Reconstituting human past dynamics over a landscape: pleading for the co-integration of both micro village-level modelling and macro-level ecological socio-modelling

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Abstract—This communication tends to elaborate a plea for the necessity of a specific modelling methodology which does not sacrifice two modelling principles: explanation Micro and correlation Macro. Actually, three goals are assigned to modelling strategies: describe, understand and predict. One tendency in historical and spatial modelling is to develop models at a micro level in order to describe and by that way, understand the connection between local ecological contexts, acquired through local ecological data, and local social practices, acquired through archaeology. However, such a method faces difficulties for expanding its validity: It is validated by its adequacy with local data but the prediction step is unreachable and quite nothing can be said for places out where. On the other hand, building models at a far larger scale, for instance at the continent and even the world level, enhances the connection between ecology and its temporal variability. Such connections are based on well-improved theories but lower the "small causes, big effects" emergence corresponding to agent-based approaches and the related inherent variability of socio-ecological dynamics that one can notice at a lower scale: for instance, the emergence of social innovations can be simulated only as an input parameter. We then propose a plea for combining both elements for building large-scale modelling tools, which aims are to describe and provide predictions on long-term past evolutions, that include the test of explaining socio-anthropological hypotheses, i.e. the emergence and the spread of local social innovations.

I. Introduction

Reconstituting human past dynamics over a landscape or a territory is more than challenging:

- Modelling is a scientific methodology but also a *de facto* constructed agreement procedure among a group of scholars from different disciplines about the functioning of a society, an environment and their interactions. It is thereby subject to points of view, assumptions and considerations which, in such a comparatively very low data modelling context, are difficult to counter-argue;
- It is nearly impossible to evaluate the importance of uncertainty and random events in the course of real history. One should acknowledge that any formalization of a historical reconstitution is actually the formalization of the average and most probable history within specific conditions, hypotheses and scenarios. Extraordinary environmental events, intra-society dynamics and breakouts are thereby impossible to reposition on its right time position. Nonetheless, a reconstruction of the complex system formed by man and his environment can help us to knit a web out of the loose ends of archaeological research.

This article describes several major modelling approaches with regard to past human dynamics, with their specific strength, drawbacks and difficulties, thereby illustrating the scale gap we would like to illustrate and by then, explaining what is the methodological and epistemological orientation we plea for.

II. Modelling past rural environment-society systems

Actually, following [1], [2] or [3], three goals are assigned to modelling strategies: describe, understand and predict. As it is the fate of archaeology to draw conclusions on a sometimes very narrow database, it is necessary to continuously develop and adapt models to propose at best historical scenario proposals, i.e. actually eliminate least-probable scenarios thanks to modelling. A more achieved but less solid step is, thanks to the previous modelling construction, to cover a quite wide range of historical scenarios through a model and by then identify the driving forces and key elements of this simulated system. This achievement may allow qualifying the level of exploration of the "space of the possible and the plausible" as a validation step, thanks to the elimination of the least possible and the least plausible scenarios. A final step may be considered, i.e. validate theories and make predictions on the results of interacting system elements. Finally, following [4], this global « descriptive » methodology (considering that, without any previous analysis, one cannot determine which variable can be considered as negligible and therefore be neglected) can allow to display a formalized, simplified version of a reconstructed historical truth, i.e. to produce a

This work was not supported by any organization

series of theoretical models, each one corresponding to a "digested" research question, dedicated to the exploration of the possible variations of one or maximum two factors.

This trend of modelling the past is highly promising because it will help to solve large and theoretical questions once parameterization and calibration have been established robustly to avoid the questioning over assumed postulates. One of the most famous simulations of the past, "Understanding Artificial Anasazi" can be categorized into such a scheme at a local "terroir"[1] level: from a study case [5], several theorized modelling experiences were assessed [6; 7; 8; 9; 10; 11; 12; 13; 14].

Humans form complex groups and societies that are bound to their environment in more or less intense interactions, the imprint of which are found in landscapes. Actually, one may note that this dependency over the environmental context and natural resources allow scientists to better feature and frame the field of potential evolutions of a rural society than a urban society, which evolution is less bound to direct environmental constraints, explaining thereby that most archaeologically related investigations using models focus on rural societies.

