 2018). To this end, the regulation of land use to preserve the remaining forests plays a pivotal role. In the case of Argentina, the introduction of the national forest law (law 26 331/2007, NFL from now on) represents an important step in this direction. Given the federal structure of Argentina, the NFL has to be implemented by each individual province through regulations. One of the most significant aspects of these provincial regulations pertains to the elaboration of maps

for the territorial classification of the native forests (*ordenamiento territorial de bosques nativos*, in Spanish, OTBN from now on) according to their conservation value. This value, reflecting hydrologic regulation, biodiversity conservation, conservation of soils and water quality, carbon sequestration, landscape diversity, preservation of cultural identities of local people, can be set to low (green area in the OTBN map), intermediate (yellow area in the OTBN map) or high (red area in the OTBN map). This designation has in turn important consequences on the type of activities allowed in each zone. Economic activities and deforestation are permitted almost exclusively in green areas, although resource uses deemed sustainable are also possible in yellow areas. It has already been noted that there is substantial variation in the implementation of the NFL among the various provinces in the Argentinian Chaco (Fernández Milmanda and Garay 2019a, 2019b). It has also been suggested that this variation can be explained by the existence and the relative strength of pro- and anti-deforestation state-society coalitions and by the extent of native forests (Gutiérrez 2017, Figueroa and Gutierrez 2018). Yet, these studies mainly rely on qualitative approaches that, while being very rich in details, do not necessarily provide a systematic analysis. The purpose of this article is to fill this gap and identify factors that are likely to be conductive to more stringent deforestation control. We develop a theoretical framework that combines the social-ecological systems (SESs) approach with historical materialism (HM). We deploy this framework to advance a more systematic explanation of the heterogeneity, among the provinces of the Argentinian Chaco, in the implementation of the NFL. We explicitly draw on the archetypes approach, intended as the study of recurrent patterns and configurations that can explain the occurrence of certain phenomena (Oberlack *et al* 2019, Sietz *et al* 2019).

2. Theoretical framework

The purpose of this section is to develop a theoretical framework that can be easily operationalised to capture the emergence of different institutional configurations.

2.1. The social-ecological systems (SESs) framework

SESs refer to those systems which include a human socio-economic component, interacting with an ecological or environmental component (Berkes *et al* 2000, Ostrom 2007, 2009, Preiser *et al* 2018). The SES framework stresses the embeddedness of the socio-economic component into the ecological component (Daly and Farley 2011, Daly 2015) (figure 1).

At times the representation of SES further distinguishes between the social and the economic component, noting that the latter is embedded in the former (Folke *et al* 2016, Olsson *et al* 2017). The SES and related frameworks have enormous value from a heuristic perspective. However, its operationalisation has notoriously remained a challenge, particularly to capture the formation of institutions (Haller *et al* 2018). We suggest a novel way in which the SES approach can be operationalised.

2.2. Historical materialism (HM)

HM is a method based on dialectics, which perceives reality in terms of interconnected processes (Engels 1892, Ollman 1993). Initially developed by Marx and Engels (Marx and Engels 1970), HM posits that history proceeds from material conditions rather than from ideas. The connections between HM and SES stems from the fact that a critical aspect of HM concerns the 'metabolic relationship' between human society and nature (Foster 2000, Saito 2017). According to HM, this relationship is trans-historical (i.e. it is a constant feature of human societies). However, its specific form at a certain point in time is the result of the historical (here intended as inherently social) and material (including necessarily nature) conditions under which society operates. These conditions include both matter/nature and social/historical relationships, in a way which resonates with the modern definition of SES (Preiser *et al* 2018). HM studies the historical processes leading to the emergence of a particular socio-economic configuration out of the interaction of its various parts, while noting that the 'whole' system constraints and selects the parts.

We use HM to open up the 'black-box' of the socio-economic subsystem within a SES. To this end we begin with an important passage from Marx's *Capital*, where, while discussing the role of technology, he notes 'Technology reveals the active relation of man to nature, the direct process of the production of the social relations of his life, and of the mental conceptions that flow from those relations (Marx 1990, p 493)'. The incipit of the passage clearly points at the fact that the socio-economic system is embedded in the biosphere. However, it is the rest of the passage that gives us an indication of what the constituent elements of the socio-economic subsystem could be. Technology affects social practices, which include not only production *per se*, but also, social reproduction and the way of thinking. A further elaboration (Harvey 2017) allows us to identify six 'moments' forming the socio-economic subsystem. They are technological processes, social relations, material production processes, daily life and social reproduction (i.e. material/economic processes), development of mental conceptions and institutional processes (i.e. cultural/institutional processes). It is important to stress how HM sees cultural/institutional processes emerging out of material/economic ones. However, this does not imply technological or economic determinism. In an important passage in the preface to *A contribution to the critique of political economy*

