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The Evolutionary Dynamics of Societies : Critical Synthesis of the Work of J.A. Tainter et al. on Sustainability, Collapse, Resilience and Energy Transitions

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Abstract

Résumé

Ce travail de master propose une synthèse critique des travaux de Joseph Tainter sur l'évolution des sociétés complexes. En 1988, Tainter publie *The Collapse of Complex Societies*, qui devient très rapidement un ouvrage de référence sur l'effondrement. La pensée de Tainter a durablement influencé les réflexions dans des champs variés autour de l'écologie et de enjeux de durabilité. L'essentiel de l'intérêt académique s'axe autour de *The Collapse of Complex Societies*. Pourtant, Tainter a (co-)publié près de 80 documents depuis 1988, la plupart avec n'étant pas relayés. Ce travail effectue une synthèse de ces documents et replace l'ensemble de la pensée de Joseph Tainter sur l'évolution des sociétés complexes. Cette synthèse met en évidence des éléments que l'auteur a développé au fil des ans, tout en essayant de clarifier certaines notions ou d'inférer leurs implications. La synthèse identifie une dynamique d'évolution des sociétés ainsi que les moteurs principaux de cette dynamique. Une approche critique est privilégiée, entre synthèse et commentaire afin d'identifier les forces et les faiblesses du modèle d'évolution établi par Tainter. Une fois le cadre théorique clarifié, le travail procède à une évaluation de la situation actuelle en discutant des options de durabilité réellement efficaces. En effet, Tainter adopte une perspective fondamentalement différente sur la durabilité par rapport aux courants mainstream ou radicaux sur la question. Cette perspective permet en conclusion d'interroger la pertinence actuelle des réflexions de durabilité tout en proposant de nouvelles pistes de recherche.

Summary

This master's thesis offers a critical synthesis of Joseph Tainter's work on the evolution of complex societies. In 1988, Tainter published The Collapse of Complex Societies, which very quickly became a reference on collapse. Tainter's thinking has had a lasting influence on thinking in various fields around ecology and sustainability issues. Most of the academic interest is focused on The Collapse of Complex Societies. However, Tainter has (co-)published nearly 80 documents since 1988, most of them with little or no coverage. This work synthesizes these documents and puts Joseph Tainter's entire thinking on the evolution of complex societies in perspective. This synthesis highlights elements that the author has developed over the years, while trying to clarify certain notions or infer their implications. The synthesis identifies a dynamic of company evolution as well as the main drivers of this dynamic. A critical approach is favoured, between synthesis and commentary in order to identify the strengths and weaknesses of the evolution model established by Tainter. Once the theoretical framework has been clarified, the work assesses the current situation by discussing truly effective sustainability options. In fact, Tainter takes a fundamentally different perspective on sustainability than mainstream or radical trends on the issue. In conclusion, this perspective raises questions about the current relevance of sustainability thinking while proposing new avenues for research.

Acknowledgments

This work owes a big share of gratitude to four special persons. My father comes first, whose generous financial support has been instrumental in securing the environment that made this work possible. My supervisor, Suren Erkman, provided invaluable intellectual guidance and respect, both prior and during the realization of this work. Our exchanges have much contributed to my critical thinking and understanding of epistemology. Joseph Tainter wrote most of the work relevant for this thesis. For his work and his inspiring attention to epistemology, I am very grateful. Finally, Pierre-Yves Longaretti's role as a supportive mentor gave me academic perspective and nurtured the desire to make a meaningful contribution to the topic.

A special thanks to my little sister who performed an express spell and grammar check.

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On a scholarly note, I'd like to thank Timothy F. Allen, Joseph Tainter, Guy Middleton and Reddit user 'Vespertine' for providing relevant information. I am especially thankful to Joseph Tainter for the opportunity to interview him. Tainter, alongside Preucel Peregrine, Suren Erkman, Guy Middleton and Mario Giampietro have send me important papers for which I am grateful.

Contents

1 Introduction

1.1 Background

What does the future consist of? Its nature is ontologically uncertain (Silberzahn, 2017), but it is possible to identify macrotrends which reduce the cone of uncertainty (Schoemaker, Day & Snyder, 2013:818). Climate change, energy scarcity and biodiversity loss are among these. The two former have been identified by a number of scholars as being the most challenging issues of the century (e.g. by Friedrichs, 2013) and the latter is gaining recognition in both academic and policy circles as ecosystemic interdependencies are recognized.

For a growing number of scholars, these macrotrends put modern societies at risk. Some observers even think that an eventual collapse is likely, should business as usual continue (e.g. Spratt & Dunlop, 2017/2018). The situation has become so tense that civil disobedience movements are emerging in many countries, demanding a major society change to avert catastrophic impacts[1].

One of the few elements of consensus seems to be a growing concern for the future. Are modern societies heading towards sustainability, collapse or an "in-between"? These are "hard" questions, which tend to be heavily influenced by people's pre-analytical visions of the future[2]. Treating these questions requires a significant degree of rigor, for their answers will be unequivocally politically received and shape people's representations.

From 1970 onwards, there has been a growing interest in academia for these questions. Multiple theoretical frameworks, conceptual propositions and discourses were developed (see Middleton, 2012). Some of the produced answers (e.g. Meadows et al., 1972/2004) have been met with harsh and often unjustified criticism (Bardi, 2011) as they questioned the *sacred value*[3] of economic growth. Some answers lack intellectual rigor (e.g. Diamond, 2005/2011) by confusing contemporary concern for the future with the analysis of the past and have been widely criticized by other scholars (see e.g. McAnany & Yoffee, 2009). Others are too specific to be operational, focusing on the past with few indications for future conduct (e.g. Gill, 2001).

[1] Like *Extinction Rebellion*, active in the UK, France, Germany, Switzerland and others.

[2] The preanalytical vision is an epistemological concept developed by Joseph Schumpeter. As its name implies, the preanalytical vision precedes the analytical effort. It shapes the latter by giving the basic elements for the analysis. Those elements are inherently subjective, as the preanalytical vision act as a reality distortion where the observer is guided either by its attention or its wishes (or both). According to Schumpeter, all humans are affected by this mechanism, including scientists. Thus, the preanalytical vision makes it impossible to achieve total scientific objectivity, because ideology can influence the analytical process by shaping the observer's perceptions. Preanalytical visions play a major role in determining beliefs, worldviews and future representations. Current future representations include: cornucopianism, neo-malthusianism, transhumanism, degrowth. See Schumpeter (1954/2006:34-9, 535-536) and Costanza (2001:459, 467).

[3] As defined by Tetlock et al. (2000): "A sacred value is any value that a moral community implicitly or explicitly treats as possessing infinite or transcendental significance that precludes comparisons, trade-offs, or indeed any other mingling with bounded or secular values".

1.2 Research focus

1.2.1 Joseph Tainter's works

One of the most influential scholars on the topic of collapse (and the epistemology of the concept) in English language is Joseph Anthony Tainter. As an archaeologist and anthropologist, Tainter produced a thorough analysis of the phenomenon of Collapse in his 1988 seminal book: *The Collapse of Complex Societies* (1990). The book was relatively well received among his peers (see Whitehouse, 1988; Chapman, 1988; Kardulias, 1989; Myers, 1989; Rule, 1989; Jones, 1989; Knapp, 1989; Rousselle, 1990), with the exception of historians (Blanton 1990; Bowersock 1991). Its influence spread far outside the field of archaeology, reaching the fields of environmental history, resilience and sustainability (e.g. Jarrige, 2015). The book appears now as a classic of the genre, which is still well considered by specialists (personal communication with Guy D. Middleton, 2 March 2019) and appreciated by the public (see Ahuja, 2012; "The Collapse of Complex Societies," 2019)[4].

After *The Collapse of Complex Societies*, Joseph Tainter progressively widened the scope of his research to the *evolution of complex societies* (author term). His posterior work includes concepts such as the effect of warfare on society, sustainability, resilience, reserve capacity, energy transitions and the productivity of invention. Some of these concepts are a direct product of the collaborations that Tainter engaged and sustained with other researchers (16 collaborations in various forms, let it be co-authoring, editing or commenting).

Starting in the new millennium, Tainter began focusing on the concept of sustainability. His unique background as a social science scientist (oriented towards long-term history) and his long-term focus produced a severe critique of sustainability thinking and a new framing of the concept. However, his perspective wasn't much echoed by environmentalists. This is unfortunate, as his critique directly challenged the possibility of sustainability as a distant objective while indirectly questioning the fundamental theoretical framework of sustainability. Should his insights be proven correct, this lack of notice will remain an important missed opportunity for environmentalism.

In total, Tainter wrote or participated in the production of more than 80 documents—including two more books—in the thirty years following *The Collapse of Complex Societies*. Most of these documents are academic (peer-reviewed articles, book chapters, proceedings of conferences, encyclopedia entries) and a small part is comprised of popular works. One third of these documents is the product of collaborations. If these collaborations have enriched and deepened the theoretical framework, Tainter's work still makes up its common thread. Most of the precision or new additions to the theoretical framework have not met the same success as the 1988 original book (in terms of citations). As a result, there is a significant discrepancy between the original diffusion of Tainter's work and the following additions.

Although roughly half of the theoretical framework on the evolution of complex societies can be traced back to Tainter's publications and collaborations after *The Collapse of Complex Societies,* there has been no attempts, either from Tainter or others to summarize the framework in a single document[5]. This is regrettable, as such a document could dramatically help specify or clarify some concepts developed in *The Collapse of Complex Societies* or in later articles, whose full implications or conceptual extensions are only explored in (sometimes unique) documents which haven't been much disseminated or read at all[6]. This situation results in a partial diffusion or lesser understanding of J.A. Tainter's whole theoretical framework and its implications[7].

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[4] As of June 2019, the book and its translations have been cited 3160 times. The interest for the book continues as of today: between March and June 2019, the book has received 71 supplementary citations.

[5] Tainter doesn't have any plan to summarize his work into a single document in the future (personal communication, 6 April 2019).

[6] This assertion is based on a per paper citation assessment as of March 2019 (see § 9.1.1).

[7] This produces three types of problems of varying degree in the literature citing Tainter: misunderstandings, misrepresentations or misuses (contrary application). See for instance : partial misrepresentation (Rees, 2002; Hardesty, 2003; Ang, 2011; Budja, 2015, Drac, 2016*, full misrepresentation (Citot, 2013; Bhowmik, 2018; Guo, 2019), partial misuse (Jarrige, 2015),

Furthermore, a close reading of Tainter's work indicates that some key concepts have been deliberately left idle by Tainter[8]. The inferences that can be drawn from these concepts have however profound implications, either for some key elements of the tainterian theoretical framework or for the most likely trajectories of modern societies[9]. These inferences reveal some significant possible conceptual extensions.

In short, there has been important additions to the tainterian framework since the publication of *The Collapse of Complex Societies*. Those additions and Tainter's critique of sustainability might have a role to play in shaping sustainability discourse. However, these additions haven't been as much disseminated as *The Collapse of Complex Societies*. A coherent and comprehensive synthesis doesn't exist and there is no indication that one is coming up.

1.2.2 Research axis

In line with the previously mentioned works (§ 1.1), this research focuses on the following question: "what are the likely evolutionary trajectories of modern societies?" In order to do so, this thesis proposes to revisit and continuing the works of Joseph A. Tainter (and associates) through a fresh synthesis of these contributions. This synthesis has several purposes:

1. Summarize the work of Tainter and associates on the *evolution of societies*;
2. Highlight key concepts or dynamics of Tainter's theoretical framework, whose significance or implications might not have been accessible to the reader of a few selected works nor obvious to the untrained eye;
3. Showcase Tainter's critique of mainstream sustainability;
4. Clarify misunderstandings, misrepresentations and misuses of Tainter's work;
5. Infer relevant conceptual extensions from the theoretical framework to appropriately answer the research question asked above. Even if those conceptual extensions have not been theorized by Tainter, their exploration can provide relevant answers for this research.

Three subquestions are proposed to guide the construction of this synthesis:

- What are the components, drivers and evolutionary dynamics of societies?
- How do the components, drivers and evolutionary dynamics affect the trajectories of societies?
- What are the robustness, limitations and foresight relevance of this theoretical framework?

The answers to the subquestions lead to the main research question, which can be further explored by asking:

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misunderstanding (because of insufficient information relative to Tainter's entire theoretical framework: Alexander, 2015). *The case of Drac is at the same time questioning and not surprising. It is questioning, because Drac is the publisher of "Le retour aux sources", the company which translated the 1988 book in French. His partial misrepresentation suggests that Drac didn't fully read or understand the book, which is puzzling for an editor. This partial representation can be however interpreted through the notorious far-right filter of the editor, which takes the wording of the original book and replaces it with its own while introducing new "arguments" (without mentioning that they are not Tainter's), only to use the whole to criticize the European Union and its elites (which he despises). This intellectual reinterpretation is shoddy, dishonest and does a disservice to Tainter's original work.

[8] Tainter indicates that some concepts having been formalized once, there was no need to come back to them afterwards. As Tainter is passion-driven (archaeology was and remains his "first love" [Tainter's terms]) and not concern-driven (as opposed, let's say, Diamond), he felt no need to showcase them anew and disseminate them (personal communication, 6 April 2019).

[9] For instance, the concept of "peer-polity" (see § 4.6). Should the concept be correct, its implications indicate that the chances of long-term sustainability for modern societies would be very slim, if nonexistent. However significant, the implications of the concept are only developed in a few papers in the 1990s and 2000s, with the bulk of the implications collected on three pages in *The collapse of complex societies* (p. 201-203), on which one has to further elaborate to get the full picture.

- How does the theoretical framework apply to modern societies?
- What can be inferred from the theoretical framework for the evolution of current societies?
- What would be the conditions for sustainability today?

1.2.3. Research objectives

Four objectives are identified to guide this research and contribute to the field:

1. Identify a model of the evolution of societies;
2. Identify its limitations and robustness;
3. Identify a set of requirements for actual sustainability according to the theoretical framework;
4. Identify conceptual weaknesses, literature gaps and objectives for future research.

1.3 Synthesis Realization

1.3.1 Methodology

This work followed the following process: sources gathering, material reading, information extraction (which has often led back to gathering through references or ideas), construction of summaries by themes, inference(s) drawing, organization of the summaries, Figure and table preparation, plan of the whole, and finally writing. Sources gathering to information extraction was extensive, with the selection of more than 90 direct or indirect contributions of Joseph Tainter (taking media appearances into account), 18 pertaining to the evolution of societies and 20 solely dedicated to reviewing the latter two (see § 9.1.1 and § 9.1.2). In the day-to-day activities from sources gathering and summary construction, the reality, the process was much more iterative and discontinuous than the ideal methodology expressed. This process also included a meeting with Joseph A. Tainter in early April 2019 as well as many insightful conversations with my supervisor, prof. Erkman and dr. Longaretti, the thesis expert.

1.3.2 Meeting Joseph Tainter and Consequences

Meeting Joseph Tainter was very instructive but provided less new information than excepted[10]. Three elements resulted from the meeting: first, the need to step back and put things in perspective, second, the decision to look for information in other places to fill apparent gaps or extend some conceptual understanding (with for instance the development of the polity evolution model) and last, the necessity to take position where no prior information was specific. This experience has been humbling, as it is confronting to take decisions. On the plus side, it allowed full appropriation to the extent that the concept was thoughtfully explored. As a consequence, some parts of this synthesis are original in regard to the consulted literature.

1.3.3 Crash course in Archaeology

At some point in the process of reading the source material, it appeared imperative to get a grasp of the contextual reality of the debates in archaeology and American anthropology[11]. As a

[10] This might be explained by the nature and object of these questions, which addressed papers and developments dating up to thirty years back.