Thus, archaeological/palaeo-environmental models can either directly analyse the social interactions between agents or use the landscape as a reference plane. The choice of the adequate modelling technique is strongly dependent on the research question but in any case, it is this co-dependency, i.e. the fact that the environment and natural resources are quickly and directly affected by human activities and at the same time these lasts are directly and rapidly affected by the availability of natural resources that explains the interest and the efficiency of agent-based modelling tools: there is in general for archaeological issues no impact of a public policy, i.e. a large transformation of the access or the state of natural resources which may affect a large group of humans. Such interactions are atomistic, i.e. they correspond to the repetition of small and direct transformations and uses of a territory at a lower spatial scale because of one or a small group of humans. De facto, they correspond well to the distributed way of conceiving large transformations of a landscape by repetitions of actions played by a multitude agents and actors that multi-agent modelling are the sole to deal with. However, the large debate initiated by [4] do have impact on the way multi-agent modelling is used for studying archaeological/palaeo-environmental issues, because they correspond to two ways of using archaeological and palaeo-environmental data for reconstituting past interactions between humans and environment: these two ways may be roughly presented following a matrix combining scales, disciplines used as inputs and drivers:

1. Scales:
   - The level of the village/hamlet (defined here along the more adequate word "terroir") unit is often used because it is the functional unit of management of a landscape, the geographic expression of a combination of rationalities that have to interact altogether. Simulating individuals under this level is impossible regarding the importance of such interactions, both direct (marriages & other social interactions but also mutual manpower support for instance). Roughly, it is the level in which micro-economic rationality can be considered, to analyse what can explain differences in the use of natural resources;
   - The level of the territory that corresponds to a culture or a group of cultures. Roughly, it is the level in which macro-economic rationality can be assessed, assuming a certain homogeneity regarding the use of natural resources within this culture comparing to others, to analyse what impacts can have an homogeneous use of these resources;
2. Disciplines used as inputs and thereby drivers: it defines what research question modellers tend to investigate:
   - Archaeology and social science is used as an input for the model and the expected results are palaeo-environmental. Changes in the model are human induced (through social transitions, social or technological innovations);
   - Palaeo-environmental data are used as inputs for the model and the expected results are archaeological. Changes are therefore environmentally induced.

Finally, and following [17], a model is a "theoretical and finalized representation of a reality formulated on the basis of situated observations, of a predefined framework that will then be applied to study cases and permits to give representations quickly". A model serves to establish structural relationships and functions existing between the factors that one would like to analyse. The objective is to determine the type of relationships existing between these factors and the weight of each factoring the relationships [18]. A model does not exist if it is only about a goal, an objective that can be problem solving, decision-support or simply experimentation [19; 20]. This definition adopts an operational standpoint, thereby insisting on the subjectivity and the need for an objective for every model. In our case, this should establish what research question is investigated with a model, i.e. what research subject and what research object is considered:

- If the subject is the history of the impact of the human expansion over a territory (which can be either the Earth itself, a portion of it or a "terroir"), the studied object is the territory, including the related natural resources, from which humans are seen solely as a transforming force, whatever the refining of the behaviour of this force can be (inclusion of innovations, etc.);

[1] The French word "terroir" is defined both geographically (the set of space managed and exploited by a village community: [15]) and socially (a socially defined territory containing a set of resources and associated rights to these resources: [16]). It is therefore a geographically defined territory, but whose definition is social: it is the geographical framework of life of a rural society. It is important to specify for the land tenure issue that the "terroir" is defined on the basis of usufruct and not of property.

- If the subject is the history of the population itself and the impact of the environment over its evolution (again whatever the size of the studied human community and the related territory), environment and related natural resources should be considered as an influencing force, even if humans itself transform the capacity of this force, and the research object is the population itself.

While it is highly promising to construct global models that integrate data of all relevant research disciplines, more local reconstructions with a narrower focus are apt to meet the needs of local to regional heritage management. The model census we have assessed non-exhaustively may lead to a classification of these models in four categories, Scale and drivers:

III. MODELLING ENVIRONMENTALLY-CONSTRAINED BUT ADAPTABLE SOCIETY-ENVIRONMENT SYSTEMS

A. *TEM (“Terroir”-based environmentally constrained models*

Following our classification, we describe here the “terroir” level models where a society and its evolution is driven by environmental constraints, regarding archaeology-originated information on its connection with natural resources, such as its tool and habitus complex.

[21] has worked over different sites of the LBK (Linear Band Keramik) culture territory in Europe: thanks to a systematic geographical census of the archaeological sites of the LBK culture over a region, the agro-ecological characteristics of the implantation sites of this culture (pedology, climate, orientation, hydrology, relative distance to other sites) can be statistically determined. Combined with what we estimates agronomy and zootechny requirements of these agropastoral systems, this methodology aims are to establish a spatial discrimination of a territory along site preferences and potentialities according to a specific culture agropastoral habits. This methodology is equivalent in [22; 23; 24; 25]. For instance, [26] tests on the Yiluo valley a combination of demographics and agriculture-based extrapolations and social assumptions based on what archaeology but also modern information provides.