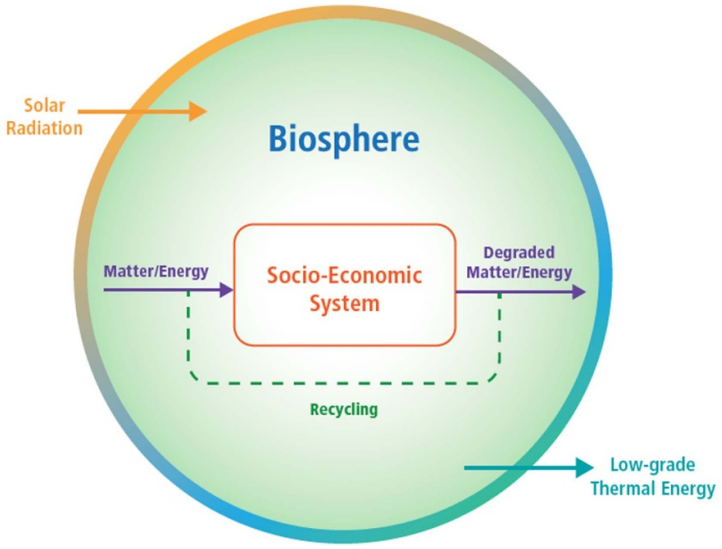

Figure 1. Heuristic representation of a SES. A SES represents the socio-economic system as embedded in the containing biosphere. The biosphere is a thermodynamically closed system, exchanging only energy (but not matter) with the outside environment. Solar radiation comes into the system and leaves the system as high entropy thermal energy. The socio-economic subsystem is an open system, as it exchanges both matter and energy with the containing biosphere. Low-entropy matter/energy enters the system, which uses it to produce and reproduce; high-entropy matter/energy leaves the system. A part of the spent materials can be recycled, thus feeding back in the socio-economic system. This diagram of natural resource flows has been obtained by the author(s) from the Wikimedia website, where it is stated to have been released into the public domain. It is included within this article on that basis.

Marx refers to the 'legal, political, religious, artistic or philosophic—in short, ideological forms in which men become conscious (p 12)' of the material economic processes (Marx 2018). Hence, any experience of the material/economic processes is influenced by the cultural and institutional ones. Bringing the two pieces together we can decompose the socio-economic subsystem into a set of material/economic processes, and a set of cultural/institutional processes. This allows us to operationalise the SES framework and study the formation of institutions.

2.3. Operationalising SES via HM

We illustrate our framework in figure 2.

The material/economic sphere engenders not only 'dominant' visions/cultures that reinforce the status quo, but also 'critical' ones. These contrasting visions reflect the way in which the material/economic practices are perceived by different activists, particularly in respect to issues of distribution of assets and output (Wood 1995). Both dominant and critical visions/cultures fight to become hegemonic and establish what Gramsci called 'common sense' (Gramsci 2014, Crehan 2016). Although a thorough discussion of Gramsci's contribution is beyond the scope of this article, it is still worth remarking how 'culture' and 'common sense', by their effect on institutions and on the material/economic sphere (and ultimately on the biosphere) play an important role in history. The effect of cultures/visions on institutions is not direct but mediated. Cultures/visions provide the 'core beliefs' behind which activists can organize and form coalitions capable of shaping institutions and social behaviour (Crehan 2016, Weible *et al* 2020, Winkler 2020).

3. Methods and data

Drawing on our theoretical framework and inspired by existing research (Figueroa 2017, Gutiérrez 2017, Figueroa and Gutierrez 2018, Fernández Milmanda and Garay 2019b), we hypothesise that the various institutional configurations associated with the implementation of the NFL in the 12 provinces of the Argentinian Chaco result from the interaction between environmental constraints, material/economic practices, reflecting technology, production, reproduction and social relationships, and the presence of organized activists expressing different visions/cultures.

We study the configuration of the OTBN in the provinces of the Argentinian Chaco. We look specifically at the demarcation of the native forests according to their conservation value and use as outcome of interest the proportion of the forest area categorised as of low conservation value (green) in the provincial OTBN. There are two reasons that motivate our choice of the outcome. First, the categorization of the forests according to their conservation value represents a crucial component of the implementation of the NFL, which has caused intense conflicts in many provinces (Fernández Milmanda and Garay 2019a, 2019b). Second, the proportion of forests classified as green in the OTBN corresponding to the Chaco ecoregion has already been quantified by the competent provincial authorities and is publicly

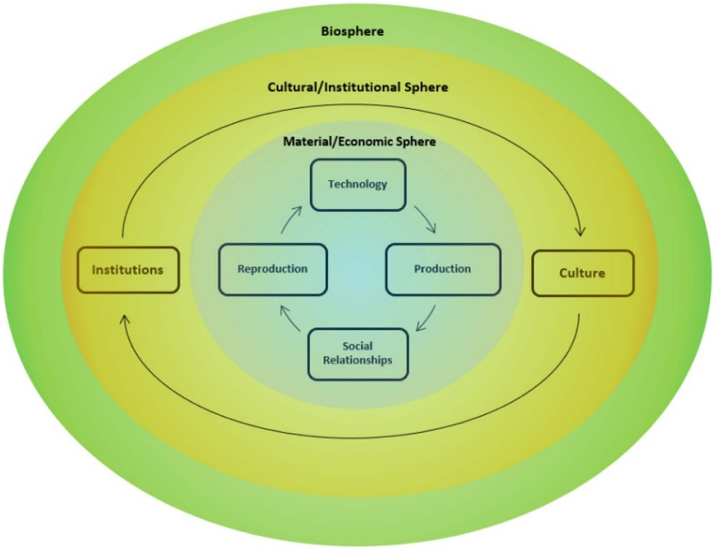

Figure 2. Operationalisation of a SES via HM. The inner circle represents the material/economic sphere with its constitutive moments (technology, production, social relationships and reproduction). The intermediate circle represents the cultural/institutional sphere with its constitutive moments (culture and institutions). This sphere emerges out of the material/economic processes while at the same time constraining them. The outer sphere represents the biosphere. Note that the biosphere constrains both the cultural/institutional and the material/economic spheres. At the same time, the biosphere emerges out of the other two spheres in a way that could be described as coevolutionary (Norgaard 1984, Kallis and Norgaard 2010). For example, recent research shows that humans have been shaping nature for at least 12 000 years (Ellis *et al* 2021).

available (supplementary table 1 available online at stacks.iop.org/ERL/17/025012/mmedia). For this reason, we are ignoring other aspects of the OTBN, like the incorporation of the sustainability criteria set out by the NFL in the demarcation of each zone (Collazo *et al* 2013). Instead, we explicitly note the limits of our institutional indicator, which should always be kept in mind when interpreting the results. We also note that while for some provinces an actualization of the OTBN maps has taken place, for others it is still pending. We therefore focus on the OTBN maps associated to the first round of regulations (i.e. the period 2009–2013, as indicated in supplementary table 1).