[11] Which is quite different from its European counterpart. American anthropology is much more directed at understanding the evolution of societies than social groups or ethnicities at the subpolity level. In this sense, American archaeology and anthropology are much more related overseas than in the old continent (Tainter,

result, the following topics were explored in a 'crash' course in archaeology and American anthropology. Some ten entries (Blanton, 2013; Gibbon, 2013; Hodder, 2013; Jones, 2013; Renfrew, 2013; Robb, 2013; Sabloff, 2013; Shennan, 2013a, 2013b) from two introductory encyclopedia (Renfrew & Bahn, 1991/2016, 2005/2013) were studied. This initiative contributed to a much better understanding of the positions and interpretation of various points of contention in other works, especially pertaining to sociocultural evolution.

1.3.4 Material Organizing

Structuring the whole corpus has been daunting. With more than 130 'core' source contributions and 90 'supporting' ones, an organizing system was badly needed. As to maintain organization and structure in the accumulated data and processed data, a system of Zettlekasten[12] was used. This decision has been instrumental for the realization of this work, with more than 300 notes created. These notes, and their associated summaries, helped much of the conceptualization and writing. They allowed traceability and fidelity to the original content while allowing for creativity and synthesis.

1.3.5 Time Constraints

Intellectual activities, including writing, often almost take more time than initially planned. This is consistent with the planning fallacy, which stems from the optimism bias, that is, the tendency to overestimate one's capacities. The planning fallacy describes how individuals tend to systematically underestimate the time needed for a task completion. Task completion typically takes more time than initially planned. This is *exactly* what happened while researching, structuring and writing this thesis. As a result, not all sections are as deeply researched, constructed and well written as initially wanted. There is significant potential for betterment and deepening—although subjected to diminishing returns. The author takes full responsibility but stresses it is not a question of insufficient time investment, but more of academic techniques and surely of unrealizable ambitions relative to the available time.

1.3.6 Further remarks

Syntheses are prone to reference overpiling, with the need to cite every document mentioning the referenced information. To avoid this cumbersome tendency, this thesis uses a 'first citation policy' for clarity. This policy states that, unless relevant additional information is provided, only the earliest chronologically published reference will be cited. This policy results in an over-representation of *The Collapse of Complex Societie*s in citations relative to the entire framework[13]. This might also underline how much the book actually exemplifies the diminishing returns to knowledge, where the first installment of a theoretical framework is of much greater significance than subsequent ones. Before going on introducing the synthesis, it should be noted that the concept of evolution is recurrent in the thesis. This concept has a particular meaning for archaeologists, as it can refer to progressivist evolutionism[14]. This is not the case in this thesis. Evolution refers to the transformation of entities across time and space within constraints. These constraints can be observed through the phenomenon of selection and can be best understood in

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personal communication, 5 April 2019).

[12] Zettlekasten is a note-taking system developed by the late German sociologist Niklas Luhmann. As other people before him, Luhmann took handwritten notes which then required organizing. As to assure structure in his note collection, Luhmann came with the innovative idea to assign unique identifiers to each of his note and then symbolically link them so. This system allowed Luhmann to be immensely productive while accurate.

[13] This is however less true for the Polity Evolution Model, which combines different works published prior to the 1988 book and other later original papers and perspective shifts.

[14] Progressivists see evolution as teleological, complexity as desirable, and societies evolving towards ever more 'progress'. This doctrine was widespread in the early 20th and still has proponents, as Jared Diamond exemplifies (Cherry, 1986: 44; Tainter, 2005c:s98; 2010:710).

an adapted transposition of the phenomenon of biological evolution (see chapter 4 on the matter).

1.4 Synthesis Introduction

1.4.1 Summary

This thesis revolves around a selection of concepts of great explicative power. Figure 1.1 summarizes the main concepts mobilized by this thesis. They can be briefly introduced (proceeding from left to right and bottom-up): the best first and least effort principle states that humans tend to go for the easiest and less tiresome solutions first (within constraints). The principles drive much of the dynamic of resource extraction and human activities, which follow a pattern of diminishing returns. Diminishing returns describe the typical productive trajectory of a production system. Returns tend to increase at first, then reach a point of diminishing returns. Beyond this point, returns still increase in aggregate, but each margin diminishes. Left unattended, this process lead eventually to negative returns, that is, returns that are absolutely negative.

Socio-ecological thermodynamics stresses the importance of energy dissipation in living and human systems for their continued existence. Different resources used as energy can, however, have varying degrees of quality, or energy gain, where gain indicates the portion of energy available for dissipation. Human and living systems organize themselves according to the obtained energy gain. When high-gain resources are discovered and put to use, systems undergo significant transitions. As diminishing returns apply to resource production, energy quality typically decreases when production is intensified.

Complexity describes the degree of differentiation and control of a society. Societies are called complex because they display a level of complexity. Complexity usually steadily increases as it is a problem-solving tool. More hierarchy or more social roles effectively address new problems as they arise. Complexity evolution, however, follows a trajectory of diminishing returns, that is, the returns to complexity increase eventually decrease and can even become negative. Complexity costs. This cost is ultimately paid in energy but can also be paid in transformations of energy (energy proxies), like money, time or work. Complexity and energy closely coevolve. Complexity growth is however constrained by energy availability. A prolonged period of diminishing returns makes a society ever more vulnerable, as its energy reserves are depleted and its high cost generate disaffection from its supporting population. At this point, shocks of varying nature might trigger collapse. Collapse is a rapid reduction of an established level of complexity.

The polity situation (geographical group of political entities) determines much of the evolutionary trajectory of societies and their exposition to collapse. More complex societies organized in dominant-subordinate polity (core-periphery) configuration tends to collapse much faster because their complexity reduction doesn't imply the risk of being absorbed by another competitor. In the converse, complex societies evolving with competitors of equal complexity (peer polity interaction) and power tend to resist collapse as long as possible to prevent absorption by a competitor. This means they become ever more complex to address the threat of competition. When societies endure diminishing returns, they require energy subsidies to survive. Energy subsidies can be obtained through high-gain resource production or wealth capture through territorial expansion. Eventually, energy subsidies run out and the whole group of competitors becomes vulnerable to shocks. If collapse happens, it happens simultaneously across the competitive group of polities.

Problems cannot stop arising partly because of the nature of complex societies. Hierarchies (or elites) in complex societies require constant legitimization. Problems can be of existential nature for the polity or other. As elites seek to maintain their power, they need to constantly address legitimacy issues, or they will be replaced. As evolution didn't select humans to think long-term, their cognition displays mainly rationality in the short-term (bounded rationality). Elites are no exception. Furthermore, groups and individuals have only a limited agent capacity in respect to the dynamics of the whole society. This, and the bounded rationality of actors, explains much of why collapses are historically unforeseen and can be only prevented when certain conditions are met. These conditions require first an existential threat to be perceived and recognized by the society and its elites and second the systematic simplification of the society, that is, complexity reduction under hierarchical control. Systematic simplification resets the cost/benefit of complexity and increases the chance of survival to the existential threat. However, regular complexity growth tends to rapidly resume as the existential threat is effectively addressed and society-wide restraint no longer justifiable.

1.4.2 Chapters Organization

As the previous paragraphs underline (as shown in Figure 1.1), this process, and thus this thesis, is truly interdisciplinary in nature. Its roots are various. They originate from domains as remote as generalized evolutionism (see § 4.1) and neoclassical economics. The concepts of this thesis, and their roots to an extent, are elaborated further in this thesis:

- Chapter 2 introduces complexity, its purpose, its elaboration pattern, its relation to energy, its economics and the inner workings of complex societies;
- Chapter 3 dives into the different regimes of energy gain, energy gradients, resource quality, and resource transitions;
- Chapter 4 presents the polity evolution framework which attempts a unification of various explicative models of sociopolitical evolution, such as the core-periphery approaches and peer polity interaction. This unification is introduced by a synthesis of the recent developments in evolutionary biology and of what can be transposed to the evolution of complexity;
- Chapter 5 builds on the three preceding chapters by addressing the different possible evolutionary trajectories of societies;
- Chapter 6 discusses the various critiques addressed to Tainter's framework and other important concepts;
- Chapter 7 conducts a contemporary assessment of the situation;
- Chapter 8 concludes with an assessment of the synthesis and some recommendations for sustainability approaches.

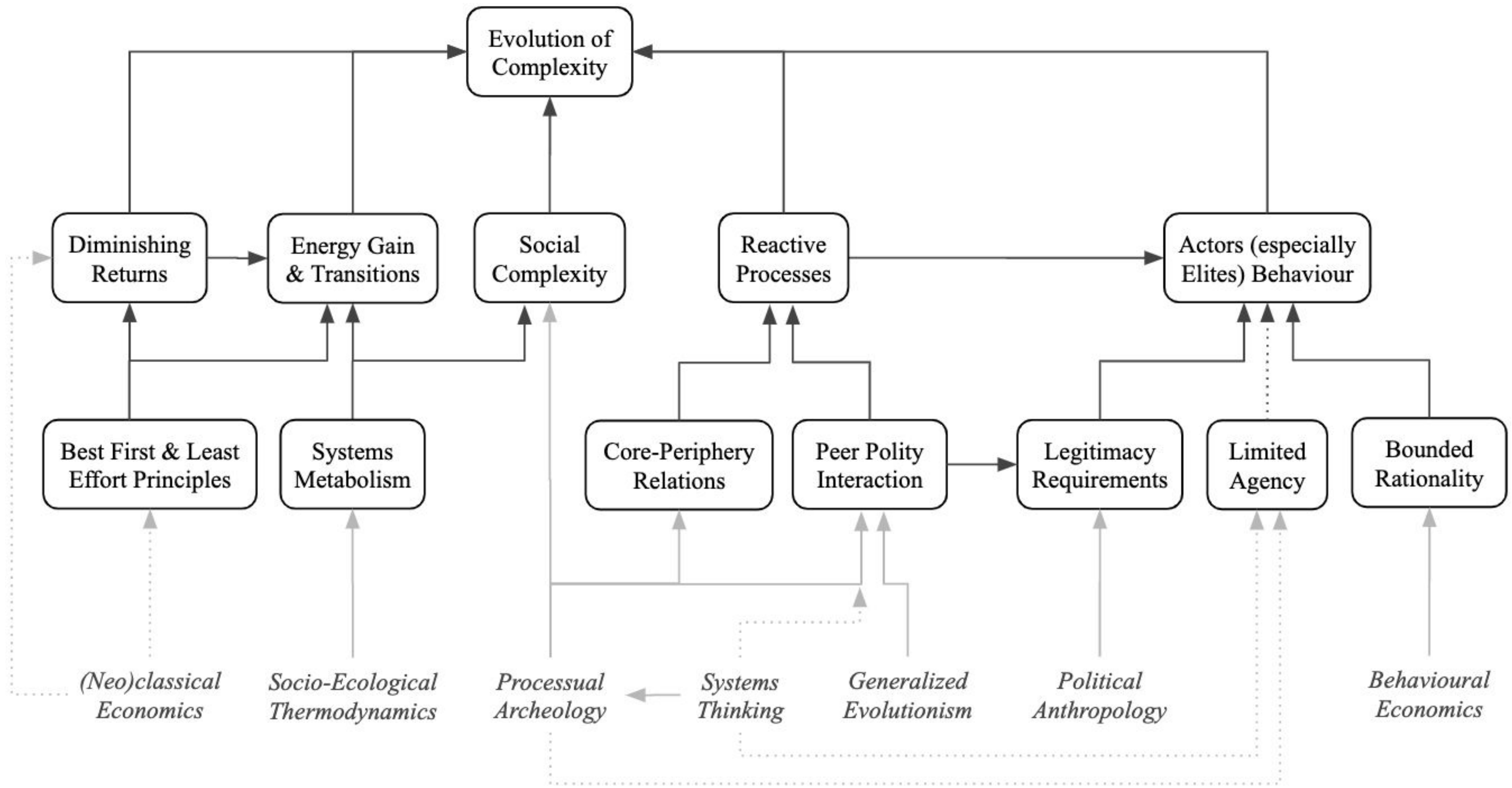

Figure 1.1. Roots and main concepts of the theoretical framework, whose purpose is to account for the evolution of complexity. Arrows indicate the constitution of the concepts or the influence upon another. Receiver boxes are constructed by emitting boxes. Grey arrows and text relate to root concepts or disciplines. Dotted arrows signal indirect connexions. Note that root concepts or disciplines are rarely, if ever, acknowledged in the corpus. The position of the concepts in the figure does not indicate their importance relative to others. The figure is intended as schema of the theoretical roots and concepts driving the evolution of complexity only. Figure by the author.

2 Complexity

Complexity is a difficult concept to handle (Taylor, 2013:60). Complexity in anthropology differs from its alter ego in mathematics, algorithmics, or even in complex system science (which it is inspired from). In anthropology, complexity is a measure of the sophistication of a society. The roots of the concept of complexity dates back to the works of Emile Durkheim on the evolution of societies. Durkheim differentiated two dimensions that changed over time: heterogeneity and inequality (Tainter, 1988/1990:23, 27). This analysis was then refined by a succession of American anthropologists (Blau, 1977; Tainter; 1977; McGuire 1983) which finally was crystallized within the work of Tainter (1988/1990) and further elaborated by his collaboration with Allen (Allen, Tainter & Hoekstra, 1999, 2001, 2003 and Allen et al., 2001, 2003). Recent scholarly contributions indicate that much of Tainter's ideas on this aspect are still relevant and in use in the literature (see Daems, 2017, 2018).

2.1 The Components of Complexity

Complexity is not an all-or-nothing characteristic. It is a continuum (Tainter, 1988/1990:4,31). Complex societies are societies that possess a degree of complexity, which tends to vary over time (Tainter, 1988/1990:4–5). More complex societies are bigger, have more parts and types of parts, have more specialized social roles and more hierarchies (Tainter, 1988/1990:23). Table 2.1 summarizes the consequences of complexity growth. Tainter refers to heterogeneity as structure and to inequality as organization. Structure refers to diversity in institutions, roles, technologies, and activities. Organization amounts to coordination through constraints. A system with much diversity is complicated. But such a system can hardly be

Domain	Consequence of Complexity Increase
Structure	More units and specialization of the units (more subgroups and specialists)
Specialization	More social, economic and technological specialization
Organization	More hierarchical levels and centralization (more coordination)
Control	More controls, both hierarchical and horizontal (bureaucratic and social)
System	More interdependence of parts and internal flows
Networks	More connectivity between the units (individuals, institutions, etc.)
Information	More flow, more information gathering and processing capacity

Table 2.1. Consequences of complexity growth. Compilation from Tainter, 1988/1990:37,91-3, 1992: 1996d; Allen, Tainter & Hoekstra, 1999:416-17, with addition and formatting by the author.

	Structure	Organization
Areas	Institutions, roles, technologies, and activities	Informal: personal ethics, social norms (peer expectations, beliefs); Formal: hierarchical directions (instructions, regulation, rules, law)
Measurements (absol. / relat.)	Width of the lowest level / width of a particular level	Number of levels of the hierarchy / higher levels contextual to lower levels
Measure	Complicatedness	Complexness*

Table 2.2. Dimensions of complexity. Note: * Complexness is a neologism as the authors conflated it with complexity. As to remove the possibility of confusion, the term of complexness is proposed. Compilation from Allen, Tainter & Hoekstra, 1999:406–414, 417–418; Tainter & Patzek:2012:189 and Ellickson, 1994:126 with additions and formatting by the author.

considered complex, because it needs constraints to make the system behave in a coherent, orderly way. In colloquial terms, one could summarize complexity to more parts, more kinds of parts and to the organization needed to make them work together. Complexity can be measured, so does its dimensions. The measure of structure is complicatedness and the measure of organization is complexness. Both can be measured in absolute and relative terms. Complicatedness is associated with width, whereas complexness relates to depth. Absolute complicatedness means the width of the lowest level of the hierarchy of the system. Relative complicatedness refers to the width of a particular level. Absolute complexness is given by the number of levels in a hierarchy. Relative complexness merely consists of the situation of one level contextual to another (Allen, Tainter & Hoekstra, 1999: 406–414; Tainter, 2011b:25; Tainter & Patzek, 2012:74-5). Table 2.2 summarizes the dimensions of complexity: structure (complicatedness) and organization (complexness).