[27] has formalized a GIS-based object model based on information from available and relevant literature and local archaeology data regarding environmental characteristics (soil, vegetation, local climate, distance to village) and cropping and livestock-keeping practices, to evaluate the environmental impact of human settlements over several village territories, along several farming scenarios (shifting, intensive garden and garden cultivation) but also diet assumptions. Considering that human population and density are generally accepted as the major driver of Anthropogenic Land Cover Change (ALCC), one may then use such models to confront simulated villages and village territories to real ones as excavated through archaeology. One may notice an equivalent methodology and principles in [28].

Following their work on Swiss archaeological sites [29], [30] have followed the same pattern for studying livestock-keeping needs and consequences on sustainability of

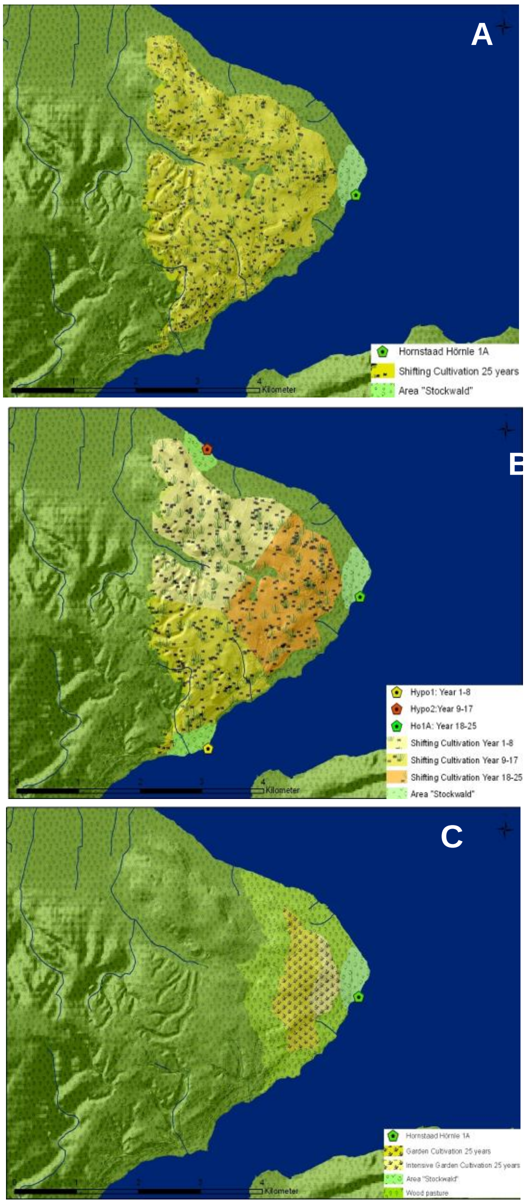

Fig.1: Simulated spatial demand for 25 years of cultivation of an assumed population of 100 people: Picture A: Only shifting cultivation, village in the settlement Ho1A. Picture B: Only shifting cultivation, with two more hypothetical 8-years long temporary settlements; Picture C: intensive/simple garden cultivation or simple cultivation, village in the settlement Ho1A.

environmental resources and livestock based farming societies: through a GIS, they have estimated the impacts on an extended village territory of the necessary livestock to both feed the population and manure the fields that are necessary to crop for feeding a population.

The research object of all these simulations is the territory and tools are GIS, archaeology and palaeo-environmental data. However, because the subject, i.e. the question differs, they are representative of the “discipline-as-input” factor differentiation: [21] used environment as input and deduce site potentialities, with the hope that further archaeological excavations may provide confirmation. [27] or [30] used archaeology as input and deduce the impact on the related territory and natural resources following various scenarios, with the hope that further carpological, palynological or any other palaeo-environmental procedures may support these modelled assumptions.

The strength of such models is to estimate upon agronomy and agroforestry-based assumptions the constraints in which agro-socio-systems may evolve. Meanwhile, they establish the maximum potential level, i.e. a carrying capacity equivalent in those specific conditions and techniques), such a society may reach but not its fragility regarding social variables and temporal “coincidences” that may (one may say even “will”) induce emergent patterns to appear:

1. The social & environmental spatial genericness: The local adequacy environment and farming practices can hardly be generalized for a spatially broader model extent: one is then forced to establish adaptation “rules” of this modelled production system, implying thereby hidden or formalized rules regarding human rationality (securization, maximisation, constraints-based sequential rationality, etc.);
2. the Social-Time genericness (innovations, adaptations): The very same problem concerning space may be applied regarding time as well: one may have to introduce evolutions of techniques, practices and/or social relations that can adapt themselves along simple (reactive, elimination) or complex procedures (learning, cognitive adaptation, etc.) to get out from the “instantness” of these models;
3. The Micro adequacies: local emergences and social differentiations: Following [31; 32; 33], once a famine or any other plague occurs, they affect only portions of the population (families, groups), mainly the most fragile ones, and not the whole population. It means thereby that only very defined and catastrophic “plagues” (for instance well-referenced and very harsh droughts), may constrain simulated populations because it constrained the whole population (see [8]; [9]; [10] and [13] on the Anasazi collapse). More generally, any social and economic dynamic may not be seen as affecting indifferently a whole population, but only portions of it, combining specific parameters (for instance at the level of a family, lack of manpower, low cropping surface per capita, bad gender repartition regarding inheritance access, etc.).