Looking at our institutional outcome (i.e. the proportion of green in the OTBN maps), there is substantial variation among the 12 provinces (figure 3). We study the role of different factors, namely environmental constraints, material/economic practices and visions/cultures, to explain this heterogeneity.

3.1. Method: fuzzy-set qualitative comparative analysis (fsQCA)

We use fsQCA, a particular case of QCA. QCA is a set-theoretical method, specifically designed to deal with situations in which a small or moderate number of cases is available to the researcher (Rihoux and Ragin 2009, Kahwati and Kane 2018). A brief description of the method is provided in the supplementary information. Here we would just like to point out that this method, while preserving the richness of information typical of qualitative approaches, allows for the systematic identification of patterns via the use of set theory and Boolean algebra.

3.2. Data

We are interested in explaining the proportion of the native forest in each province that has been assigned to the category of low conservation value (GREEN). From our theoretical framework we know that the explanatory factors include the environmental context, the material/economic structure and the existing visions/cultures about deforestation. With respect to the environmental context, we consider the extent of native forests in each province, at the time when the provincial regulations establishing the OTBN were approved (i.e. 2009–2013 as indicated in supplementary table 1), expressed as a percentage of the total province area (NATFOR). The underlying rationale is that provinces with larger forest areas are more likely to have a higher proportion of green in the OTBN maps, since they feel there is a relative abundance of natural resources which can be sacrificed to promote development (Gutiérrez 2017). With respect to the material/economic structure, our purpose is to capture those elements that, reflecting technology, production and reproduction processes and social relationships, relate positively to the outcome of interest. For technology and production, we consider the proportion of the province area occupied by agricultural units with clear delimitations (AUD). This type of agricultural units denotes capital-intensive production, as opposed to small-scale peasants who almost exclusively operate on lands without clear

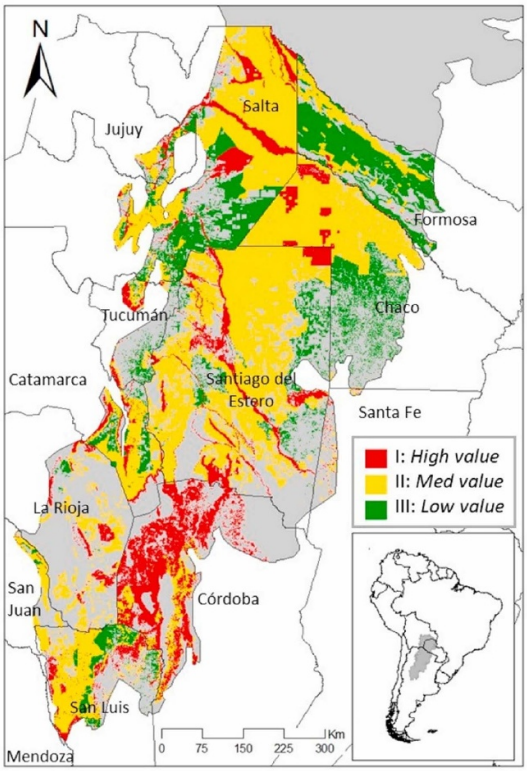

Figure 3. Map of the OTBNs in the 12 Argentinian provinces of the Gran Chaco. The figure illustrates the zoning in the OTBN maps in the 12 provinces of the Argentinian Chaco. The great heterogeneity can be easily spotted. Formosa, for example, categorised about 74% of its remaining forests as of low conservation value, while Cordoba and Santa Fe 0% (see supplementary figure 1). Source: Reprinted from Vallejos *et al* (2021), Copyright (2021), with permission from Elsevier.

demarcation of limits. Regarding reproduction, we note how the diffusion of capital-intensive agriculture is also associated with declines in rural populations, as small-scale peasants and indigenous peoples are expulsed from the land (Mioni *et al* 2015). We therefore consider the proportion of the population in each province being characterised as rural (RURPOP). Concerning social relationships, the diffusion of capital-intensive agriculture brings with it the dissolution of patron-client or family-based work relationships, in favour of wage labour. We use the proportion of non-family workers (NONFW) in agriculture to capture the type of social relationships reflecting a certain material/economic configuration positively associated with the outcome of interest. The combination of these three factors allows us to determine to what extent the material/economic configuration is favourable to capital-intensive agriculture and thus likely to yield a high proportion of green in the OTBN maps.