2.1.1 Defining Constraints

Constraints are the embodiment of complexity (Allen, Tainter & Hoekstra, 2001:295). Constraints work by removing degrees of freedom of the controlled parts. Thus, constraints channel and limit behaviour, making the system more predictable (Tainter, 2012a:371; 2015a, Tainter & Patzek, 2012:74; Allen et al., 2017:2). This predictability gives coherence to the system. Constraints can be formal or informal. Informal constraints range from personal ethics to social norms like peer expectations and beliefs, while formal constraints are hierarchical, such as instructions, regulation, rules and law (Allen, Tainter & Hoekstra, 2001:295; Tainter & Patzek, 2012:72). Table 2.3 summarizes the principal types of constraints. Most constraints are hierarchical. Constraints can be active (as instruction) or passive (like delays in communication). They can be overt (a spoken rule) or covert (like social norms observance; Lobo, Tainter & Strumsky, 2012:290; Tainter, 2015a). Constraints stem mainly from organization through

Controller	Rules	Sanction	System
Actor	Personal ethics*	Self-sanction	Self-control
Social forces	Norms	Indirect sanction**	Informal control
Organization (hierarchy)	Organization rules	Organization enforcement	Organizational control
Government (hierarchy)	Law	State enforcement	Legal system

Table 2.3. Systems of constraints. Notes * Self-control through personal ethics arises from reflexion or socialisation (Ellickson, 1994:126); ** Sanctions administered by gossips, vigilantes, and other nonhierarchical third-party enforcers (Ellickson, 1994:131). Adapted from Ellickson, 1994:131.

Advantages of Hierarchies	Disadvantages of Hierarchies
Can act expeditiously mobilize resources for an effective response	Ignore the substance of signals from below (only measure their forces)
Respond quickly and uniformly to fast-developing crises over large areas	Slow movement of information to the top
Rules and responsibilities known to all	Slow or ineffective at addressing new or unusual problems
Clear decision-making chain	Expedient decisions not necessarily popular
Suppression of internal dissent	Considerable investment in coercion
Powerful security means	High costs

Table 2.4. Advantages and disadvantages of hierarchies. Selected compilation from Tainter, 1999:9; McIntosh, Tainter, & McIntosh, 2000:31; Crumley: 2005:4

hierarchies, but social groups can also limit the behaviour of their members. Specialization is a rare case of constraints arising from structure.

2.1.2 Defining Hierarchies

Constraints are especially embedded in hierarchies. Hierarchies have advantages and disadvantages. The advantages of hierarchies can be subsumed to information flow control, capacity for resource mobilization and constraint enforcement. Their disadvantages are their costs and their unpopularness. Hierarchies are specifically well suited to quickly address usual situations. In the converse, handling unusual situation tends to last longer as hierarchies must first establish procedures and boundaries of operations (Crumley: 2005:4). Table 2.4 specifies the advantages and disadvantages of hierarchies.

Hierarchies exert constraints in an active and a passive way. Higher levels always constraint lower levels (McIntosh, Tainter, & McIntosh, 2000:30). Active hierarchical constraint is straightforward like policy setting or directing an operation. Passive constraints are more subtle, but quite as frequent as passive ones. Passive constraint works by not acting, or by acting at a slower pace than lower levels. Hierarchies routinely limit the activity of lower levels by being unresponsive (Tainter, 1999b:9). This explains much of the inertia of bureaucracies, which in fact exercises constraints on all subordinated entities (McIntosh, Tainter, & McIntosh, 2000:30).

Hierarchies must be supported to work. Support is achieved by convincing people of their legitimacy. Hierarchies are mainly represented by elites. Thus, elites must continuously invest in legitimization activities to remain in power (Allen, Tainter & Hoekstra, 2003:157). This simple fact has considerable implications (see chapter 5).

2.1.3 Defining Function

Societies develop complexity because of its function. The function of complexity is to solve problems. Societies couldn’t survive if they weren’t able to solve problems (Tainter, 1988/1990:37-8). Problems can be internal or external (Tainter, 1992:106). Problems can be absolute or relative. Absolute problems are existential. They pertain to the survival of the system. Solving relative problems is optional, but often necessary for the legitimacy of the hierarchy. Problem perception can vary among different actors. Perception is most often focused on immediate problems, for remote ones are cognitively difficult to grasp (Tainter, 2007:373, 2008b:xv). This is why potential existential problems can take very long periods of time to be solved, or not be solved at all. As long as they don’t impose a perceptible existential threat, solving relative problems might not be in the best short-term interest of the society and its power holders. The need to solve relative problems is very probably not felt equally within the society. Thus, defining problems in their relative sense is a terrain for a power struggle. This explains why societies tend to respond to the need of their elites first, as they have more power to frame them

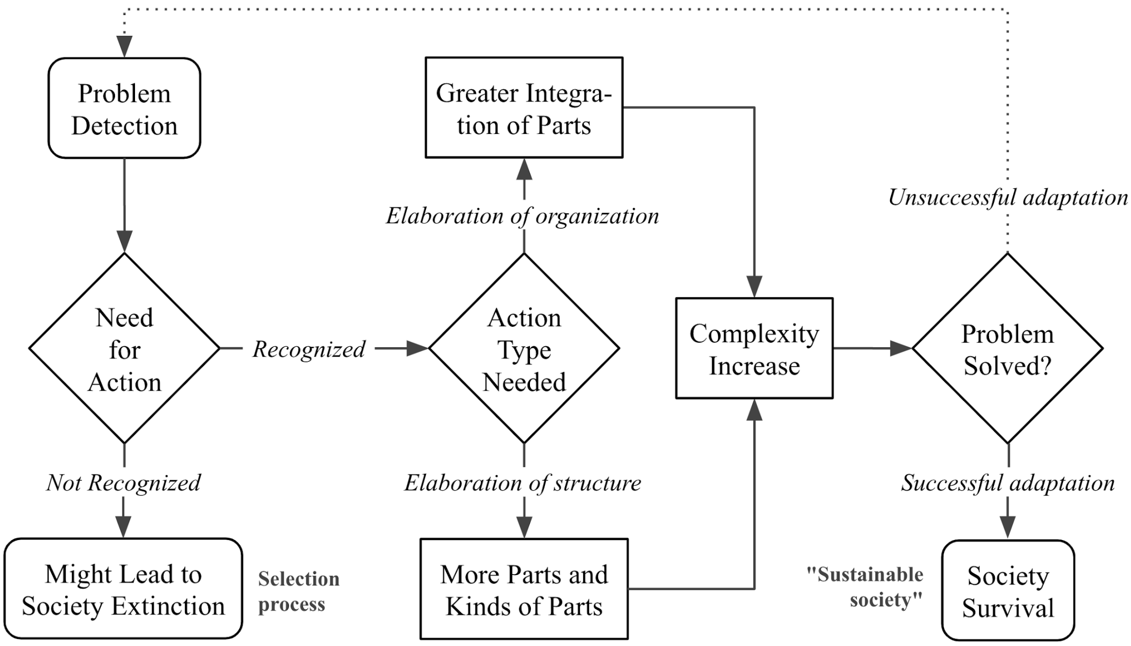

Figure 2.1. Process of complexity growth. See also 'The importance of selection' (§ 4.2.1) and 'reactive processes' (§ 4.4). Inspired by Daems (2019) and Tainter's corpus. Figure by the author.

as problems needing solutions[15]. Figure 2.1 suggests the process that operates in complexity growth.

Complexity is not only a problem-solving tool, it is also a competitive advantage. More complex societies have more powerful hierarchies. They can therefore better produce or mobilize resources in case of competition (1995: 398-9). Therefore, complexity can be considered as an adaptive strategy (Tainter, 2000b:8).

2.2 The Elaboration of Complexity

Complexity tends to constantly grow. This is because problems, either absolute or relative, continuously arise (2000b:8). Complexity then grows in two ways: in structure and in organization (Allen, Tainter & Hoekstra, 1999:406–414). Elaboration of structure equates to develop more parts and kinds of parts, while elaboration of organization corresponds to greater integration of parts (Tainter, 2000b:6, see Figure 2.1) Complexity grows as a system. This has two meanings. First, a growth in one dimension of complexity is likely to provoke the increase of the other dimension. Second, a complexity increase in one segment of the society will probably spur development of complexity in another (Tainter, 1988/1990:117). Increasing complexity will overall provoke the effects described in table 2.1.

When there is elaboration of structure, complicatedness increases. The process is described as a complication. When organization is elaborated, complexness grows. The process is called complexification. The major difference between complication and complexification is the scope of application. Complication pertains to one level of the hierarchy, whereas complexification can act on all levels. Their benefits also differ. Complication respond to immediate and local problems by adding roles, specializing production, etc. It is mainly an *ad hoc* process on ground level which

[15] The distinction between absolute and relative problems and the clarification on problem perception has been inferred from the corpus but does not Figure in it *per se* (with maybe a loose inference in Tainter, 1992:106). This understanding is capital to the development of complexity, the nature of problems can become a definitional conflict over different perceptions and values as what should be considered a problem.

occurs frequently. It does, however, the whole system to be less predictable, as organization is fixed. Complexification, on the other hand, is the product of hierarchical decision. As the pace of higher levels is slower the lower levels, complexification is thus rarer. Complexification fixes the lack of integration by restoring a certain level of constraint. This temporarily resets the cost-benefit ratio of complexity. This is why complexification tends to be far more noticed, as it underlines a contrast before and after its application, whereas complication is more continuous (Allen, Tainter & Hoekstra, 1999:406–414, 417–418). This explains much of why complexity growth tends to be most of the time unforeseen (Tainter & Patzek, 2012:208). Table 2.5 summarizes and extends the different processes of elaboration of structure and elaboration of organization. Figure 2.2 plots complexity growth (with elaboration of structure and organization) over time. The Figure is also of interest for § 2.4.2.

	Elaboration of structure	**Elaboration of organization**
Summary	More parts, more kinds of parts	Greater integration of parts
Process involved	Specialization (structural elaboration)	Integration (vertical elaboration)
Differentiation	Horizontal	Vertical
Cause	Day-to-day local problem-solving	Hierarchical problem-solving (mostly) or in following the capture of vast energy subsidies
Effects on hierarchy	Widens the span of the hierarchy (addition of new parts and kinds of parts)	Increases hierarchical depth (addition of new levels or constraints)
Effects on freedom	Introduces more degrees of freedom (because more parts are harder to control)	Removes degrees of freedom of lower parts of the hierarchy through constraints on behaviour
Effects on behaviour	Makes behaviour more complicated (difficult to control, predict, or mend)	Makes behaviour simpler (more controllable, predictable and more actionable)
Consequences	Immediate problems at the local level are solved	Structural elaborations are terminated or streamlined; the system becomes more coherent and functioning.
Costs	Increasing upfront and maintenance costs	One-time high upfront costs, relatively constant maintenance costs
Benefits	Diminishing benefits (because of diminishing marginal returns)	Partial reset of the costs and benefits of structural elaboration (until the system experiences diseconomies of scale)
Dynamic	Diminishing marginal returns	Diseconomies of scale (over the long term)
Frequency	Continuous	Occasional and sudden
Perception	Mundane	Important
Process	Complication	Complexification

Table 2.5. Principal differences in the structural and organizational dimensions of complexity. Compilation from Allen, Tainter & Hoekstra, 1999:406–414, 417–418; Tainter, 1996a, 2000d:6,8, 2006d:92, 2011b:89-90, 2013b:2; Tainter & Patzek:2012:189 with additions and formatting by the author.

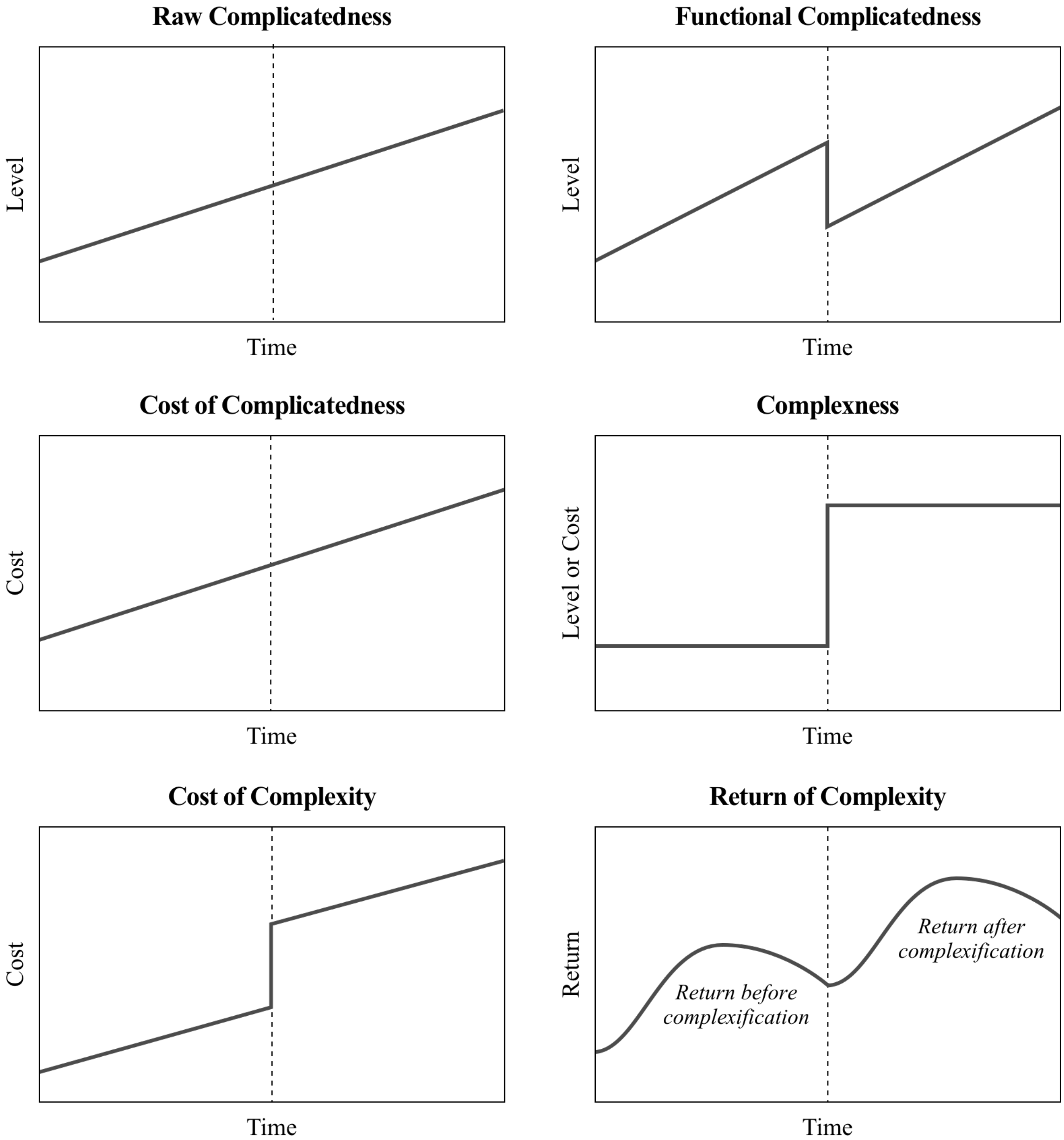

Figure 2.2. Complexity, complicatedness and complexness growth over time. The dotted lines correspond to the same moment. Graphs redrawn from Allen, Tainter & Hoekstra, 1999:418 with additions.