B. WEM: “World” size environmentally constrained models

Modelling prehistoric and pre-industrial society-environment systems is as well essential to understand the co-evolution of climate and humans over recent millennia and the current state of the Earth System. Such an analysis should be settled at the global scale, simply because it is the sole relevant scale for apprehending human-induced climate changes. In additional to human impacts on the environment that could have led to regional and even global climate change, many of the ecosystems that are highly valued today for the services they provide to humanity are the result of long-term interactions between society and their environment. Because detailed observations of these interactions will always be limited in space and time, global human-environment models may be useful tools to bridge spatial and temporal gaps in data and to test hypotheses about the large-scale development of society and the environment.

Despite its promise, global modelling, however presents several additional challenges compared to the “terroir scale” described above and firstly, the lack of data: The foremost among these challenges concerns data both for driving models and as an evaluation of model output. Outside of Europe and parts of East Asia, critical information on subsistence lifestyles, the timing of key transitions, and palaeo-demography needed to parameterize models is not available because of a lack of investigations in these regions or a poorly preserved archaeological record. Likewise, palaeo-environmental and ethnographic information that is highly valuable for model evaluation is largely absent from many continents where geographic conditions and local history led to poor preservation of archives, both natural and human.

Regarding the three points described in the previous sections, they obviously meet the spatial genericness criterion (a) but they methodologically do not include completely the requirement (b) regarding time: rules of the model do apply all along simulations but the model lack time-related adaptability. Finally, the point (c) is not answered as such models do belong to the (2) palaeo-environmental “Disciplines used as inputs and drivers” scheme meaning that changes are environmentally driven.

Nevertheless, there are several promising methodologies that are currently being applied to understand society-environment systems at global scale. These models may be roughly divided into two categories:

i. data-driven approach where demographic and subsistence data are inputs to the model;
ii. an “organic” approach, where the model simulates potential human population and subsistence lifestyle as prognostic variables. Both of these approaches have advantages and disadvantages and are currently under rapid further development.

The data driven approach is typified by the ALCC scenarios KK10 [34; 35] and HYDE [36]. These scenarios are the result of empirical models that take geographically distributed estimates of population at any time in the past and combine them with information on climate and soils in order to estimate the magnitude and spatial distribution of land use. The models used to generate these scenarios represent subsistence lifestyle implicitly, i.e., everyone on earth at a given time is presumed to have the same type of subsistence strategy. While HYDE makes a simplistic distinction between land use for crop or pasture based upon present-day geographic patterns of land use, it does not consider changes in per capita land use over time (intensification). In contrast, KK10 models intensification as a non-linear function of population density itself, so that low population densities use relatively large amounts of land. This difference in the representation of per capita land use among the models leads to very large differences in the global pattern of land use in the past (Fig. 2).

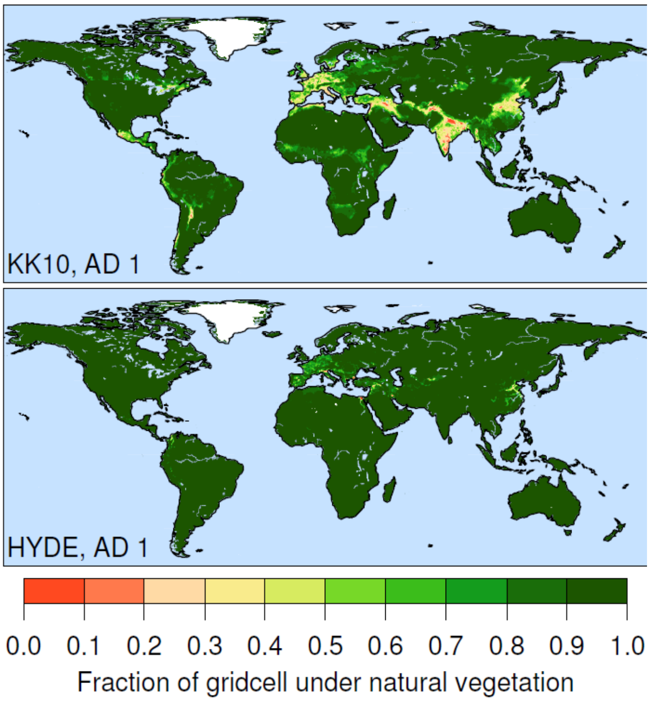

Fig. 2. Comparison between global anthropogenic land cover change scenarios KK10 and HYDE for the year AD 1. The large discrepancy between the scenarios in the maps is caused by differences in the treatment of per-capita land use. HYDE fixes the spatial pattern of per-capita land use observed in AD 1961 for all time periods in the past, whereas KK10 models per-capita land use as a function of population density, with intensification occurring at higher densities.