Our theoretical framework suggests that a particular material/economic configuration will engender both visions/cultures that are organic to it and antagonistic to it. In the context of the Chaco ecoregion, it has been noted how two distinct visions/cultures with respect to the issue of the expansion of capital-intensive agriculture and deforestation exist: one, associated with large-scale producers, sees agricultural expansion in terms of development and poverty eradication; the other, held mainly by peasants and indigenous peoples, sees it mainly in terms of loss of cultural identities and lack of access to institutions (Zepharovich *et al* 2020). Recent research points to the existence of two opposed state-society coalitions, one pro and the other anti-deforestation, in the formulation of the OTBN (Gutiérrez 2017, Figueroa and Gutierrez 2018). Rather than accounting directly for the impact visions/cultures have on institutional configurations, we consider the presence and the strength of state-society coalitions that express the contrasting cultures/visions. Drawing on (Fernández Milmanda and Garay 2019a, 2019b), we assume the strength of the pro-deforestation (PRODEF) coalition to be directly related to the presence of large landowners. We therefore consider the share of the total agricultural area belonging to extremely large (i.e. larger than 20 000 ha) agricultural units. To determine the strength of the anti-deforestation coalition (ANTIDEF) we carry out an extensive literature search in five different databases in English and in Spanish (see supplementary information for details). We interrogate the databases to determine whether for each province: (a) anti-deforestation organizations existed at the time the regulation for the OTBN were discussed; (b) whether such organizations had a weak local base or (c) whether they developed a strong local base; (d) whether they had established strong links with local (provincial) institutions and/or (e) with national institutions. We expect anti-deforestation coalitions to be most effective at shaping institutions when they emerge out of a diffuse/popular base and when they display strong ties with both the national and provincial state apparatus. On this basis, we assign different scores to the ANTIDEF variable, in the following way. If no anti-deforestation existed (case (a)), then the ANTIDEF condition would take the value of 1. One additional point is assigned to the value of ANTIDEF for each additional criterion met (with the exception of criterion (c), which would give two additional points, thus assuming that having a strong base 'includes' having a weak base). As a result, the ANTIDEF condition can take a value ranging from 1 (if no anti-deforestation organization existed) to 5 (if one or more organizations existed, with a strong local base, connected to both local and national institutions). The literature search also allowed us to identify nine local experts who worked on the elaboration of the OTBN (see supplementary information). They were interviewed to validate both the PRODEF and ANTIDEF indicators for each province. The conditions and the outcomes used in the analysis are summarised in table 1, alongside the data sources.

Table 1. Outcome and determining factors. The table shows the chosen outcome variables (i.e. GREEN) and the various factors that contribute to its realization. The table also indicates the data sources and the period to which the data refer.

Variable	Description	Source	Timeframe
GREEN	% of the native forest area classified as of low conservation value (green colour)	Data available at http://estadisticas.ambiente.gob.ar	2009–2013
NATFOR	Extent of native forest area as % of the total province area	Elaboration of data available at http://estadisticas.ambiente.gob.ar	2009–2013
AUD	Extent of agricultural units with definite limit as % of total province area	Censo Nacional Agropecuario, 2002. Available at http://estadisticas.ambiente.gob.ar	2002
RURPOP	% of population classified as rural	Censo Nacional de Poblacion y Vivienda, 2001. Available at http://estadisticas.ambiente.gob.ar	2001
NONFW	% of agricultural workers classified as non-family workers	Censo Nacional Agropecuario 2002. Available at http://estadisticas.ambiente.gob.ar	2002
PRODEF	Strength of the pro-deforestation coalition. It is captured via the % of agricultural area pertaining to units larger than 20 000 ha	Censo Nacional Agropecuario 2002. Available at https://datos.gob.ar	2002
ANTIDEF	Strength of the anti-deforestation coalition. It is captured by looking at the existence of anti-deforestation groups and their organization (see text).	See text and supplementary information.	2007–2012[a]

[a] Based on extensive literature search and experts interviews.

We note that there are some differences in the timeframes of some variables (i.e. some variables refer to 2009–2013, while other to 2001 or 2002). The chosen data sources, however, represent the best available information. Moreover, the current analysis is not dynamic but relies on the variability across the different provinces. We believe that over the period 2002–2013 the interprovincial heterogeneity has not substantially changed. Such a belief is supported by the fact that, while there has been a substantial expansion of the agricultural sector across all the provinces, particularly over the period 2004–2009, the relative number of active agricultural enterprises in each province hardly changed between 2002 and 2013 (see supplementary information and supplementary table 6).

3.3. Models and analysis

Before specifying the models and performing the analysis, the raw data are calibrated and transformed into fuzzy-set data. For space reasons, the calibration strategy is presented in the supplementary information.

After calibration, we construct a new variable representing the aggregate material/economic conditions (ECON) conductive to GREEN, by taking the average of the variables AUD, NONFW and non-rural population, denoted as ∼RURPOP (i.e. the ∼ denotes the negation or complement of a variable). This procedure has the purpose of reducing the number of possible logical remainders (i.e. theoretically possible combination of conditions that are not observed in practice) and mitigate the issue of limited diversity (Pahl-Wostl and Knieper 2014). We analyse the following model:

$$\text{GREEN} = f(\text{NATFOR,ECON,PRODEF,ANTIDEF})\,. \tag{1}$$

We do test whether any of the factors on the r.h.s. of equation (1) qualify as necessary conditions (see supplementary information for details). Necessary conditions should be dropped from the fsQCA analysis, which focuses on sufficient conditions (Rihoux and Ragin 2009). In line with standard practice, we also look at the conditions that can explain the complement of GREEN (i.e. non-GREEN written as ∼GREEN). Formally this is equivalent to analysing equation (2) below. All the analyses are performed with the fsQCA software:

$$\sim\text{GREEN} = f(\text{NATFOR,ECON,PRODEF, ANTIDEF})\,. \tag{2}$$

4. Results and discussion

We begin by reporting the results for the necessary conditions. For both equations (1) and (2), we find that none of the individual factors qualifies as necessary. In equation (1) only ∼ANTIDEF (with a consistency of 0.8185 and a coverage of 0.575) comes close to the consistency threshold while passing the coverage threshold, and in equation (2) this is only the case for ∼NATFOR (with a consistency of 0.7633 and a coverage of 0.80.49).

With respect to the sufficient conditions, we present the results separately for equations (1) and (2)

Table 2. Truth table for equation (1).