2.3 The Energetics of Complexity

Energy is indissociable from complexity. It is, according to Tainter, the "true cost of complexity" (Tainter & Patzek, 2012:79). There are two reasons for this: entropy & metabolic requirements and coevolution. In summary, all physical systems are subject to the second law of thermodynamics[16]; Complexity and energy closely coevolve together, pulling one when the other increases. This section summarizes Tainter's view on the relationship between energy and complexity. One should note here that the energetics of complexity might not exactly follow a physical analysis, although it is clearly inspired from it. As with other social science thinkers, Tainter's appeal to energy must be judged not for its inexact analogies with energy in physics, but for its greater relevance in anthropological terms. For instance, Tainter uses energy and resources

[16] Thermodynamics is the "science of admissible conversions of energy" (at least, one of its aspects, Tainter & Patzek, 2012:24).

interchangeably and refers to energy extraction as energy production. One cannot really "produce" energy. For the sake of the synthesis, the original wording will be kept while acknowledging its inaccuracy from the physics perspective. This point also applies to chapter 3.

2.3.1 The Thermodynamics of Complexity

The second law can be approximated as follows: the quality of resources (including energy) deteriorates over time (Tainter & Patzek, 2012:25). In other words, entropy (disorder) continuously increases until it reaches thermodynamic equilibrium. The thermodynamic equilibrium is a state where no energy exchanges take place within the system. Entropy rates vary according to the nature of the structure. Thus, for a system to remain stable, a continual flow of resources (including energy) must be fed into the structure (Tainter, Scarborough & Allen, 2018:329). The concept can also be approached from a metabolic angle. All socio-ecological systems operate at a certain metabolic rate, meaning they require an equivalent flow of resources (namely energy) to ensure their basic functions and remain in existence (Tainter, 1988/1990:91; Taylor & Tainter, 2016:1006). Remove energy from the system and it ceases to exist (Allen, Tainter & Hoekstra, 2003:335). It is no different for complex societies.

The fundamental influence of energy on complexity can be specified as follows. Complexity carries a metabolic cost. When complexity increases, its metabolic rate increases accordingly. More complex societies have a higher metabolic cost than simple ones; they require a greater energy amount per capita (Tainter, 1988/1900:91, 2011b:26, 2019a:86). Similarly, Tainter sees complex societies as thermodynamic structures. The more complex the structure, the farther its position from the thermodynamic equilibrium (Tainter, 2017:41). In living systems, complex societies included, thermodynamic equilibrium means extinction. The farther a system is from the thermodynamic equilibrium, the more energy it requires to prevent entropy and remain in existence in its present form (Tainter, 2017:41; Tainter, Scarborough & Allen, 2018:329).

2.3.2 The Energy-Complexity Spiral

As mentioned, energy and complexity coevolve together. Tainter terms this dynamic the 'Energy-Complexity Spiral'[17]. The spiral—portrayed as a double helix—stresses how energy and complexity mutually interact as two poles of an equation (Tainter's wording, Tainter, 1988/1990:91; Tainter & Allen, 2015:2). When complexity increases, or decreases, so does energy flows and vice-versa (Tainter & Patzek, 2012:198). It is a system of positive feedback (Tainter & Patzek, 2012:192). The idea behind the energy-complexity spiral has long been recognized by anthropologists (e.g. White, 1949), but Tainter's metaphor specifies three ways in which this interaction works[18] (Tainter & Patzek, 2012:94; Tainter & Allen, 2015:2):

1. Solving problems increases complexity, which compels energy production;
2. Surplus energy causes complexity to grow;
3. Energy production needs complexity (organization) to aggregate surpluses.

Figure 2.2 summarizes the three ways in which energy and complexity interact in the spiral.

[17] The concepts stems from an original disagreement between Allen and Tainter pertaining to the drivers of complexification (elaboration of organization). Allen's viewed complexification arising from energetic positive feedbacks, whereas Tainter's saw it as an hierarchical decision (in the prolongment of his previous work). The confusion is manifest in Allen, Tainter & Hoekstra (1999, 2001a:480-2), then acknowledged by the authors (2001b:297), who also stress the need for new terminology. The problem is eventually settled in Allen et al. (2003) in an important paper. The paper formalizes the concepts of Energy Gain and Resources Transitions, which build up on complexification arising from positive feedbacks (see chapter 4). This solution recognizes that complexification can be the outcome of both hierarchical decisions, which is the case most of the time, and from positive feedbacks following a high-gain resource transition (see chapter 3). The solution was so well-suited that Tainter then integrated complexification arising from positive feedbacks in the concept of Energy-Complexity Spiral (2011b:26).

[18] While the concept is the product of Tainter's later works, the mutual interaction of energy and complexity was already clearly stressed in his 1988 opus (see 1988/1990:92).

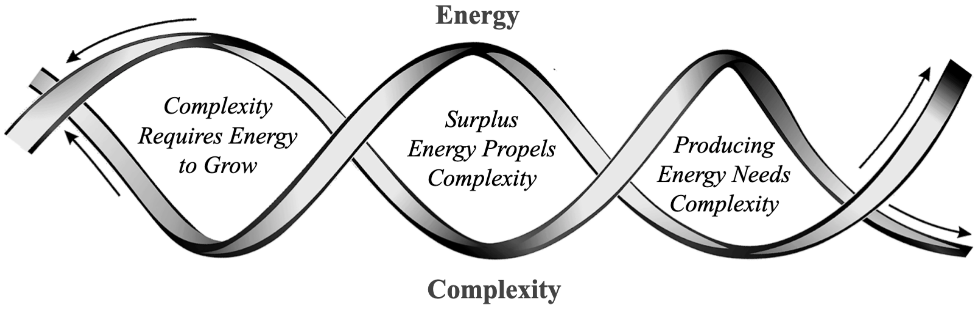

Figure 2.2. The energy-complexity spiral (represented by a double helix). Energy and complexity coevolve together and interact in the three ways shown between the helix. Adapted from the helix of Tainter, 2011b:26 with additions by the author.

The most common interaction is the first one, that is complexity requiring energy to growth. Day-to-day problem solving, followed by hierarchical problem-solving is the main driver behind increasing complexity. In this way, complexity usually compels energy production to sustain the new established level of complexity (Tainter, 2011a:92). This way illustrates how, most of thetime, complexity appears *before* there is additional energy to support it and thus compels energy production. The second way is a rare alternative to the first one, with complexity emerging *after* new energy has been made available. This propriety is a normal characteristic of ecosystems, which complexify in the presence of additional energy. That phenomenon follows Howard Odum's 'Maximum Power Principle', that is, the tendency of biophysical systems to process the maximum rate of energy whenever possible. For Tainter, human societies are no exception (Tainter & Patzek, 2012:93; Taylor & Tainter, 2016:1007-8).

This phenomenon can be explained with the third way in which energy and complexity interact: producing energy needs complexity. Energy surpluses are useless if they cannot be effectively aggregated. Increasing organization serves this purpose (Tainter & Allen, 2015:2): processing information and elaborating constraints to make energy production economically profitable. This necessity also applies to the intensification of energy production. Back to the second way, this process results in the increase of both energy consumption and complexity. In summary, surplus energy generates complexity because it needs complexity to be exploited. This creates a positive feedback loop where complexity and energy consumption mutually increases (Tainter, 2011a:91-2).

Increasing energy consumption is not without its drawbacks. As the essence of energy consumption is energy degradation, which produces entropy. The process creates all sorts of entropy-related problems (such as waste, climate change, etc.). These problems add up to those generated by diminishing returns to energy production (see § 2.4.2). Should these problems be solved, then complexity would increase, requiring an intensification of energy production, which then requires more complexity, etc. This feedback loop constitutes a fourth way in which energy and complexity coevolve in the spiral with the problems generated by energy production. Figure 2.3 summarizes how the different interactions between energy and complexity are mutually reinforcing. These relations will be further developed while discussing the concept of energy gain and resources transition (chapter 3).

2.4 The Economics of Complexity

2.4.1 The Cost of Complexity

If energy is the true cost of complexity, how is it paid? That cost can be paid for directly or indirectly in two 'currencies': energy or energy surrogates. Paying the cost directly in energy is

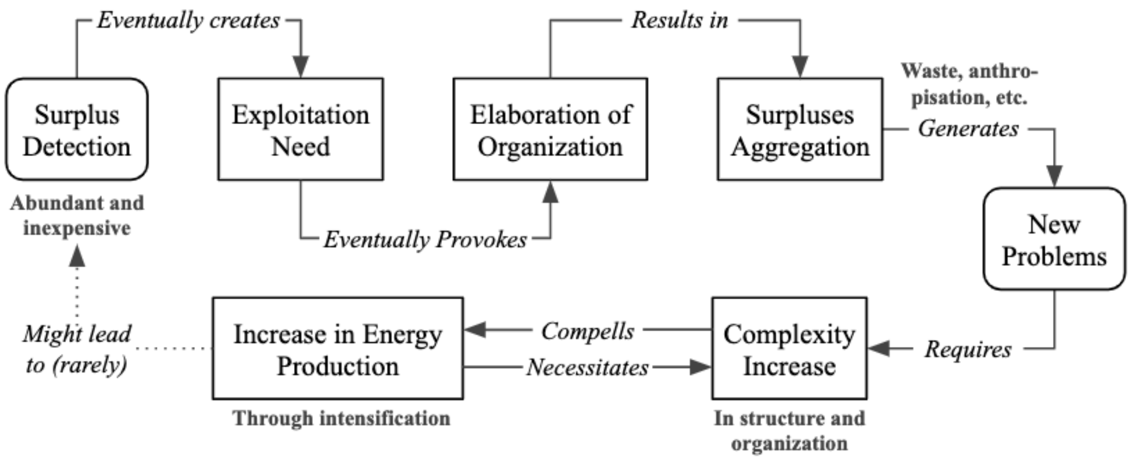

Figure 2.3. Different processes in which energy and complexity interact and mutually stimulate with each other. Figure by the author.

uncommon as it taps directly into a resource flow (like solar radiation) or a stock (as fossil fuels)[19]. Most of the time, the cost is paid in energy surrogates, which are the products of energy (Tainter & Patzek, 2012:79). Specifically, energy surrogates are the products of the transformation of energy into matter or time. Energy surrogates might take the form of labor, money or even annoyance and stress[20] (Tainter & Crumley, 2007:71; Tainter, 2013b:3). Energy surrogates can be used to either fabricate the products of energy or acquire them by trade (Tainter, 2019a:89). Both energy resources and energy surrogates operate under the laws of thermodynamics, meaning that left unattended, their quality (concentration) tend to depreciate over time (Allen et al., 2010:540). While energy surrogates are very useful to pay the cost of complexity (see box 2.1), the ultimate resource remains solely energy (Tainter, 2013b:14).

Box 2.1. The role of money and debt in the development of complexity

The role of money as energy surrogate is central in the development of complexity. As the most common energy surrogate, money facilitates direct access and use to other resources and energy surrogates (Tainter, 2019a:89). Money also permits the development of debt.

Both money and debt allow to acquire today goods of services, which are the transformation of past energy and energy surrogates. While money (earned) is the product of past energy and energy surrogate, debt is a commitment to future energy production. To be more specific, debt compels the production of future value to repay the indebted amount, thus requiring energy and energy surrogates (mainly in the form of labor, which is the energy transformation of matter and time). In summary, money uses past energy and debt bets on future energy. Money can also stimulate future energy production by paying in advance.

Both money and debt are time-shifting strategies of energy, where the products of today's energy production are to be repaid by the production of future energy production. (Tainter, 2019a:99). Thus, both money and debt play an important role in securing the supply of future energy. In doing so, money, debt and their fiduciary derivatives (like gold) can power entire societies and facilitate payment of the cost of complexity.

[19] The distinction between the two reflects the distinction between renewables and non-renewables resources. However, this dichotomy is observer-dependent, as most of the stocks are in fact very slow flows (with the possible exception of metallic deposits). The observer recognizes them as stocks because of his time-constrained perspective, although stocks can be 'renewable' in the very long-term. This is why the time scale of analysis is critical when determining stocks and flows (Allen et al., 2009:591).

[20] The relation of energy with time might be less straightforward than with money. Tainter describes this relation within social systems as such: "Time is money, in a popular saying [...] Time is also energy [...] We save time (or try to save time) by substituting the work of energy-consuming appliances. Wastage of time (i.e., energy) produces annoyance, and the perception that we have not enough time leads to feelings of stress" (Tainter & Patzek, 2012:79).

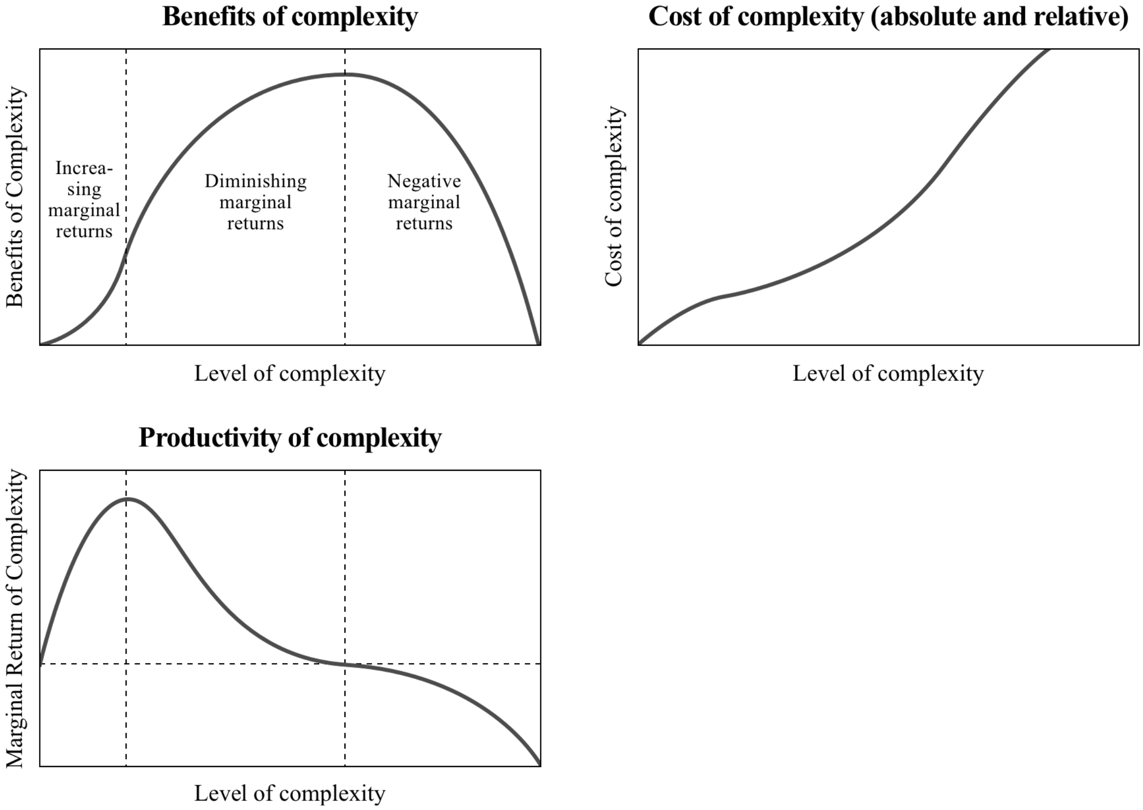

Figure 2.4. Evolution of the returns, marginal returns and costs to complexity of diminishing returns. Inferred from Tangri, 1966:487-8 and Pindyck & Rubinfeld, 2018:209–279.