As noted above, neither model takes directly into account the way in which different subsistence lifestyles may use the same landscape, e.g., foragers vs. shifting cultivators vs. permanent agriculturalists vs. pastoralists. This distinction among land use types, in particular the shift from foraging to farming, may be critical for understanding the pattern of land cover change and human impact on the environment during pre-industrial time. While the agricultural transition could be prescribed in models based on archaeological records, lack of investigations or well-preserved sites implies that in many parts of the world prescription would be based on guesswork or assumptions. An alternative approach is to use a model that explicitly simulates subsistence lifestyle changes, as in the “organic” approach mentioned above.

Currently the best example of this approach that has been developed and applied at continental to global scale is the GLUES model (Global Land Use and technological Evolution Simulator [37]). GLUES simulates human population density, technological change and agricultural activity directly, based on the concept of gradient adaptive dynamics, where adoption of a subsistence lifestyle, e.g., Neolithic agriculture, by any given group of people at any particular time depends on endogenous environmental and social factors, e.g., potential productivity, population density, and exogenous factors, including the presence of farming peoples in neighbouring regions. Simple rules in GLUES, including continent size and climate, allow the model to simulate the spontaneous transition to farming in certain world regions [38]. Once farming is established, the model simulates the advection of peoples and diffusion of ideas and technology across environmental gradients. The GLUES model is driven by static maps of potential productivity and climate on regions of ca. 1000 km2 that are defined as areas of relatively homogeneous climate and productivity. GLUES can further use information on climate variability prescribed as discrete events in space and time to influence human activities and populations. GLUES prognostic outputs include population density, relative proportions of farming versus farming people in the region, and the level of technology used by the farming people. The major disadvantage of GLUES is that it may produce histories of society-environment interactions that are at-odds with reality, e.g., the spontaneous development of agriculture in places where it is not know to have occurred. Additionally, GLUES in its current form cannot simulate major technological transitions beyond the initial adoption of agriculture, e.g., metallurgy, urbanization, or the development of complex societies, with focuses on specific sites such as Western Europe [39] or the Indus civilization [40].

Such models answer the points a and b with a formal justification of the appearance of such technical innovations [41]. More globally, they cannot answer the point c:

1. Social innovations, such as socio-anthropological family evolutions and/or political structures, are less likely to be modelled, while such social innovations may have a determining impact on the “capacity” of a society for conquering new territories, following non-Malthusian hypotheses [42; 43; 41]. For instance, [44] have suggested some variations of the family structures in Eurasia, linked with the appearance of unequal families and the consequences on the cultures’ differential “capacity” of expansion.
2. The effects of “coincidences”, i.e. emergences may disappear as such conjunctions are smoothed while going at a broader scale, both socially and spatially.

IV. Modelling innovative societies in its environment

A. *TSM: “Terroir”-based society-driven models*

The focus on technical and/or social aspects of changes at the local level has been studied as well. Meanwhile, tending to answer the combination of point a and b (innovations and differentiations on one hand, and conjunctions on the other hand), such studies are de facto related to a KISS approach [4] for this specific question:

- The first possibility is theoretical models through which a question on innovations and conflicts is analysed [45; 46];
- Others are more focused on very local situations on which many data and information are available and build some archaeology and or socio-anthropology hypotheses to test, with the model as the test bed for various social and/or technical scenarios [27; 47; 48; 49].

One of the major development on modelling past local “terroirs” concerns Anasazi. The innovation there was to include social factors along environmental ones for modelling a “terroir” [12; 13]. However, the advantage of describing an “island” territory, i.e. a closed system where no influence from outside may be considered faced the default of this “island” situation: droughts did have a so huge impact that it overcomes all social configurations. Such a modelling project may be more effective in study sites where environment is not a so blatant challenge.

[50] describes a model of the LBK expansion that tend to describe a combined model that opens partly this possibility of integration: because the purpose of this model was to raise hypotheses on socio-anthropological and economic organisations and not dedicated to analyse its impact on environment, it takes for granted biophysical aspects and tends to integrate and combine environmental rules from literature and available data through inference: The use of databases from the European Commission provides the access to present-day soil characteristics (pedology and altitude), from which was deduced the pedology of the LBK period, following the soil retro-evolution methodology assessed by [51]. The World Climate project [52] provides the access to present-day climate data (temperature and rainfall), from which was roughly reconstructed the climate and its variability at that time. The palynology-based climate reconstruction of [53] provides the average Europe temperature and rainfall time deviations with present-day figures, while the World Climate project provides the statistical deviations both in terms of time (seasonal variability based on 50 years of data) and space (with a precision of 10 km x 10 km cells, transposed and adapted to 1ha-cell in the model). Within this simulated environment, family organisation and manpower availability are settled along with what archaeology and palaeo-analysis provides on the past farming system possibilities. Altogether with inferences from present-time agronomy and zootechny that both constrain the possible combinations of the farming system, such a model may be a test for testing hypotheses on the functioning of this past society. Similar models were built with the integration of demographic and social issues along environment, with environment and natural resources and stresses as inputs and variable impacts on the population evolution and differentiation as outputs such as [54] or [55].