NATFOR	ECON	PRODEF	ANTIDEF	N[a]	GREEN	RAW consist.	PRI consist.[a]	SYM consist.[a]
1	1	0	0	1	1	0.963	0.896	0.896
1	1	1	1	1	1	0.954	0.75	0.75
1	1	1	0	2	1	0.943	0.821	0.917
1	0	0	0	2	1	0.866	0.740	0.740
0	1	0	0	2	0	0.613	0.432	0.432
0	0	1	0	3	0	0.483	0.072	0.075
0	1	0	1	1	0	0.476	0.208	0.208

[a] *N* denotes the number of cases per row; PRI consistency (proportionate reduction in inconsistency) and SYM consistency (symmetric consistency) are two alternative consistency measures developed specifically for fuzzy set (Ragin 1999).

respectively. For both expressions, the associated truth tables have only seven rows, thus indicating that there are nine logical remainders. For this reason, we perform the analysis by seeking parsimonious solutions, which incorporate all logical remainders, and intermediate solutions, which include only easy logical remainders (see supplementary information for further details). This approach allows us to distinguish between core conditions, which are retained in the parsimonious solution, and contributing conditions, which appear only in the intermediate solution (Ragin 2009). Core conditions should form part of every solution. Contributing conditions are important and should be removed only by making strong assumptions against the existing theoretical knowledge. For completeness, we also obtain the complex solutions, which do not include logical remainders (see supplementary information).

The solutions of fsQCA display two broad measures indicating the quality of fit, both ranging between 0 (low) and 1 (high). Consistency indicates the degree to which cases that have membership in the conditions (i.e. the r.h.s. of equations (1) and (2)) have membership in the outcome set (i.e. the l.h.s. of equations (1) and (2)). Coverage measures include solution, raw, and unique coverage (Kahwati and Kane 2018). They indicate respectively the proportion of membership in the outcome that is explained by the complete solution, by each term of the solution and uniquely by each solution term.

4.1. Conditions leading to GREEN

The truth table for equation (1) is presented in table 2. For the analysis of sufficiency conditions, due to space reasons, we only display the intermediate solutions (table 3) while the parsimonious and complex solutions can be found in the supplementary information (supplementary tables 3 and 4).

The solution paths in table 3 indicate that the large extent of native forests (NATFOR) in combination with either the absence of strong anti-deforestation coalitions (∼ANTIDEF) or with an economic base oriented towards capital-intensive agriculture and a strong pro-deforestation coalition (ECON*PRODEF) is conductive to the outcome GREEN. The large extent of native forests (NATFOR) is a core condition, as it appears also in the simple solution (see supplementary table 3). This is in line with previous research indicating that provinces with large forest areas perceive forests as abundant and not in need of protection (Figueroa and Gutierrez 2018).

The first solution path in table 3 (**NATFOR**∗∼ANTIDEF), shows how the outcome GREEN occurs when NATFOR is combined with the absence of strong anti-deforestation movements (∼ANTIDEF). Formosa and Tucuman, among others, well exemplify this case. In Formosa native forests account for around 61% of the provincial area, the largest proportion in the whole Chaco ecoregion. The formulation of the OTBN in Formosa has not received much scholarly attention. However, it has been noted how the peasant movement—relevant anti-deforestation activists in Formosa—are 'weak and co-opted' (Fernández Milmanda and Garay 2019b). Our interviews with local experts confirm this. As a result, Formosa turns out to be the province with the largest share of native forest area declared as of low conservation value (GREEN), namely 74.25%. Some important caveats apply. The provincial regulation identifies two categories of GREEN. The first one, defined as a corridor where up to 20% of the area can be deforested (Torrella *et al* 2018) and a non-corridor area where deforestation can reach up to 60% (Vallejos *et al* 2021). Indeed, Formosa represents an exceptional case in that the OTBN has been formulated mainly by a team of ecologists based at the University of Buenos Aires (personal communication of one interviewee). The province of Tucuman has experienced significant deforestation in the past with most of the remaining forests falling in the Yunga ecosystem, situated on land too steep and/or in areas with too high precipitation to be of interest to agriculture (personal communication of one expert). Despite the past deforestation, Tucuman still has relatively high forest cover, which stands at about 40% of the provincial area. With respect to the presence of anti-deforestation activists, in Tucuman only two organizations have been mentioned: Pro-Yunga and Pro-Eco. The former is centred mainly around its founder, while the second is perceived as too radical. In both

Table 3. Intermediate solutions for equation (1).

Path	Raw coverage	Unique coverage	Consistency	Provinces with >0.5 membership
NATFOR*∼ANTIDEF → GREEN	0.644 128	0.288 256	0.880 779	Formosa (0.8,1), San Luis (0.76,0.69), Santiago del Estero (0.6,0.28), Tucumán (0.6,0.56), Chaco (0.6,0.84)
NATFOR*ECON *PRODEF → GREEN	0.418 149	0.062 2776	0.94	San Luis (0.76,0.69), Salta (0.54,0.59), Tucumán (0.53,0.56)
Solution coverage	0.706 406			
Solution consistency	0.884 187			

Core conditions are represented in bold.