2.4.2 Complexity as an Economic Function

Complexity can be analyzed as an economic function, which has costs and produces benefits (Tainter, 2000b:8). Thus, societies invest in complexity while expecting a return (Tainter, 1995:399). But each unit of investment doesn't produce the same benefit. As other production functions, complexity as a whole also follows the law of diminishing marginal returns. The 'law' is more of a principle but its prevalence has been widely acknowledged. The principle states: "as the use of an input increases with other inputs fixed, the resulting additions to output will eventually decrease" (Pindyck & Rubinfeld, 2018:218). This means that the marginal return, that is, the difference in output per each increment in input. Applied to complexity, the law indicates the returns of complexity will eventually decrease[21]. Economic functions subjected to diminishing returns typically display three phases. In the first phase, the returns increase: benefits (the economic output) increase faster than costs. In the second phase, the returns diminish while still being positive: costs increase faster than benefits. In the third phase, returns become negative, costs still increase while benefits actually decrease. Table 2.5 summarizes this phenomenon, while Figure 2.4 visually explores the cost-benefit relation and Figure 2.5 indicates the various shapes of the diminishing returns curve.

There are two main reasons for this, which are related: the best-first principle and the least effort principle. Both have profound implications. The best-first principle is the human tendency to use the resources with high return on investment first. That means, to exploit first resources (sources of energy and raw materials) that are most profitable to find, extract, process and transport to where they will be used. The best-first principle operates within constraints, these

[21] This holds for both structure and organization. In fact, the law of diminishing marginal returns might only hold for the returns to structure. Although Tainter doesn't mention it as such, it is likely that the returns to organization are subjected to diseconomies of scale. In economics, diminishing marginal returns apply to production function where one factor is fixed. This factor is organization. When there are no fixed factors, economies and diseconomies of scale apply (Pindyck & Rubinfeld, 2018:209-279). This is why considering both diminishing marginal returns and diseconomies of scale make sense while preserving Tainter's original insight.

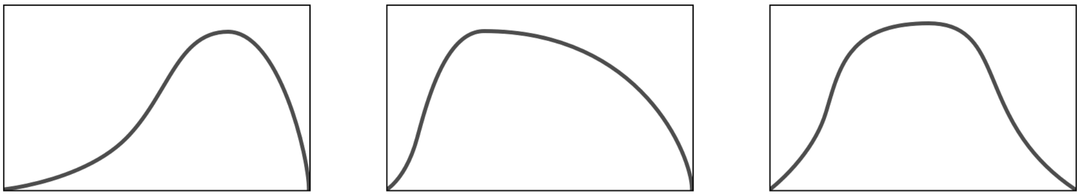

Figure 2.5. Different shapes of diminishing return curves. These curves are, with exceptions, not symmetric because the rates of growth and decline operated to changing dynamics. Inspired by Beattie, 1974:109.

being to know what resource is best and to have the means (technological, economical, etc.) to obtain and process it (Tainter, Scarborough & Allen, 2018:329). The least effort principle is the natural propensity of humans and animals to try to accomplish a task at the least perceived cost (Tainter & Patzek, 2012:99). In practical terms, the principle implies that humans take the path of least resistance whenever possible. If a task can be done more efficiently, meaning in a less energy-intensive way (for the same result), humans will do it this way. Both the principles imply that problem-solving systems are likely to use the easiest, most effective and least demanding solutions first, which eventually leave no alternative than to adopt costlier and less effective solutions next (Tainter, 1988/1990:92, 117).

Returns	Benefits	Costs	Cost-benefit relation
Increasing	Increasing at an increasing rate	Increasing at a decreasing rate	Costs below benefits. Benefits rising faster than costs.
Diminishing	Increasing at a decreasing rate	Increasing at an increasing rate	Costs below benefits. Costs rising faster than benefits.
Negative	Decreasing	Still increasing at a more increasing rate	Benefits below cost. Cost still rising even as benefits are negative.

Table 2.5. Phases of diminishing returns. Inferred from Pindyck & Rubinfeld, 2018.

3 Regimes of Energy Gain

It takes energy to get energy (Tainter & Patzek, 2012:5). This simple reality has important implications on the relationship between energy and complexity. The concept of Energy Gain emphasizes these implications. Gain refers here to either the return on investment or the net return after subtraction of expenses (Tainter, Scarborough & Allen, 2018:328). These two notions are interrelated and express the same thing in different ways. The application of the concept to energy is not new, in fact, it has been formalized since the works of Howards Odum and then expanded by Charles Hall as Energy Return on Investment (EROI) (Tainter et al., 2003:1)[22]. Here, energy gain describes either the amount of energy necessary to make a resource unit available to society or the net gain from the operation. The conflation of the two notions might be confusing for some. However, the concept of energy gain invites to consider the broader dynamic at play: is the return on investment or its net return either high or low? In other words, is the energy gain high or low? This indication has profound repercussions for the evolution of complexity.

Allen & Tainter contributions on the concept concentrate on the different dynamics that complexity and energy production exhibit when energy gain is either high or low, or varies between the two. This extension of the concept allows for a typologization of the characteristics of complexity between both ecosystems and societies subjected to either high- or low-gain energy supply (although this section only focuses on human systems). These characteristics have been tested across systems and indicate several regularities in time, space, and biota (Tainter et al., 2003:1; Tainter & Allen, 2015:15). The advantage of this approach is that its biological focus makes it less likely to be permeated by value-judgments (Allen et al., 2001a:482). Analyzing human societies through the lens of high- or low-gain systems highlights patterns in energy exploitation behaviours and in evolutionary strategies (Allen et al., 2001a:482; Allen et al., 2010:538; Allen et al., 2010:537). These regularities appear strong enough for Allen & Tainter to warrant further generalizations (Tainter et al., 2003:1). Before going into the implications of different regimes of energy gain (Tainter, Scarborough & Allen, 2018:328), two concepts must be introduced: energy gradients and resource quality. These concepts form the base of energy gain. (This chapter should be interpreted with the same caveats expressed in § 2.3 regarding the use of physical notions of energy and their application to societies. The chapter summarizes Tainter's & Allen's concepts of energy. While these concepts might not correspond to their equivalent one in physics (or even distort them), the generalization between high- and low-gain systems is of greater relevance. These generalizations should be judged for their explicative potential and not their accuracy in physical terms.)

3.1 Energy Gradients

An energy gradient represents the (symbolic) difference of potential energy between two states. Gradients are commonly portrayed as a slope, which can be either steep or shallow

[22] Odum termed 'energy transformity' the ratio between emergy (embedded energy) over the energy obtained. (Tainter et al., 2003:2).

Description	Steep Gradient	Shallow Gradient
Temperature	Hot—cold	Warm—cold/Hot—warm
Water flows	Headwater—valley floor	Mid reach—estuary/Valley floor—mid reach
Biomass	Wood—ashes	Charcoal—ashes/Wood—charcoal
Wealth	Rich—poor	Modest—poor/Rich—modest
Power	First world—third world	Second world—third world

Table 3.1. Examples of literal and metaphorical gradients. Data from Allen, Tainter & Hoekstra, 1999:410 with additions and formatting by the author.

(Tainter & Patzek, 2012:186). Gradients can be literal or metaphorical (Tainter, Scarborough & Allen, 2018:331). Table 3.1 shows several examples of gradients. Gradients can be applied to resource use. In this case, the gradient is the difference between the quality of a resource before and after use (Tainter & Allen, 2015:11). A great difference indicates a steep gradient, whereas a shallow difference is evidence of a shallow gradient (Tainter et al., 2003:3). Energy is produced by dissipating gradients, meaning decreasing the difference of potential energy between the starting and the ending state. Reaching the ending state terminates energy production (Tainter & Patzek, 2012:187). For instance, dissipating wood with fire generates energy (in the form of heat and light) until only ashes remain. No further energy gain can be extracted from ashes.

Gradients are useful to understand the variation of energy gain in society for the same resource. Gradients can be analyzed in two categories: absolute or effective. Absolute gradients refer to the state of a resource before and after dissipation. Effective gradients take into account the cost of resource production. Any cost increase reduces the effectiveness of the gradient (Tainter, Scarborough & Allen, 2018:332). For instance, coal can present a very high energy gradient. This gradient is likely diminished when production costs are subtracted from the energy produced by burning coal. Steep effective resource gradients deliver high net energy gain and shallow effective gradients produce low net energy gain. Effective gradients thus determine the gain category of resources (Tainter, Scarborough & Allen, 2018:330-1).

3.2 Resource Quality

Resource quality translates energy gradients in a useful way for analysis. The concept of resource quality goes beyond simple energetics by integrating the dynamic effects of sociotechnological factors in resource use. The concept is therefore more suited to describe resource production in human systems. Building on effective energy gradients, resource quality is determined by two factors: the return on investment or resource production (or net return as previously mentioned) and the resource utility to society (Tainter et al., 2003:2; Taylor & Tainter, 2016:1019). The return on investment varies according to several factors: the resource type, the deposit quality (for mineral resources) and the ease of extraction, which changes with technology (Tainter & Allen, 2015:3). The usefulness of a resource is determined by two contexts: the technological level of a society and its economy type.

Technology significantly increases or reduces resource quality, for its development state can make the overall resource exploitation (location, extraction, processing, distribution) economic or not (Tainter et al., 2003:2). The authors give the following example: "Petroleum [. . . gives an effective high-gain] today largely because it occurs in liquid form. As a liquid, it can perform more useful work per unit of heat equivalent in today's technologies than can coal. Conversely, when Watt was developing his steam engine, the heat value and liquid form of petroleum were of little use, because the new technologies of that day required wood or coal" (Tainter et al., 2003:2).

	High-Quality Resources	Low-Quality Resources
Gradient	High (steep energy degradation)	Low (shallow energy degradation)
Concentration	Denser (energetically, nutritionally, symbolically)	More dispersed (energetically, nutritionally, symbolically)
Accessibility	More accessible	Remoter
Distribution	Locally abundant but globally scarce (relative to the production unit)	Locally scarce but globally abundant (relative to the production unit)
Production	Easy, energy efficient (requires less work), cheap	Difficult, energy intensive* (requires more work), costly
Energetics	Farther from primary production and so from thermodynamic equilibrium	Closer to primary production and so to thermodynamic equilibrium
Dynamics	Subject to depletion	Less subject to depletion
Examples (relative to the context)	Fossil fuels, surface concentrated ore deposits, giants shallow pools of oil	Solar and wind power production, low-grade mined powder, deep offshore fragmented oil fields

Table 3.2. High- and low-quality resources summaries. Note: * Necessity to invest dig deeper, more work to maintain production levels, in often more difficult conditions while generating more waste. Selection and arrangement from Allen et al., 2001a:482; Allen et al., 2017:226, 232; Cleveland (2008); Lobo et al. (2017:67,76); Taylor & Tainter (2016:1019); Tainter & Allen, 2015:10; Tainter et al., 2003:2; Tainter, Scarborough & Allen, 2018:329, 340 with additions and formatting by the author.

Resource quality might vary in response to technological and economic development and is therefore dynamic.

High quality resources differ from low-quality resources in their gradient, concentration, distribution, accessibility, energetics and exploitative dynamics. Table 3.2 shows the principal differences between the two typologies. Resource concentration degrees depend of transformation processes, which increase quality while reducing quantity (Tainter et al., 2003:1). Ecosystems continuously concentrate resources, but inefficiently. In average, each transformation in a trophic chain only retains 10% of the previous energy contained (Tainter, 2013b:4). This maybe explains why the only great resource concentration process (e.g. fossil fuels) are of geological nature. These processes remove swathes of resources for giant periods of time and concentrate them underground until their energy quality is maximized.

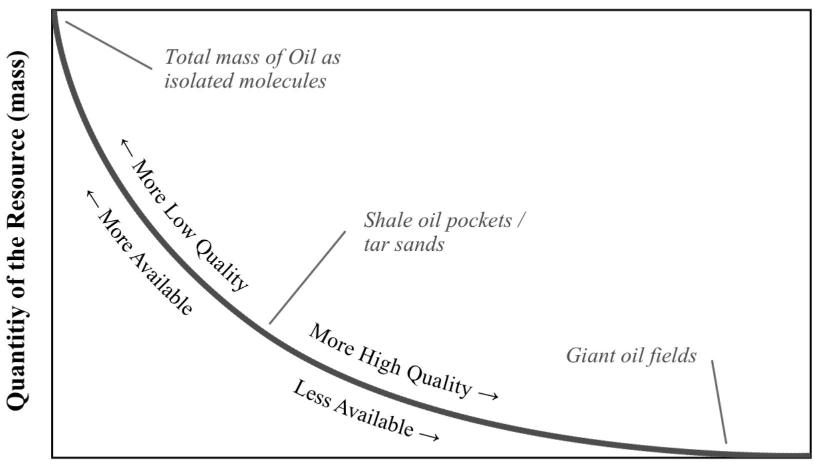

Figure 3.1. Theoretical relation between resource quality and quantity. Inspired by Allen et al., 2010:540. Figure by the author.

The formation of coal presents a good example. While the total energy of coal is great, it is far less than the combined energy of all the vegetation required to make it, but is much more concentrated than all forms of plant energy (Tainter et al., 2003:2). High and low-quality resources also differ in quantity and quality. Resource and energy are not evenly distributed in the universe. High-quality resources tend to be concentrated in a few places, while low-quality resources are largely distributed (Tainter & Allen, 2015:3). This pattern is consistent with the second law of thermodynamics. The amount of low-quality material ends to be greater than to total amount of high-quality resources. Similarly, low-quality material is almost always more dispersed than concentrated (Allen et al., 2010:540). Figure 3.1 represents this theoretical resource distribution.

3.3 Effective Energy Gain

This distinction introduced by resource quality helps then separate energy gain from effective energy gain[23]. Effective energy gain is constrained by its usefulness to society and is relative to production technology. An effective high-gain occurs when a resource useful for society dissipates a high energy gain (relative to production technology). An effective low-gain also results from the dissipation of a useful resource, which, however, produces only a low energy gain (relative to production technology). But the distinction between high—and low gain can be both absolute and relative within and between resources. For instance, burning oil at the wellhead produces high gain. This energy is, however, diminished when gasoline reaches the gas station, for production, refining and transportation costs have been subtracted. Oil in aggregate exhibit higher gain than coal also in aggregate. However, shale oil production might produce lower energetic gains compared to certain surface lignite mines.

3.4 High- and Low-Gain Energy Systems

As mentioned in the introduction of this chapter, energy gain is of central importance in the evolution of complexity (Tainter & Allen, 2015:17). Effective energy gain can be categorized in a dichotomy between high- and low-gain energy systems. This dichotomy is illustrative and not absolute. Like resource production, energy gain systems operate on a continuum between these two opposites (Tainter et al., 2003:3; Tainter, Scarborough & Allen, 2018:330). These different regimes of energy gain have significant impacts on societies and their evolution. Specifically, low— or high-energy gain shape resource use and landscape occupation, and constraint the organization of societies in fundamentally different ways (Tainter et al., 2003:1; Tainter, Scarborough & Allen, 2018:332).