However, building such a model based on the inevitable assumption of a common complex of society rules face the obvious argumentation from archaeologists that such an assumption cannot be applied on a so vast territory such as the LBK extent. More globally, one may question the genericness that formally comes from other sources and societies: Applying such hypotheses onto a past society implies considering them as generic and thereby applicable to broader spatial territories and cultures of the same period. If not, how can we justify the relevancy of one social hypothesis for explaining a past local combination of events from which archaeologists get their information and thereby their “selection” of hypotheses? I.e. how to extend a conceptual model that can fulfil the point 1?

B. WSM: “World” size society- driven models

Several attempts were assessed to extent the previous category of models to a global scale, with the necessity to answer the requirement a: social & environmental spatial genericness. A possible way can be seen in [56], with the assumption of a theory, in this case circuit theory, and focuses over the studied factors, movements of people in this case.

A model was tried to be assessed for answering the three points we raised (a, b: social-time genericness (innovations, adaptations), c: micro adequacies and local emergences/coincidences) for both the everyday life, including social, family and agro-ecological constraints, at the local scale and the population spatial and demographic dynamics at the global scale: The Obresoc project [57] tries to reconstitute the expansion of the LBK culture throughout non-Mediterranean Europe, thanks to the assumption that what was collected from archaeology on spots related to the same culture is valid for all the sites of the same culture, thereby assuming the genericness point a. Processes of reactive adaptation were formalized but no cognitive nor selective appearance of technical or social innovations may occur, i.e. it does not answer the point 2. Finally, the conjuncture adequacy or inadequacy between time, society and space and the related emergence was considered as the model agreed that the driving force, humans, act at the local scale, following the local modelling scheme of [50] thanks to the local connection between access to natural resources and manpower availability and that local changes may affect the dynamics at the global scale along the long era of the LBK culture. One can then consider it tends to answer the point c. However, such a local connection was erased for simplicity purposes but also for idealistic assumptions [58] thereby annihilating the emergence potential of this tentative. Similar model attempts were built with the integration of demographic and social issues along environment, and natural resources and stresses as inputs and variable impacts on the population evolution and differentiation as outputs, such as one of the most achieved ones, [59] on ancient Mayas.

More globally and following [58], hypotheses on the rationality that may have driven past societies should integrate the everyday constraints at the family or the individual level because it is at this very level that differential environmental, social and agro-ecological constraints are experienced. Without transferring directly the knowledge of present-time human socio-anthropology, inference from this knowledge, and especially the notions of conflicting and limited rationality and planning, of restricted information and interaction but also the huge impact of emergence and non-consistency of a society (for instance, the variable, seasonal and anthropologically restricted availability of manpower in such a context of labour scarcity) may see their importance in modelling past rural societies. Finally, one may conclude, following here [60], that the genericness point we raised may be partially reached through inference from “existing inferential frameworks (e.g., certain strands of evolutionary archaeology[2]) but that explicitly "sociological" simulation remains a challenge" letting impossible the access to the exploration of emergent dynamics we plea for through the points b and c.

V. Building a grid of analysis for expanding the genericness of a past society-environment model

A. Pointing out quality criteria for modelling

B. Combining four objectives for expanding model genericness

Coming back to the two series of criteria we establish, one may point out that building a model that fulfils all these requirements may be:

- Very difficult to build, both humanly and technically: it needs a lot of time to build a model with many disciplines, which means managing consortiums of thematic scholars whom the value of a model depends on the perfect spatial and temporal adequacy with specifically their own data, defining altogether within the consortium the variables to include and, even more difficult, to exclude from the model, collect or mimic/recreate the data and information corresponding to each variable of the model; more disciplines are included in a model, more building such a tool is a harsh task[3];
- Very challenging to validate: two validation steps are to be considered: confrontation with external data and sensitivity analysis [62]. As described by [63] and [62], there is no absolute validation of a model. Following [64], a theory and therefore a model is temporarily accepted until it is rejected. Field data confrontation is technically challenging but not methodologically. On the other hand, sensitivity analysis complexity increases dramatically with the number of variables which are to be integrated in a model;
- Useful under only specific conditions: outputs of a very multidisciplinary mode are harder to interpret for a monothematic scholar, meaning that the more a model is multidisciplinary; the more the use of it may be de facto restricted socially to modellers and the more publications are harsh to be published: journals are mainly thematic-oriented and model description increases with the number of disciplines, decreasing thereby their acceptance.