cases, the organizations do not emerge out of a diffuse base, although Pro-Yunga is reported to have connections to local institutions (Langbehn 2013, Langbehn *et al* 2016). Overall, the first solution path shows a good coverage (both overall and unique). Notice that Tucuman also appears in the second solution path (**NATFOR***ECON*PRODEF). This path posits that alongside the core factor NATFOR, it is the prevalence of capital-intensive agriculture (ECON) and strong pro-deforestation coalition (PRODEF) that are conductive to a high proportion of GREEN. Agricultural units with clear delimitations account for a relatively high share of the provincial area, about 22%; non-family workers represent more than 24% of the agricultural workforce; about 80% of the population lives in urban areas. Overall, these factors indicate an economic structure in line with capital-intensive agriculture. Moreover, agricultural land ownership is quite concentrated. Units larger than 20 000 ha (representing 0.05% of total agricultural units) account for over 13% of the agricultural area, while units larger than 1000 ha (representing less than 2% of the total agricultural units) account for about 64% of the total agricultural area and units smaller than 1000 ha (representing about 98% of the total agricultural units) account for about 36% of the agricultural area. This suggests that the pro-deforestation coalition is likely to be quite powerful. San Luis shows a similar pattern, with about 23% of the forests classified as GREEN. The area of native forests is large, about 41% of the provincial area, the economic structure is oriented towards capital-intensive agriculture and land ownership is quite concentrated, with units larger than 20 000 ha (representing 0.7% of farms) accounting for over 20% of the agricultural area (Minaverry 2018). The second solution path also shows a good solution coverage, with Salta being the only province that is uniquely covered by this solution. Salta has 19.23% of its forest classified as GREEN. While this seems low compared to the 74.25% of Formosa, it is still above two thirds of the provinces. Salta has the third highest extent of native forest (NATFOR), covering about 53% of the provincial surface. Scholars describe the organized pro-deforestation activists in Salta (e.g. La Rural, ProGrano) as having strong ties to government and administration (Langbehn 2013). Land concentration captures this aspect quite well, with Salta scoring the highest among the Chaco provinces. Large farms (above 20 000 ha) represent about 0.5% of the agricultural units and account for over 32% of the planted area. The economic configuration (ECON) shows that capital-intensive agriculture is quite prominent in Salta. At the same time, Salta is peculiar as it is also characterised by the presence of a strong anti-deforestation movement. This aspect is discussed in the next subsection.

4.2. Conditions leading to ∼GREEN

The truth table associated with equation (2) is presented in table 4. The parsimonious and the intermediate solutions, for the sufficiency conditions associated to equation (2), coincide, and are presented in table 5. The complex solutions are displayed in the supplementary information (supplementary table 5).

The solution paths in table 5 indicate that strong anti-deforestation coalitions (ANTIDEF) or the small extent of native forests in combination with an economic structure based on extensive agriculture (∼NATFOR*∼ECON) can explain ∼GREEN. The province of Cordoba, with no GREEN area in its OTBN, exemplifies the first condition well. Cordoba has relatively strong anti-deforestation activists, including both local and international ones (e.g. Greenpeace), (Gutiérrez 2017). The Cordoba peasant's movement (MOCACO) and the representative of the Centre for Human Rights and the Environment (CEDEHA) were important players in the provincial committee for the elaboration of the OTBN (COTBN) and achieved a strong mobilization in favour of the protection of native forests (Cáceres 2015). Through their involvement in COTBN, these activists had strong links with the state apparatus. It is worth noting that while Cordoba has no GREEN areas, anti-deforestation activists heavily criticized

Table 4. Truth table for equation (2).

NATFOR	ECON	PRODEF	ANTIDEF	N^a	∼GREEN	RAW consist.	PRI consist.[a]	SYM consist.[a]
0	0	1	0	3	1	0.938	0.888	0.925
1	1	1	1	1	1	0.863	0.25	0.25
0	1	0	1	1	1	0.862	0.792	0.792
1	1	1	0	2	0	0.707	0.075	0.083
0	1	0	0	2	0	0.705	0.567	0.567
1	1	0	0	1	0	0.681	0.103	0.103
1	0	0	0	2	0	0.618	0.259	0.259

[a] *N* denotes the number of cases per row; PRI consistency (proportionate reduction in inconsistency) and SYM consistency (symmetric consistency) are two alternative consistency measures developed specifically for fuzzy set (Ragin 1999).

Table 5. Intermediate (and parsimonious) solutions for equation (2).

Path	Raw coverage	Unique coverage	Consistency	Provinces with >0.5 membership
ANTIDEF → ∼GREEN	0.467 085	0.263 323	0.745	Córdoba (1,0.99), Salta (0.8,0.41)
∼NATFOR*∼ECON → ∼GREEN	0.479 624	0.275 862	0.879 31	Catamarca (0.78,0.72), LaRioja (0.72,0.97), Jujuy (0.56,0.65)
Solution coverage	0.742 947			
Solution consistency	0.792 642			

the OTBN law 9814/2010 for allowing activities that could lead to deforestation in red and yellow zones, contravening to the requirements of the NFL (Silvetti 2013, Gutiérrez 2017). The province of Salta also appears in the first solution path. However, while Salta is characterised by the strong presence of anti-deforestation activists, the share of GREEN in the OTBN map is relatively high (and not low, as one would expect from the strong presence of anti-deforestation coalitions). The elaboration of the OTBN in Salta has been highly conflictual (Seghezzo *et al* 2017), due to the significant presence of peasants and indigenous peoples, alongside capital-intensive agricultural units (Gabay and Alam 2017). This has resulted in the province having a considerable area of yellow (medium conservation)—also termed 'social yellow' (Barboza *et al* 2020).

The second solution path (∼NATFOR*∼ECON) implies that provinces with small forest cover (∼NATFOR) and an economic structure oriented towards extensive agriculture (∼ECON) will probably approve OTBN with low proportion of GREEN. The provinces of Catamarca and La Rioja, where forest cover stands at about 24% and 11% of the total area respectively, exemplify this path well. The proportion of native forests classified as GREEN is relatively low in both provinces, standing at around 12% in Catamarca and less than 4% in La Rioja. Both provinces are characterised by an economic structure prevalently composed of small producers.

As already mentioned, the current analysis rests on the assumption that the heterogeneity across the provinces has not changed over the period 2002–2013. This assumption is well supported for the factors reflecting ECON and PRODEF, as the relative importance of the agricultural sector in the various provinces hardly changed over this period. However, we also note that an expansion of the agricultural sector took place in the Chaco ecoregion. We expect that such a development makes the case for the realization of the outcome GREEN sharper.