The central difference between high—or low gain lies in the societal resource metabolism. Both systems require high quantities of energy. Whereas high-gain systems take in high-quality resources, low-gain systems must first concentrate low-gain resources (Allen et al., 2009:586). This characterization is consistent with Odum's concepts of endosomatic metabolism and exosomatic metabolism. In the first case, energy is converted outside the system by third-party processes. In the other case, energy is converted inside the system. Endosomatic system presents therefore a lower effective energy gain than exosomatic systems (Allen et al., 2017:226).

Both systems follow the Maximum Power Principle, that is, the tendency of systems to maximize their energy dissipation per time unit. According to Alfred Lotka, living systems, including human ones, acquire and evolutionary advantage when they conform to this principle (Taylor & Tainter, 2016:1007-8). Energy dissipation can be defined as input quantity times

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[23] This distinction is not made by Allen and Tainter, who conflate energy gain and energy quality. It seems however important, as it might otherwise add confusion to the discourse.

degradation (Allen et al., 2010:541). Degradation is the process by which the quality (gradient) of a resource is reduced. As the quality of the resources diminishes, the degradation becomes more difficult and time-consuming as the energy gradient becomes shallower.

High and low gain systems employ opposite strategies to maximize energy flow: whereas high-gain systems maximize energy dissipation by consuming more resource (although inefficiently), low-gain systems maximize energy dissipation by degrading more of the resource. If low-gain systems degrade relatively more of the resource, high-gain systems degrade more in total (Tainter, Scarborough & Allen, 2018:330). This is logical, for increased degradation of high-quality resources would deliver less energy per time unit than degrading them profligately but inefficiently. High-gain systems dissipate therefore more energy per unit of time and per capita. Low-gain systems degrade more of their resources because it is their only option to maximize dissipation (Allen et al., 2001a:482). Both strategies present different adaptive peaks related to significant different resources and social contexts (Allen et al., 2010:547).

These differences in energy dissipation strategies have various organizational repercussions for the two systems. These repercussions follow the dynamics between energy and complexity described in the energy-complexity spiral (see § 2.3.2): low-gain systems (the most common) require complexity; whereas high-gain system (which have energy surplus) generate complexity. These differences are summarily explored in the two sections below and extended in table 3.3. Section 3.1 expands the trajectories of high- or low-gain system in human societies. This chapter might seem long or unnecessarily abstract to connect two propositions of the energy-complexity spiral to other works in energetics. Three answers can shed light on the why of this chapter: it connects Tainter et al. works with the whole corpus, it explores various dynamics where complexity is driven by energetics alone and finally, it gives necessary theoretical depth to support future propositions.

3.3.1 High-Gain Systems

The steep gradient of high-gain systems demand organization to be harnessed. At the same time, its returns are high enough that organizational elaboration "pays" for itself (Allen, Tainter & Hoekstra, 2003:350). The system evolves in a positive feedback loop, where further resource harnessing generates more complexity at little cost (Tainter & Allen, 2015:14). The consequence for high-gain human systems is that much of the activities are then subsidized, which promote further complexity as the costs do not burden the population. The apparent abundance of inexpensive energy has several consequences: energy conservation (within societies) isn't incentivized and if resources are non-renewable, they may be quickly depleted. Therefore, high-gain systems tend to be brief relative to other historical processes (Tainter, Scarborough & Allen, 2018:341).

3.3.2 Low-Gain Systems

The consequences of the shallower gradient of low-gain systems is a mandatory complexity growth to maximize dissipation and ensure survival. In order to maximize the processed energy, low-gain systems can purse two strategies: deeper degradation of resources and increasing aggregation of inputs (Allen et al., 2010:542). These strategies require extensive organization to ensure their success. Producers must be compelled to degrade deeper, and energy aggregation must be coordinated (Tainter & Allen, 2015:10). This high complexity imposes high costs on the society (Tainter & Allen, 2015:17). However, economies of scale in resource degradation and extensive aggregation can cover the overall costs. This works by increasing inputs at a given degradation level until the energy extracted cover the costs of the whole process. If input aggregation meets a limit, then degradation must be increased (Allen et al., 2010:541-2). Failure to do so means termination of the system. This can work so effectively that the total amount of energy extracted by a low-gain system might exceed the energy dissipated by a high-gain system (Allen et al., 210:550). As long a low-gain resource can be degraded deeper with economies of scale, the system will persist. This is why low-gain system typically last longer than high-gain systems (Allen et al., 2003:4; Allen et al., 2010:541).

High-gain Systems	**Low-gain Systems**
Steeper energy gradient	*Shallower energy gradient; closer to*
Farther from thermodynamic equilibrium	*Closer to thermodynamic equilibrium*
Use high-quality resources (ready-made resources previously concentrated)	*Use low-quality resources* (raw materials requiring concentration before use)
Exploits a new type of resource	*Intensify the exploitation of an existing resource or expands it* by processing lower-grade materials
Perceived resource abundance	*Perceived resource scarcity*
High return to energy gathering	*Low return to energy gathering*
Effective but inefficient: more work is done by more throughput because of abundance and minimal demands	*Efficient: more work is done by more degradation* out of necessity to maximize energy aggregation
High net energy output per capita. Energy production constitutes a small portion of the budget	*Low net energy output per capita*. Energy production constitutes a high portion of the budget
Exosomatic metabolism. Energy is converted outside the system	*Endosomatic metabolism*. Energy is converted inside the system
Local and concentrated energy production	*Dispersed and extensive energy production*, as an increasing area is needed to aggregate the equivalent high-gain amount.
Can process small quantities	*Must process large quantities*
Provokes great indirect environmental deterioration (in time and scale)	*Provokes heavy direct environmental deterioration*
Minimal demands on system. Organized by the steep energy gradient with minimal explicit effort	*High demands on system*. Organized with significant effort as the aggregation of low-gain resources requires it to be efficient
Self-organized by its history. Minimal energy production pressures increase agency. Economy more likely to be liberal	*Organized in reference to environment*. Maximal energy production pressures reduce agency. Economy more likely to planned
Generate high complexity. Complexity growth is not required for survival	*Require extensive complexity*. Complexity growth is mandatory for survival
Inserts new levels at the top of the hierarchy. May cause a supersystem to emerge through positive feedback, superposing itself to the old one	*Inserts new levels in the middle of the hierarchy*. Tends to solve problems by proliferating components
Impressive in energy capture, although also impressive in organization at little relative cost.	*Impressive in organization and structure*, although also impressive in energy capture due to the extensive aggregation
Predictable by resource flux (the rate at which the resource is captured and spent)	*Predictable from constraints* (environmental, social, etc.)

High-gain Systems (continued)	**Low-gain Systems (continued)**
More immune to perturbations, provided that the primary resources remain available. The steep energy gradient ensures that such entities either self-repair or that a similar system emerges in place	*More vulnerable to instability*. Small energy margins meaning any variation in the aggregated energy can disrupt the system. This vulnerability also means that the system is overall less predictable
High-quality resource use will likely initiate a high-gain phase	*Entering a low-gain phase subject to chance*, because the system is less predictable
Brief duration. High-gain resources are either rapidly depleted or the resource base is exceeded. The system might then transform into a low-gain configuration	*Significantly longer duration*. Systems usually persist as low-gain resources are globally abundant. In excessive scarcity, the system might become 'super low-gain' or disappear

Table 3.3. High- and low-gain system summaries. Selection and arrangement from Allen et al., 2001a:480,482-3; Allen, Tainter & Hoekstra, 2003:335; Allen et al., 2009:586; Allen et al., 2010:537-8, 541; Allen et al., 2017:226, 232; Tainter et al., 2003:3–5,9–11, Tainter & Allen, 2015:10-4 with additions and formatting by the author.

4 Polity Evolution Model

Tainter's theoretical framework is much rooted in evolution. Evolution should not be confounded with evolutionism, a false friend stemming from progressivist thought. This much discredited view considers sociocultural evolution (i.e. complexity change) as teleological, proceeding towards ever more "progress", i.e more complexity (Cherry, 1986: 44). In Tainter's framework, evolution refers to the principles of the proven theory of evolution to sociocultural change. Although evolution—and its associated dynamics—are structural in Tainter's framework, they are almost never acknowledged as such[24], with only a handful of mentions in Tainter's work (Tainter, 1992, 1998, 2003d) or in associated productions (Allen, Tainter & Hoekstra, 2003; Allen et al., 2009; Allen et al., 2010). Instead Tainter mobilizes various concepts (such as competition, core-periphery relations, peer polity interaction, reactive processes) that cohere in an evolutionary framework. This model can be subsumed in four propositions:

1. Polities (socio-political units—societies) evolve according to the principles of evolution, such as selection, variation and transmission;
2. The interactions between polities determine much of their evolutionary dynamic:
3. Within this framework, history can be subsumed to a succession of reaction to processes to other polities and events;
4. Symmetrical or asymmetrical interpolity configuration present different evolutionary trajectories.

As to avoid confusion and acknowledge its central focus, it is proposed to name this model the 'Polity Evolution Model'. Polities are distinct socio-political units (societies, inferred from Renfrew, 1986:2). This chapter synthesizes much of the literature underlying the model in order to explicit these propositions. As such, this synthesis integrates the source on which Tainter's reflexion is based (Renfrew, 1982), prior works supporting the model (Price, 1977), further productions by Tainter (1988/1990, 1992, 1998, 2003d) or associated authors (Renfrew, 1986; Snodgrass,1986; Cherry & Renfrew, 1986; Renfrew & Bahn 1991/2016; Cherry 2005/2013), some criticism on peer polity interaction—a component of the model (Cherry; 1986; Knapp, 1986; Roskams, 1987; Peebles; 1987, Irwin, 1987; Gilman, 1987; Wells, 1987; Haselgrove, 1988; Crumley, 1988; Claessen, 1989; McGuire, 1996; Kuusela et al., 2018), a conceptual perspective shift (Smith, 2009) and various addenda (Johnson, 2004 and Taylor, 2013). The proposed synthesis keeps most of the original substance and intent intact while making explicit certain significant underlying properties and structuring the concepts of the cited literature.

As to give coherence to the whole, the synthesis is accompanied by an introduction to Generalized Evolutionism, a recent transposition of the principles of evolution into a social context (Tang, 2017). Generalized Evolutionism unifies previous attempts at bridging evolutionary biology and social sciences while incorporating groundbreaking scientific discoveries in the field. This addition is supported by previous hints in the above-mentioned contributions (Price, 1977; Cherry, 1986 and Knapp, 1989) or in the works associated with Tainter's theoretical framework (Allen, Tainter & Hoekstra, 2003; Allen et al., 2009 and Allen et

[24] This might stem from the discredit of sociocultural evolutionism, which tainted the word 'evolution' or the bad reputation of the fraudulent concept of 'social Darwinism', which may have prevented social theorists from acknowledging Darwinian dynamics in name for fear to be called out.

al., 2010). The overall goal is this combination—generalized evolutionism and the polity evolution Model is to produce a convincing explanation for the evolution of polities matching most of recent history. Should that goal be achieved, then this combination could be considered satisfactory and used in a predictive capacity (Cherry, 1986).

4.1 Generalized Evolutionism

Transpositions of the principles of evolution in a social context are not new. In recent years, some scholars have been pushing generalized Darwinism (e.g. Aldrich et al., 2008; Hodgson & Knudsen, 2006; R. Nelson, 2006; R. R. Nelson, 2007), while other scientists discussed Lamarckism in the evolution of culture (e.g. Wilkins, 2001). However, recent discoveries in evolutionary biology[25] might prove these two paradigms false (Tang, 2017:588). These discoveries suggest that biological evolution is neither (neo-)Darwinian nor (neo-)Lamarckian. As a result, previous transposition attempts seem now either improper or invalid (Tang, 2017:598). Although many Darwinian principles remain accurate, a new paradigm appears necessary (Tang, 2017:595, 598). In this sense, Tang proposed in 2017 'Generalized Evolutionism' as a response to the limitations of the two previous generalization paradigms. Its goal remains similar: transposing the principles of biological evolution into broader contexts.

Generalized evolutionism unifies generalized Darwinism and generalized Lamarckism. Generalized evolutionism recognizes that social evolution contains both elements of the two paradigms, thus signaling the end of the debates between the two approaches. The new paradigm stress that evolution in social systems is far more complex than formerly implied (Tang, 2017:588, 605). The founding principles of evolution are left unchanged: *variation, selection, and inheritance* (Tang, 2017:601), but generalized evolutionism stresses that inheritance can happen both vertically (from parent to child) or horizontally (between current entities). It might be therefore more convenient to name inheritance, transmission, which accounts better for the different ways traits can be exchanged (in a genetic or epigenetic way, see Tang, 2017:591, 602, 606). For Tang, this proposition gives generalized evolutionism more versatility and explicative power than generalized Darwinism to explain the numerous intricacies of social evolution (Tang, 2017:606).

4.2 Evolutionary Perspectives of Sociocultural Change

There is much evidence that complexity evolves according to the three principles mentioned above. Environments and specific pressures select for certain types of societies. Societies tend to either adapt to certain environments in short, punctual and significant ways or in slow and continual variations. Finally, information is very often transmitted horizontally within and between societies. This application of evolutionary principles to sociocultural evolution has been welcomed by several scholars (Price, 1977:209; Cherry, 1986: 44; Knapp, 1989:198), who either applied or recommended implementation of the selection or variation principle (e.g. Cherry, 1986: 44)[26].

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[25] Three main discoveries question the very foundations of the Darwinian and Lamarckian approaches: first, epigenetic inheritance is now widely recognized. Epigenetic inheritance stresses that the transmission of traits can happen outside the direct gene replication. Rather, inheritance in an epigenetic context can happen by imitation but then involve modification of the DNA. Second, the discovery of prion-like proteins shook the previous evolutionary paradigms, as these proteins cannot replicate, but still can transmit diseases. Third, the study of ecological niches indicates that both their construction and inheritance happen entirely outside the genetic realm, while still exercising significant selection pressures on genetic and epigenetic traits (Tang, 2017:595-7).

[26] While horizontal transmission would have made sense from the very beginning, the notion would only

Several theoretical frameworks have been developed to explain sociocultural evolution through evolutionary principles, even if they were not acknowledged as such (Cluster-interaction model: Price, 1977; Peer polity model: Renfrew & Cherry, 1986; Reactive processes: Tainter, 1988/1990, 1992, 1998, Interaction sphere model: Smith: 2009). The advantage of evolutionary models is their observational and neutral nature in analysis (Knapp, 1989:198). This stands in stark contrast to the progressivist views of evolution, which attribute value judgments to evolution (Tainter, 2005c:s98; 2010:710). While horizontal transmission makes evident sense with the integration of imitative and emulative dynamics (which will be covered in § 4.5.2- 4.6.4), the principle of selection, either "natural" or "artificial" (Tang, 2017:601-5) stands out.

4.2.1 The Importance of Selection

The principle of selection is of fundamental importance in sociocultural evolution. Two elements must be understood at this point: first, selection eliminates unfit players. It retains only the fittest. But fit players can never secure continual survival, as selection pressures might change. These pressures might be physical, environmental or competitive (Cherry, 1986: 44). Second, selection implies a continuous tension with adaptation. Adaptation stems from variation. Variation can originate from intentional or involuntary changes. Adaptation is a product of the former. It is a deliberate transformation of an entity to increase its chances of future survival (Allen et al., 2009:592). Entities undergo adaptation to ensure future selection. As mentioned earlier, selection in biological evolution—and thus in social systems—isn't an intentional process but an observational one (Knapp, 1989:198). This explains why adaptation, if done in the wrong direction, can be detrimental or even terminal. As a result, players in evolution experience a continuous tension between selection and adaptation, because they cannot know what outcome will eventually materialize. (Allen et al., 2009:592)

This can be summarized as such: Players can only secure short-term successes in evolution. Long-term success is determined by continuity, i.e. survival. Players must continuously respond to selective pressures, to which they might adapt or not (Allen et al., 2009:592; Allen et al., 2010:538). As selective pressures might quickly change, evolution selects players that have been proven able to rapidly and effectively adapt or that are just lucky. As a result of the above, it can be said that evolution mainly selects for short-term survival. For instance, evolution in humans selected for short-term rational decision making as adaptive traits (Tainter, 2007:373, 2008b:xv). This realization has profound implications for the evolution of past and contemporary societies (see § 4.5).