It means therefore that the ultimate goal of one modeller of the past is not forcefully to build the ultimate model that can answer and/or explore all the combinations of a past human-environment interaction. However, and following [65], including a variable, a factor in a model in a very simplistic way, because it is acknowledged as important, is a smaller error than not considering it:

- This is usually supported with the usual assertion concerning the lack of data. However, whatever the variable in a spatialized model, data are never fully and perfectly available, for present-time data and even more for data concerning past periods. Such a perfect source cannot exist, once we acknowledge that spatial data can be completed only through reconstructions, at least partially, based on interpolations or inferences. Thereby, lacking data can be compensated by assumptions based on inference as well;
- Following [66] or [67], models where disciplines are combined but also interact may produce emergence of unexpected phenomena. More globally, one cannot always define ex ante the impact range of many variables. This apply especially for social variables, such as availability of manpower dedicated to rural activities, which may have multiplied impacts over the transformation power of humans over natural resources;

We thereby propose the two following points:

- A methodology of model combination to answer the requirements we proposed above;
- A guideline of models according to objectives and available data;

C. Combining four objectives for expanding model genericness

Combining scale (§1), genericness (§2.1), driver criteria (§1 & §2.2), we consider that four criteria may be used for analysing the validity of past society & environment models:

1. Adequacy to scale and spatial genericness: simulation outputs correspond as much as possible to local data along time;
2. environmental genericness: the model can be considered as reproducing correctly environmental dynamics along a broad territory;
3. social genericness: the model is acceptable regarding social dynamics, including innovations' appearances, adaptations and social differentiations;
4. Validity regarding dynamics: It includes conjunctions, emergences, shocks, sudden events that may impact evolutions of a system.

The four types of models we described in the previous sections may be categorized along these four genericness paths, following Table 1:

[2] We here include as well present-time originated anthropological theories.

[3] Some co-modelling methodologies do exist such as ARDI [61]

TABLE I. CRITERIA OF GENERICNESS FOR MODELLING PAST SOCIETIES AND THEIR ENVIRONMENTS

Model types	Scale and spatial genericness	Environ-mental genericness	Social Genericness	Validity regarding dynamics
TEM	Yes: it is de facto an "instantané"	No, because of the scale	No	No
TSM	Yes, with variations along scenarios. ex.: 1 scenario = 1 innovation	No, because of the scale	Yes, with drivers ruling innovations' appearances or not, following theories	Yes, locally, thanks to social drivers. Environmental ones are less integrated because of scale
WEM	No, too broad	Yes, even with huge simplifications	Yes, with drivers ruling innovations' appearances or not, following theories[1]	No
WSM	No, too broad	Yes, through present time farming system	No (not yet?)	Yes, socially and environmentally

Based on this classification, we propose a grid of organisation of genericness expansion, along scale and inclusion/exclusion of social dynamics: once one scholar has a model corresponding to one archetype we described in table 1, different ways for expanding its genericness start from the initial model and may follow different procedures according to the genericness objective one scholar may have, following Figure 3, itself defined by the pursued research question:

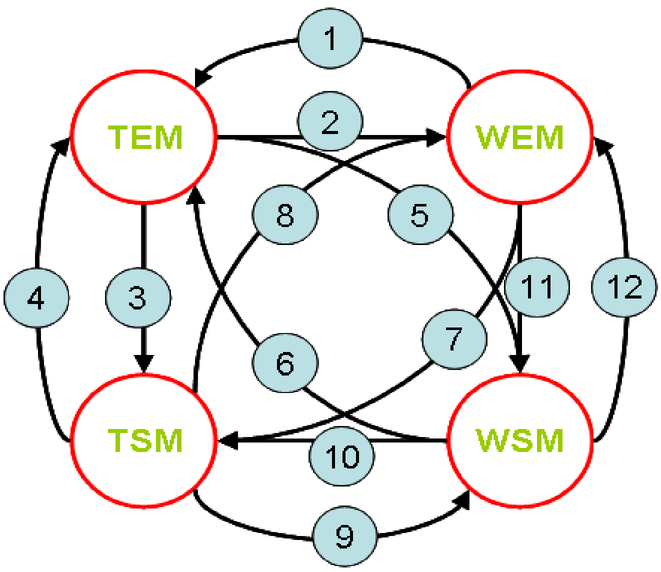

Fig. 3: Diagram of validity expansion paths, from one of the four model archetypes

These combinations of factors induces the definition of twelve pathways of genericness expansion, each one describing a methodology of model uses according to scales and drivers, each one allowing the exploration of one research question, that we described in Table 2. As a matter of fact, establishing an selection arborescence of procedures of combination and use of models according to different criteria (scale, disciplines as inputs and drivers, consistency principles, etc.) leads to so many combinations that establishing an arborescence for choosing which methodology is the most efficient for answering one scholar research question is yet to be built.