Summing up, HM is based on dialectics and as such it understands that the 'truth is the whole': a system emerges out of the interactions of its parts (Levins 2008). When applied to the study of a SES, HM provides important insights. First, it sheds lights on what the different parts of the system are and how their interaction does matter. Institutions should not be studied in isolation but in conjunction with the larger environmental, material/economic and cultural context. Secondly, HM posits that material/economic processes engender cultures/visions and institutions. It is not a mere chance that in the provinces with an economic structure oriented towards capital-intensive agriculture, like Tucuman for example, we also find strong pro-deforestation coalitions. Thirdly, HM emphasises the existence of contradictions, reflecting distributional issues, which can provide leverage points to transform the system. Lastly, HM explicitly recognises that cultures/visions can shape institutions and in turn impact on the material/economic sphere. Salta, again, is a good example. Here most of the native forests have been classified as of medium conservation value (yellow). Although this result is often criticised as being insufficient, one must appreciate how it follows from the

mass mobilisation of peasants, indigenous peoples and civil society in a province characterised by a strong capital-intensive agricultural sector.

5. Conclusions

Our results indicate how similar institutional outcomes can result from the interaction of differently configured parts. Take the cases of San Luis and Formosa as examples. The former province is characterised by a large area of native forests, a strong pro-deforestation coalition and an economic structure oriented towards capital-intense agriculture. The latter is characterised also by a large area of native forests, but it has no strong anti-deforestation movements. In both cases, the result is a relatively large area of native forests being classified as GREEN. Moreover, our results also show how the mobilisation of anti-deforestation actors, primarily indigenous peoples and peasants, animated by cultures/visions antagonistic to agricultural extractivism, can be very effective at shaping institutions. The case of Salta illustrates this case quite well. The practical implications of our results point to the key role of antagonistic cultures/ideas in the formation of appropriate state–society coalitions so as to resist agricultural expansion and protect the remaining forests.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Authors' contribution

Conceptualization: M G C; Data collection: M G C, S F; Data analysis: M G C; Writing—initial draft: M G C, S F; Writing—final draft and revisions: all authors.

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References

Barboza A G J S, Pocoví J M C, Venencia C, Huaranca L L, Agüero J L, Iribarnegaray M A, Escosteguy M, Volante J N and Seghezzo L 2020 Ten years of contested enforcement of the forest law in Salta, Argentina. The role of land-change science and political ecology *J. Land Use Sci.* **15** 221–34

Berkes F, Folke C and Colding J 2000 *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience* (Cambridge: Cambridge University Press)

Cáceres D M 2015 Accumulation by dispossession and socio-environmental conflicts caused by the expansion of agribusiness in Argentina *J. Agrar. Change* **15** 116–47

Collazo M A G, Panizza A and Paruelo J M 2013 Ordenamiento territorial de bosques nativos: resultados de la zonificación realizada por provincias del norte argentino *Ecol. Aust.* **23** 97–107

Crehan K 2016 *Gramsci's Common Sense: Inequality and Its Narratives* (Durham: Duke University Press)

Daly H E and Farley J 2011 Ecological economics *Principles and Applications* 2nd edn (Washington, DC: Island Press) p 544

Daly H 2015 Economics for a full world great transition initiative (available at: www.greattransition.org/publication/economics-for-a-full-world)

Ellis E C *et al* 2021 People have shaped most of terrestrial nature for at least 12,000 years *PNAS* **118** e2023483118

Engels F 1892 *Socialism, Utopian and Scientific* (London: S. Sonnenschein)

Fernández Milmanda B and Garay C 2019a Subnational variation in forest protection in the Argentine Chaco *World Dev.* **118** 79–90

Fernández Milmanda B and Garay C 2019b The multilevel politics of enforcement: environmental institutions in Argentina *Polit. Soc.* **48** 3–26

Figueroa L M 2017 ¿Estándares federales alterados? Análisis comparativo de la implementación de la Ley de Bosques en las provincias argentinas (2007-2015) *Soc. Ambient.* **13** 105–28

Figueroa L M and Gutierrez R A 2018 Enfrentados por el ambiente *Construir el ambiente—Sociedad, estado y politicas ambientales en Argentina* (available at: www.teseopress.com/construielambiente/chapter/capitulo-2-enfrentados-por-el-ambiente-incidencia-de-las-coaliciones-sociedad-estado-en-la-proteccion-de-bosques-nativos/)

Folke C, Biggs R, Norström A, Reyers B and Rockström J 2016 Social-ecological resilience and biosphere-based sustainability science *Ecol. Soc.* **21**

Foster J B 2000 *Marx's Ecology: Materialism and Nature* (New York: Monthly Review press)

Gabay M and Alam M 2017 Community forestry and its mitigation potential in the anthropocene: the importance of land tenure governance and the threat of privatization *For. Policy Econ.* **79** 26–35

Gramsci A 2014 *Quaderni del carcere* (Torino: Einaudi)

Gutiérrez R A 2017 La confrontación de coaliciones sociedad-estado: la política de protección de bosques nativos en argentina (2004–2015) *Rev. SAAP* **11** 283–312

Haller T, Belsky J M and Rist S 2018 The constitutionality approach: conditions, opportunities, and challenges for bottom-up institution building *Hum. Ecol.* **46** 1–2

Hansen M C *et al* 2013 High-resolution global maps of 21st-century forest cover change *Science* **342** 850–3

Harvey D 2017 *Marx, Capital and the Madness of Economic Reason* (Oxford: Oxford University Press)

IPCC 2014 *Climate Change 2014: Synthesis Report* (Geneva: Intergovernmental Panel on Climate Change)

Kahwati L C and Kane H L 2018 *Qualitative Comparative Analysis in Mixed Methods Research and Evaluation* (London: Sage Publications)

Kallis G and Norgaard R B 2010 Coevolutionary ecological economics *Ecol. Econ.* **69** 690–9