Selection can explain much of the development and evolution of complexity. As complexity is a problem-solving tool, complexity growth can be interpreted as an adaptive strategy (Tainter, 2000b:8). Thus, one can expect that evolution would favour a certain development of complexity. The widespread emergence and persistence of centralised polities in the last 5000 years supports this assertion (Cherry, 1986: 44). Selection can also be helpful to understand the development of hierarchies in and between societies. Social systems, as species, experience both internal and external selection. This means that members of social systems may evolve under different pressures than the social system as a whole. Selection pressures, both internally and externally, can explain, among other things, how domination, power and exploitation came to be within and between social systems (Cherry, 1986: 44).

4.2.2 Evolutionary Approaches of Sociocultural Change

In this regard, anthropology has produced in the 1970s and 1980s two sets of frameworks explaining sociocultural change in an evolutionary perspective (McGuire, 1996:55): the Core-periphery approach and Peer polity interaction. Both imply the role of selection in the development of complexity. Both analyze change as the product of interactions between different polities (McGuire, 1996:55-4). They, however, differ in their approach: whereas a core-periphery framework mainly addresses changes as the result of power imbalances between polities

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be developed long after this period. Hence its absence.

Box 4.1. The two main approaches of sociopolitical change

The core-periphery approach stems from the transposition of World-System theory (see for instance: Wallerstein 1974/2011) into archaeology. World-System theory is an interdisciplinary approach* that analyzes world history as the result of power imbalances between different polities. In this framework, the world—or one coherent subset—is divided between "core" and "peripheral" polities**. This core-periphery approach analyzes changes as an asymmetrical process, where the core has greater influence (complexity, economic and military power) on its periphery than the converse. As such, sociopolitical change is mainly explained through dominant power relations between polities and organization of the periphery to serve the economic interests of the core (Smith, 2009:56). The main problem with this approach is that it is too totalizing and deterministic and so fails to capture the intricacies at the various scales of interaction (McGuire, 1996:51; Kuusela et al., 2018:766). If dominance explains much, dominance isn't as prevalent as the model might imply. In reality, peripheries can have more autonomy than anticipated, core-periphery relations seem more negotiated than dictated and innovation can also originate from the peripheries (McGuire, 1996:51 Smith, 2009:56).

The peer polity interaction (PPI) approach is an indigenous development to archaeology. This approach is partially based on Price's 'Cluster-Interaction Model' (1977)***, which Renfrew (1986) extensively expands. More than a continuation of Price's model, it appears that PPI was mainly developed as a reaction to the misapplication of World-System theory in archaeology. The major difference between the two approaches is that PPI doesn't assume power asymmetries between the interacting polities and tends to be more regional (Kuusela et al., 2018:766; McGuire, 1996:55-4). As its name suggests, the approach is focused on peer polities, that is, polities of equivalent power and complexity. Peer polities mainly interact on a symmetrical level and their mutual interaction conditions much of their evolution (Renfrew, 1986:2,4; Tainter, 1988:201; Taylor, 2013:90). As a result, long periods of interaction create various homologies (symbolic, material or structural) between the interacting polities (Renfrew, 1986:2). However, this approach is not without flaws. First, real polities are difficult to find. Power imbalances tend to be the norm, even if they can be significantly reduced in some situations (Smith, 2009:62). Second, PPI might be totalizing. The focus on peer polity interactions overlook other important processes in sociocultural evolution, such as other interactions (either symmetrical or symmetrical) occurring at different scales (McGuire, 1996:55; Kuusela et al., 2018:766). Third, structural homologies can also occur in core-periphery configuration (Smith, 2009:63).

Notes: * Although originally developed with a sociological lens; ** And semi-peripheries for the contemporary world, although this nuance isn't relevant here; *** The peer-polity approach has in fact even more ancient precursors, both although not mentioned in Price's or Renfrew's work: Bennet's idea of cotradition (1948, cited in Crumley, 1988:429) and Caldwell's interaction sphere (1964, cited in Haselgroove, 1988:463).

(asymmetrical relations), a peer polity framework analyzes change as the result of continual exchange and conflict between polities of equivalent complexity (symmetrical relations). While these approaches differ in kind (see table 4.1), they can both be useful if correctly applied. Box 4.1 proposes a brief summary of the development and characteristics of both approaches while discussing some selected critiques.

Core-periphery and peer polity approaches share many similarities. They are similar in intent and they both attribute great significance to the interaction between the polities and thus to the dynamic of the system. They mainly differ, as mentioned earlier, in the scale of analysis and in the balance of interactions (McGuire, 1996:55-4). These characteristics permit conceptual unification within constraints (see Tainter, 1988/1990, 1992, 1998; Smith, 2008:56–68). Unifying these approaches present many advantages. First, unification produces a more comprehensive model, as it can effectively address more configurations. Second, it incorporates much of the strengths of incorporated approaches while eliminating much of their associated criticism (as the

	Core-Periphery	Peer Polity
Relations	Dominant-subordinate	Equivalent (in average)
Interactions	Asymmetrical	Symmetrical
Distribution	Higher complexity gradient	Lower complexity gradient
Dynamic	Peripheral polities conditioned by the core (dominant polity)	Conditioned by their own mutual interaction
Competition	Intermittent competition	Continued competition
Shared traits	Mostly remain within the dominant state/empire (which can then radiate towards the whole interaction sphere)	Peer-polity-wide, developed by their mutual interaction of the peer polities, supra-institutions

Table 4.1. Principal differences between the core-periphery and peer-polity configurations. Inferred from Renfrew, 1986:2, 4; Tainter, 1988:201-2, 1992:104; Taylor, 2013:90.

unification partially addresses it). Third, it stresses the regularities of the long-term evolution of polities (which is here of interest) and thus emphasizes their differences by removing everything they have in common. This proposition was first suggested by Smith (2009:15, 55-6, 62, 71), which this synthesis adopts as the 'Polity Interaction Model'[27]. The model differs from Smith's original proposition by some conceptual additions and a broader supporting literature. The following sections introduce the polity interaction model, present the common characteristics and dynamics of polities while highlighting their differences if needed. As already mentioned, chapter 6 explores their long-term trajectories.

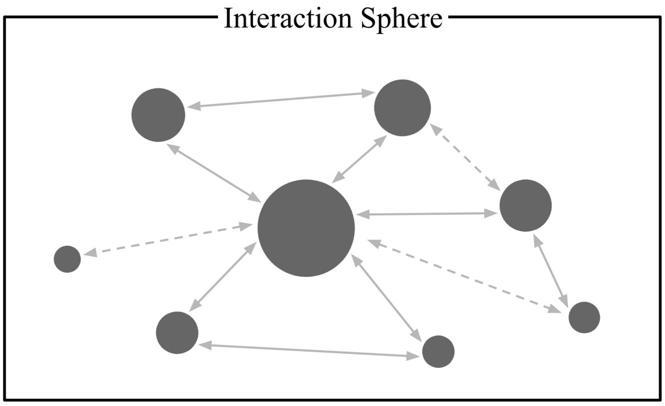
4.3 Polity Interaction Model

4.3 Introductory Concepts

The polity interaction model describes the nature, types, products and outcome of the interaction of different polities within an interaction sphere. An interaction sphere can be defined as the system where these interactions and exchanges occur (Renfrew & Bahn, 1991/2016:600). Its area is relative to the number and size of polities. The polities constituting an interaction sphere may range from equal to unequal can form alliances and federations or be organized in a dominant-subordinate hierarchy (Smith, 2009:63-4). Polity interaction designates the full range of interchanges taking place between different polities within an interaction sphere over a long-time period that have significant social, political and economic repercussions (adapted from Renfrew, 1986:1 and Smith, 2009:55, 64). Polity interaction may be organized in a peer polity fashion (see § 4.6) or core-periphery configuration (see box 4.1) or in the mixture of the two (Smith, 2009:85). Figure 4.1. displays an illustrative interaction sphere with unequal polities, organized mainly in a core-periphery situation with some polities evolving nevertheless as equals. Table 4.1. summarizes the main differences between the two configurations.

[27] Smith proposed the name of 'Interaction Sphere Model' to unify core-periphery and peer polity approaches. As this synthesis makes also use of Bennet's concepts of interaction sphere (1964) and still stresses distinctiveness between core-periphery and peer polity configurations, it would be confusing to reuse Smith's proposition. This justifies a new naming.

Figure 4.1. Hypothetical interaction sphere consisting of unequal polities in mainly core-periphery situation with some polities evolving as equals. The arrows represent the interactions between the polities. Dotted lines indicate weaker interactions (see § 4.4). Figure by the author.



4.4 Interactions

Interactions range from artistic exchanges to trade while also encompassing interpolity warfare. They are various in nature. They can be competitive, imitative, transactional, informational (in ideas, symbols, inventions, aspirations, and values) or a combination of the previous. Interactions involve the exchange of energy, matter, or information (Cherry in Cherry & Renfrew, 1986:152; Renfrew & Bahn, 1991/2016:387). Interactions take place at different levels (elites, tradespeople, specialists, etc.) in the polity (Snodgrass, 1986: 58). As such, they can be perceived differently within the social stratification of a society and between societies (Renfrew, 1982:286). Interaction typically involves 'action at a distance', meaning that the elements of the interaction create a reaction on the receiving end (Renfrew in Cherry & Renfrew, 1986:157). Interaction can be direct or indirect. Indirect interaction involves third parties which relay messages or convey goods. For instance, commerce goods can carry a message or embody different values between trade partners. These characteristics might provoke changes in the receiving polity (Renfrew in Cherry & Renfrew, 1986:157)[28]. Thus, interactions without intended contact can be as impactful[29]. Interaction can take different forms: warfare, symbolic competition, competitive emulation, symbolic entrainment, transmission of innovation and trade. The following subsections introduce them in detail and conclude by emphasizing the role of interaction enablers.

4.4.1 Warfare

Warfare makes polities interact through the application of military force. Conducting war doesn't necessarily have the purpose of gaining territory, as it can act as a communication channel between polities (Renfrew, 1986:16; Renfrew & Bahn, 1991/2016:388). Practicing war requires sufficient levels of material and to an extent, of social support (Cherry, 2005/2013:148). War is more destructive than productive and loot acquisition is too irregular to be considered profitable in the long-term. As conducting war is costly and rarely repays itself, prolonged warfare promotes intensification of resource production, the development of complexity and centralized leadership (Renfrew, 1986:8; Renfrew in Cherry & Renfrew, 1986:155; Cherry, 2005/2013:148). In the long-term, warfare selects for polities capable of the above (the others being likely absorbed).

[28] Goods and symbols can produce such action at a distance. For instance, the diffusion of coinage is likely to have provoked such an action at a distance, with the idea of money travelling with the pieces (Renfrew in Cherry & Renfrew, 1986:157).

[29] For instance, Tainter (1992:185-6) recounts how the Yanomami of the Amazon Basin became a fierce indigenous group in modern times. There is no evidence of them being particularly conflictual before being in contact with western-manufactured goods. This contact is pivotal in their history. As these goods, either obtained by trade or gift through intermediaries, were perceived as instruments of prestige, an intense rivalry developed within Yanomami. Their rivalry eventually turned the Yanomami fierce and violent, which in turn provoked structural changes in their societies. This is significant, as all of these changes occurred without direct interaction of other polities.

4.4.2 Competitive Emulation

Competitive emulation describes the various instances (other than war) by which polities, or their elites, compete with each other to achieve higher inter-polity status (Renfrew, 1986:8). Competitive emulation can take many forms: formal and informal contests in areas such as sports, arts, etc. where polities indirectly compete through their representatives (Renfrew & Bahn, 1991/2016:388); competition in conspicuous consumption, that is, the exposition of ever more wealth or power to outdo the other competitors (Renfrew, 1986:8). The rationale behind this kind of competition is to gain prestige by doing the same as others but bigger and better. Conspicuous consumption competition range from the construction of monumental architecture (ceremonial centers, temples, etc.) to expensive gestures, such as giving feasts and gifts (Renfrew, 1986:8; Renfrew, 1987:190; Cherry, 2005/2013:148). In such, competitive emulation can be characterized as a form of symbolic warfare (Smith, 2009:67). While indeed less hostile than warfare, competitive emulation also requires polities to intensificate production and develop complexity to ensure conservation of competitive abilities (Renfrew, 1986:8; Cherry, 2005/2013:148).

4.4.3 Symbolic Entrainment

Symbolic entrainment describes the tendency of symbolic systems to converge when polities interact (Renfrew & Bahn, 1991/2016:388). Symbolic systems range from writing to social and hierarchical systems. Symbolic entrainment works in two ways: diffusion of symbolic systems from complex to less complex societies and legitimation of the current order. Symbolic entrainment explains how and why complex symbolic systems spread. A symbolic system, when either effective or successful, carries with it the prestige of a more complex society. When less-developed societies become exposed to these systems, they are likely to adopt them if they don't directly conflict with their internal organization (Renfrew, 1986:8; Renfrew in Cherry & Renfrew, 1986:153-4). The diffusion of symbolic systems can also be enabled by the elites, as they can then be later used to legitimate and increase elite power and wealth (Smith, 2009:67). Symbolic entrainment also creates reinforcing effects which maintain the current order. This mechanism can be explained as such: the existence of a social order in a neighbouring polity tend to legitimize its presence in one other (Renfrew, 1986:9)[30].

4.4.4 Transmission of Innovation

The transmission of innovation is a form of symbolic entrainment (Renfrew, 1986:9). Innovation must be distinguished from invention. Innovation represent widespread diffusion and acceptance of one invention (Renfrew, 1986:10). Innovation here mostly refers to technical innovations, but can also include organizational innovation (Renfrew, 1986:9). The transmission of innovation work in the same ways as symbolic entrainment: diffusion in the absence of direct conflict and reinforcement through neighbouring adoption (Renfrew, 1986:10; Cherry, 2005/2013:148).

4.4.5 Exchanges of Goods and Trade

Goods exchange and trade are two close forms of interaction between polities. The differ in their intent, where the former is more aimed at reciprocity and prestige and the latter directed towards economic profit. An increased flow of one or the other tends to accrue structural transformations in polities (Renfrew, 1986:10). This can be explained in four domains: the development of trading institutions, the growing social exchanges, the production intensification and economic specialization. Trade eventually requires the creation of institutions to organize allocation and distribution of goods (Cherry, 2005/2013:148). Growing social exchanges generate an interpolity socialization which increases other forms of interaction (symbolic entrainment, transmission of innovation, competitive emulation and military practices to an extent, see Renfrew, 1986:10). Furthermore, trade economics can trigger either the intensification of production or specialization to meet commercial demand (Cherry, 2005/2013:148). In all cases, trade demands directly or indirectly production intensification to either finance the required level

[30] As Renfrew puts it: "The specific state is legitimized in the eyes of its citizens by the existence of other states which patently do function along comparable lines." (Renfrew, 1982:289)

of complexity or increase the volumes available to trade (Smith, 2009:69). As a result, trade tends to make interacting polities ever more economically linked (Renfrew & Bahn, 1991/2016:388).