De facto, choosing a model procedure depends practically on the availability of data, inducing the methodologies: the more the model is global, the more combinations of human and environment systems may be built, the less such a system can be built along "organic" and systemic approaches and the more the model relies on palaeo-environmental data, which are more or less the sole available at this scale, i.e. a Malthusian environmentally-determined modelling of human-environment interactions.

We then plea for avoiding this over-deterministic approach, chosen mainly for its practicability and for combining:

1. The micro-level, where archaeology reduce the choice in:
   - The possible and plausible socio-anthropological societies, with no *a priori* consistency in its organization but solely in its functioning at the family level (whatever the organization of this last);
   - The possible and plausible farming and environmental systems coming from inference from present-time non-mechanical farming systems and taking account the constraints and assets from its socio-anthropological organization as defined above and of course its possible and plausible local "terroir"-level biophysical characteristics. Agronomy and zootechny may establish the agriculture consistency at the local level along a systemic "organic" approach;
   - The hazards, risks, and variabilities at the same level (epidemics, plagues, family fluctuations) but also adaptation and resilience practices in present-time non-mechanical farming societies;
2. The transition process to the global level, by losing as less as possible the richness of the local scale, through:
   - The simple iteration and juxtaposition of "terroir" models with inclusions of exchange procedures (goods, information, humans, etc.) between models, reconstituting the global level. However, this procedure requires huge computer capacities;
   - The "smart simplification" through the introduction of "terroir" agents, each agent being built based on parameters established from a sensitivity analysis of several "terroir"-like models, each one corresponding to a combined archetype of ecosystems and cultures;
3. The reconstitution of the global level, as a confrontation step:
   - A model resulting from the above procedures, to be acceptable thanks to a confidence-building confrontation with paleo-environmental data such as pollen databases;
   - An independent territory reconstitution, purposely built for confronting it with the model outputs;

TABLE II. PATHS OF GENERICNESS FOR MODELLING PAST SOCIETIES AND THEIR ENVIRONMENTS

	Methodological procedure	Related research question
1	TEM→WEM procedure:	**Integrative world models improvement approach:** Step by step improving world models by including results from various local case study models
2	WEM→TEM procedure:	**World models Testing approach:** Analysing world models results for specific locations, to compare with results from local archaeologically-constrained models; Building first trials of local models, to be compared with archaeological data
3	TEM→TSM procedure:	**Local impacts of innovations/adaptations evaluation approach:** Using a TEM model as a test-bed for analysing innovations & adaptations to shocks ‘costs/benefits’, not to compare with data
4	TSM→TEM procedure:	**Innovations appearance identification approach:** Several TSMs are tested to see if they fit better with archaeological data and TEM data: which innovations appearance and statistically-defined chaotic events explain farming system situation, sustainability AND diachronic evolution?
5	TEM→WSM procedure:	**Integrative world models improvement approach, including global shocks:** Step by step improving world models by including results from various local case study models AND integrating large scale variability (climate, for instance)
6	WSM→TEM procedure:	**World models Testing approach:** Analysing world models results for specific locations, to compare with results from local archaeologically-constrained models and timely constrained “snapshot models”; Building first trials of local models, to be compared with archaeological data
7	TSM→WEM procedure:	**Integrative world models improvement approach, smoothing local shocks:** Step by step improving world models by including results from various local case study models, including local variability & innovations
8	WEM→TSM procedure:	**World models Testing approach, including local shocks:** Analysing world models results for specific locations, to compare with results from local archaeologically-constrained models, including local variability to see if it is smoothed at large scale ;
9	TSM→WSM procedure:	**Integrative world models improvement approach, including shocks:** Step by step improving world models by including results from various local case study models, transferring local variability & innovations at a global scale
10	WSM→TSM procedure:	**World models Testing approach:** Analysing world models results for specific locations, to compare with results from local archaeologically-constrained but including innovations & shocks models; Building first trials of local models, to be compared with archaeological data
11	WEM→WSM procedure:	**Large scale Shocks impact evaluation approach:** Analysing impacts of shocks at a global scale by using a WEM model as a test-bed for analysing innovations & adaptations to shocks ‘costs/benefits’, not to compare with data
	WSM→WEM procedure:	**Large scale Innovations appearance identification approach:** Several WSMs are tested to see if they fit better with archaeological data and WEM data (once one is settled): which

4. A plan of experiences, with a series of scenarios, each one corresponding to a combination of alleles of several variables, based on the experience of the different scholars associated in model-building, assuming that a model is no more than a formalization of representations settled as a lab of experimentations.

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