Langbehn L *et al* 2016 Arenas públicas, modelos de desarrollo y políticas de protección del ambiente:: la ley de bosques entre 'conservación' y 'producción *Cartografías Del Conflicto Ambiental En Argentina II* ed G Merlinsky (Buenos Aires: CLACSO) pp 141–68 (available at: www.jstor.org/stable/j.ctvt6rkxj.9)

Langbehn L 2013 Conflictos y controversias por el Ordenamiento Territorial de Bosques Nativos en Salta. La cuestión ambiental y el control sobre el territorio *Cartografías del*

conflicto ambiental en Argentina ed M G Merlinsky (Ciudad Autónoma de Buenos Aires: Ediciones CICCUS) pp 223–54
Levins R 2008 *Dialectics and Systems Theory Dialectics for the New Century* ed B Ollman and T Smith (London: Palgrave Macmillan) pp 26–49
Marx K 1990 *Capital: A Critique of Political Economy* vol **1** (London: Penguin Classic)
Marx K 2018 *A Contribution to the Critique of Political Economy* (Moscow: Progress Publischers)
Marx K and Engels F 1970 *The German Ideology* (New York: International Publishers Co)
Minaverry C M 2018 El derecho ambiental en la gestión de los bosques nativos (Espinal) en Argentina *Soc. Ambient.* **16** 157–77
Mioni W, Godoy Garraza G and Alcoba L 2015 *Tierra sin mal (Yvimarae'y)—Aspectos juridicos e institucionales del acceso a la tierra en Salta* (INTA)
Norgaard R B 1984 Coevolutionary agricultural development *Econ. Dev. Cult. Change* **32** 525–46
Oberlack C *et al* 2019 Archetype analysis in sustainability research: meanings, motivations, and evidence-based policy making *Ecol. Soc.* **24**
Ollman B 1993 *Dialectical Investigations* (New York: Routledge)
Olsson P, Moore M-L, Westley F and McCarthy D 2017 The concept of the anthropocene as a game-changer: a new context for social innovation and transformations to sustainability *Ecol. Soc.* **22**
Ostrom E 2007 A diagnostic approach for going beyond panaceas *PNAS* **104** 15181–7
Ostrom E 2009 A general framework for analyzing sustainability of social-ecological systems *Science* **325** 419–22
Pahl-Wostl C and Knieper C 2014 The capacity of water governance to deal with the climate change adaptation challenge: using fuzzy set qualitative comparative analysis to distinguish between polycentric, fragmented and centralized regimes *Glob. Environ. Change* **29** 139–54
Piquer-Rodríguez M, Butsic V, Gärtner P, Macchi L, Baumann M, Gavier Pizarro G, Volante J N, Gasparri I N and Kuemmerle T 2018 Drivers of agricultural land-use change in the Argentine Pampas and Chaco regions *Appl. Geogr.* **91** 111–22
Preiser R, Biggs R, de Vos A and Folke C 2018 Social-ecological systems as complex adaptive systems: organizing principles for advancing research methods and approaches *Ecol. Soc.* **23**
Ragin C C 1999 Using qualitative comparative analysis to study causal complexity *Health Serv. Res.* **34** 1225–39
Ragin C C 2009 *Redesigning Social Inquiry: Fuzzy Sets and Beyond* (Chicago, IL: University of Chicago Press)
Rihoux B and Ragin C C 2009 *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) and Related Techniques* (Los Angeles, CA: Sage Publishers)
Rogelj J *et al* 2018 Mitigation pathways compatible with 1.5 °C in the context of sustainable development *Global Warming of 1.5 °C. An IPCC Special Report Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (IPCC)
Saito K 2017 *Karl Marx's Ecosocialism: Capital, Nature, and the Unfinished Critique of Political Economy* (New York: Monthly Review Press)
Seghezzo L, Venencia C, Buliubasich E C, Iribarnegaray M A and Volante J N 2017 Participatory, multi-criteria evaluation methods as a means to increase the legitimacy and sustainability of land use planning processes. The case of the Chaco region in Salta, Argentina *Environ. Manage.* **59** 307–24
Sietz D, Frey U, Roggero M, Gong Y, Magliocca N, Tan R, Janssen P and Václavík T 2019 Archetype analysis in sustainability research: methodological portfolio and analytical frontiers *Ecol. Soc.* **24**
Silvetti F 2013 ¿Por qué la legislación no protege los bosques nativos de argentina? conflictos socioambientales y políticas públicas *Mundo Agrar.* **13** 21
Torrella S, Piquer-Rodríguez M, Levers C, Ginzburg R, Gavier-Pizarro G and Kuemmerle T 2018 Multiscale spatial planning to maintain forest connectivity in the Argentine Chaco in the face of deforestation *Ecol. Soc.* **23**
Vallejos M, Camba Sans G H, Aguiar S, Mastrángelo M E and Paruelo J M 2021 The law is spider's web: an assessment of illegal deforestation in the Argentine dry Chaco ten years after the enactment of the 'forest law' *Environ. Dev.* **38** 100611
Weible C M, Ingold K, Nohrstedt D, Henry A D and Jenkins-Smith H C 2020 Sharpening advocacy coalitions *Policy Stud. J.* **48** 1054–81
Winkler H 2020 Towards a theory of just transition: a neo-Gramscian understanding of how to shift development pathways to zero poverty and zero carbon *Energy Res. Soc. Sci.* **70** 101789
Wood E M 1995 *Class as Process and Relationship Democracy against Capitalism: Renewing Historical Materialism* (Cambridge, MA: Cambridge University Press) pp 76–107 (available at: www.cambridge.org/core/books/democracy-against-capitalism/class-as-process-and-relationship/B1CF64315DADA748B7FA20649BAB7746)
Zepharovich E, Ceddia M G and Rist S 2020 Perceptions of deforestation in the Argentinean Chaco: combining Q-method and environmental justice *Ecol. Econ.* **171** 106598