4.4.6 Interaction Enablers

Some polity members are instrumental in shaping the interactions of their polity with others (Renfrew in Cherry & Renfrew, 1986:158). As such, they are enablers of interpolity interaction. Two groups of people fall within this category: traders (or trading companies) and elites. Table 4.2. proposes a summary of interaction forms with their associated exchange type and key enablers. People involved in trade have a special influence, for they travel and transmit material and information both ways (Renfrew in Cherry & Renfrew, 1986:158). Elites are often central in the development of interactions for three reasons: First, elites possess most of the decision-making capacity, can mobilize resources, have the means and time to travel. They can therefore significantly influence how the polity interacts with other societies. Second, elites respond most to horizontal signals, that is, signals emitted by other elites (as the process of competitive emulation and symbolic entrainment stresses, see Renfrew, 1986:15-6)[31]. Third, elites can use utilize interaction as means to assure and reinforce their legitimacy (Smith, 2009:68). In summary, elites particularly matter in interaction development because: they have important power to influence their polities; might reap benefits from the interaction; and are especially responsive to other elites.

4.5. Interaction Consequences

Sustained interpolity interactions have various consequences, some of which might determine the whole evolutionary dynamic of the interaction sphere. As to properly explicit these consequences, the following sections separately specify the dynamics, effects and products of interaction.

4.5.1 Interaction Effects

As hinted in the previous sections, increased interaction and exchanges provoke sociopolitical change (Smith, 2009:64). This change can be subsumed into two main processes: intensification of production and complexity increase. As mentioned earlier (the energy-complexity spiral), both are closely related. Interactions stimulate production intensification because of the increased demand for traded goods and to finance further complexity elaboration. Complexity grows to organize production (and its specialization) but mainly respond to the problems contextual to the interactions. These problems might be war (which played historically an important role), competitive emulation, the development of a new symbolic system requiring more non-energy producing specialists, the affirmation and reinforcement of legitimacy based on the public distribution of goods, etc. (Inferred from Renfrew, 1982:286-7; Renfrew in Cherry & Renfrew, 1986:155).

These changes cost, but they are not without benefits. These benefits can be material or symbolic. Although complexification tends to increase social stratification, benefits profit both the elites and the population (Renfrew, 1982:286, 289)[32]. Material benefits for the population include a greater availability of goods, while symbolic benefits might range from pride for its polity or institutions to religious or secular beliefs of righteousness and protection (inferred from Renfrew, 1982:286). Elites benefits are, as mentioned, greater opportunity to secure their position, increase their legitimacy and wealth extraction. Increased interaction-sphere-wide economic specialization and purchasing power may also make (more) luxury goods available to the elites (Renfrew, 1982:286). Save for the interaction dynamic which compelled intensification and complexity growth, it is likely that fewer benefits would have materialized (Renfrew, 1982:286).

[31] In converse, elites are typically unresponsive or slow to address vertical signals – signals coming from lower levels of the hierarchy (Tainter, 1999b:9).

[32] although historically elites tend to accrue a disproportionately amount of benefits relative to costs (Tainter, 1988/1990:36)

Interaction Form	Exchange Type	Key Enablers (Decision-Makers)
Warfare	Material, information	Elites
Symbolic competition	Information	Mainly Elites
Competitive emulation	Information	Mainly Elites
Symbolic entrainment	Information	Traders, elites and ad hoc process
Innovation transmission	Information	Traders, elites and ad hoc process
Increased exchange of goods	Material, information	Ad hoc process, traders and elites

Table 4.2. Interaction forms and their associated exchange types and key enablers. Partially inferred from Renfrew, 1986:15-6 and Renfrew in Cherry & Renfrew, 1986:158.

4.5.2 Interaction Dynamics

Interactions create different interaction-sphere-wide dynamics. Interactions tend to generate positive feedback and interdependencies (though not always the case). Positive feedback is created as polities show increased exchanges and begin to coevolution. This dynamic can because mutually reinforcing, like warfare. Conducting war requires mutual continuous intensification of production until the end of the conflict (Smith, 2009:64-5). At a certain point, a change in one polity (complexity, symbolic system, economic or military strategy) is likely to be replicated in one other, and then to the whole interaction sphere (Smith, 2009:64). This integration can also generate mutual interdependencies (Smith, 2009:70). These interdependencies can be economical, symbolic or even military (in the case of alliances).

Most of the polity interaction are competitive (warfare, competitive emulation), may have competitive traits (trade) or contribute to competitive traits (symbolic entrainment and transmission of innovation). Competition forms therefore a significant part of the dynamics of the interaction sphere. As polities seek to avoid (more) subordination, remain independent, or maintain a dominant position, they are likely to increase their military, economic or symbolic power. This dynamic has important implications: competition will eventually drive much of the intensification of production and complexity growth; and this dynamic is likely to create positive feedback and thus ever more complexity (Smith, 2009:64, 70).

4.5.3 Interaction Products

Over the long-term, polity interactions can produce specific interaction-sphere-wide phenomena. The first is interregional communication and the second are structural homologies. Interregional communication can be best described as a 'lingua franca' of common(s) language(s), cultural norms, communication codes and shared beliefs and symbolic systems that facilitate interpolity communication. The development of these shared traits is most likely to occur first in the groups of interaction enablers (Smith, 2009:69–70). Most polities in a core-periphery situation never go beyond this point. Structural homologies are a more systematic extension of interregional communication into institution structure, architecture[33], art styles, writing, religious beliefs, military tactics, etc. Structural homologies are the product of sustained and longer interactions (Renfrew, 1986:5; Smith, 2009:63)[34]. The development of structural homologies marks a turning point in an interaction sphere, as it indicates the development of a common identity, a shared way of life and tendency towards homogenization (Renfrew, 1982:287, 287).

[33] Monumental construction is particularly well suited to account for the extent of competitive emulation. Monumental construction tends to follow structural homologies but might differ in slight details to ensure recognition. As such, competition consists of building ever 'bigger' and 'better' monuments (Renfrew & Bahn, 1991/2016:388).

[34] One could say that structural analogies are mainly the products of necessary adaptations to similar environmental pressure and are therefore not linked to mutual interactions. This might be the case for some of the structural analogies, but cannot account for their entirety (see Renfrew, 1986:5).

4.6 Specificities of Peer Polities

Peer polities are a subset of polities. Peer polities represent the highest politically autonomous order in an interaction sphere. Polities in a peer polity configuration possess an equivalent, or near equivalent level of complexity, population, technology, organization, per capita output and military capabilities (Renfrew, 1986:2, 4; Tainter, 1992:104 Taylor, 2013:90). The inclusion of 'near equivalent' is important, because peer polity interaction is more about the absence of a dominant polity than their strict equality. A polity which is self-governing and nears the scale of other neighbouring polities can be therefore considered a peer polity (inferred from Renfrew, 1986:5–6). A group of peer polities constitutes a cluster (Price, 1977:210). Peer polity interaction is more frequent, intense and lasts longer than polity interactions (Renfrew, 1986:5). As such, interactions within the cluster are stronger and more significant than all other possible interactions (Renfrew, 1982:286; Renfrew, 1986:7). Figure 4.2. illustrates a hypothetical interaction sphere containing an interaction sphere, one cluster and five peer polities. The following subsection summarizes the specificities in form, dynamics and products of peer polity interaction.

4.6.1 Interaction Forms

Peer polity interaction distinguishes itself from polity interaction in two forms: warfare and competitive emulation. First, warfare between peer polites has been regularly identified as the most intensive form of peer polity interaction (Tainter, 1992, 1998; Middleton, 2008:168). With the development of a lingua franca and structural homologies, the rules of conflict tend to become more codified and the conduct of war more ritualized (see Renfrew, 1986:16; Renfrew & Bahn, 1991/2016:388). In parallel, warfare selects effective military systems, which are then likely to resemble each other more and more. Box 4.2 illustrates this phenomenon with the emergence of the hoplite-phalanx system in the Mycenaean Cities-States, a classic peer polity situation. Second, a specificity of competitive innovation in a peer polity configuration is that it might become more significant than warfare, when the latter becomes too costly. Furthermore, competitive emulation through monumental architecture construction might also occur in supra-polity institutions (see § 4.6.4), like in shared ceremonial or arbitration centers (Renfrew & Bahn, 1991/2016:388).

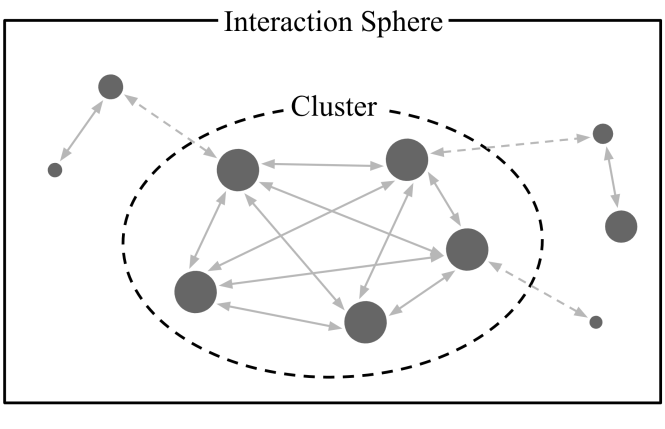
4.6.2 Interaction Effects

Interaction effects of Peer polity interaction are similar in kind to those of polity interaction but with much more intensity. Peer polity interaction carries an increased emulative and competitive drive. As a result, complexity growth and production intensification are greater in a peer polity configuration (inferred from Renfrew, 1982:287). Furthermore, when peer polities experience uninterrupted competitive interactions (see § 4.6.3 below), peer polities continuously increase in complexity in a mechanism that tends to sustain itself (Cherry, 1986: 43; Tainter, 1988/1990:213).

4.6.3 Interaction Dynamics

A peer polity configuration differs from a core-periphery situation by the independence of its polities, which are mainly conditioned by their own interaction and not a dominant neighbor

Figure 4.2. Hypothetical interaction sphere in a mainly peer polity situation. The five central polities (peer polities) evolve in a cluster. The arrows represent the interactions between the polities. Dotted lines indicate weaker interactions (see § 4.4). Figure by the author, inspired by Renfrew (1982:286)



Box 4.2. The emergence of the hoplite-phalanx system in Mycenaean Greece
The simultaneous emergence of the hoplite-phalanx system across the Mycenaean Cities-States is a 'textbook' case of peer polity interaction (Rosenstein, 2010:293). There are several reasons contributing to this. First, it shows the transmission of innovation in the Mycenaean cluster (in military equipment, tactics and socio-political organization). This phenomenon underlines the imitative nature of the peer polity interaction. Second, it indicates system-wide reorganization associated with socio-political changes (positive feedback) driven by the necessity to avoid conceding a military advantage. This trait stresses competitive interaction and adaptiveness. As Snodgrass (1986:51) puts it: "The notion that all citizens above a certain property qualification should be obliged to serve in the army of the polis, equipped at their own (considerable) expense, and that by so doing they secured certain minimal rights as citizens, arose sufficiently soon after the emergence of the polis itself [. . .]. The hoplite phalanx was the embodiment of the polis idea translated into action."

Third, the emergence of the hoplite-phalanx system is significant as it emphasizes structural homologies (as mentioned in military equipment, tactics and socio-political organization) and conventions in warfare (rituals and coded rules). "In the Archaic period especially, armies were used in the main for a single tactical purpose (the pitched battle on level ground) and in a single formation (the close—order phalanx), Campaigns were decided by a single engagement, whose verdict was invariably accepted by both sides; there were no reserves worth mentioning since it was essential to field one's maximum strength for the first encounter, and the training of other arms, apart from the heavy infantry, thus neglected. [. . .] The rules of this game were apparently accepted without question by every Greek polis" (Snodgrass, 1986:51) And finally fourth, it indicates peer polity status. "As long as success attended this form of warfare, however, the Greek polities conformed to it with what seems an excess of zeal. [. . .] But a hoplite army had become a symbol of polis status, and that was enough" (Snodgrass, 1986:52).

(for the difference, see table 4.1). Peer polities don't evolve with fewer constraints, they merely trade the influence of asymmetrical relationships for the continual necessity to maintain their independence (Shennan, 1987:375). In difference to polity interaction, where competition is more intermittent, peer polity interaction is characterized by potentially permanently competitive interaction (inferred from Tainter, 1988:201, 213). Peer polities tend to constantly maneuver to expand their influence or territory and to secure a better position, let it be military or economic (Tainter, 1988/1990:213). As other polities, peer polities form alliances. The difference lies in that alliances may quickly shift in order to ensure that no polity achieves a permanent ascendency over the rest.

This necessity, combined with the imperative to remain at equivalent levels of power drives the need for greater competitiveness of peer polities (Renfrew, 1982:287, 1986:2, 9). As a result, peer polity interaction typically shows an upwardly spiraling pattern of competition with no end in sight but the potential domination of one polity over the others (Tainter, 1988/1990:213). As a result, peer polities tend to undergo long periods of complexity growth which exponentially increases costs and compels ever more resource production. This situation is likely to last, as every advantage development is short-lived. Innovations, either organizational, technological, tactical, military, logistical or economical, are quickly imitated by the other peer polities and thus lose their benefits, while maintaining their costs (Tainter, 1988/1990:214, 1992:125). As such, continuous peer polity competition is a powerful stimulator of complexity growth (Tainter, 1992:125).

4.6.4 Interaction Products

While some products of peer polity interaction are similar to these of polity interaction, all indicate an intensification in the interactions or polities. Six different products can be identified: closer and mutually benefiting interactions between the elites of different polities, regime betterment, widespread structural homologies, mutual conventions regulating some forms of interaction, ethnicity formation and the development of supra-institutions.

Closer and mutually benefiting inter-elite relations tend to develop for two reasons: to ensure military support when required and to ensure and accrue their legitimacy or the status quo within their polity. While the former can be achieved by concluding alliances, as through intermarriage, the latter usually work by inter-elite exchange of prestige goods and symbolic knowledge to impress the population. These interactions tend to intensify most in periods of political unrest (Cherry in Cherry & Renfrew, 1986:152). Regime betterment describes how the increasing demands (costs) of peer polity interaction compels hierarchies to improve the living and political conditions of the populations to ensure their continued participation in financing the costs of the ever-growing competition. This process might result in government to become more participatory (like in Mycenaean Greece) or the promotion of 'good government' (as in the Warring States of Ancient China, inferred from Tainter, 1988:201–202).

The difference between 'simple' polities and peer polities is that the latter tend to display widespread and not selected structural homologies, that is: close political institutions, same system of writing, same language (or interpolity communicational language) similar religious beliefs (with local variations), similar culture, similar symbolic system(s) and a common set of values (Renfrew, 1986:4–5 and Renfrew in Cherry & Renfrew, 1986:156). These common values enhance the emergence of conventions (Renfrew, 1986:2; Renfrew in Cherry & Renfrew, 1986:156). Conventions are written or unwritten agreements regulating one or several forms of peer polity interactions. Conventions determine what kind of behaviour is considered acceptable or not (inferred from Renfrew in Cherry & Renfrew, 1986:154). As their application solely depends on the self-enforcement, other polities can only sanction misbehaving polities by war[35]. Historically, conventions seem to have been principally applied to warfare and trade regulation (Renfrew in Cherry & Renfrew, 1986:154). Mycenaean warfare illustrates the significance of conventions (see also box 4.2).

Ethnicity formation is a byproduct of a prolonged process of widespread and structural homology development (Renfrew in Cherry & Renfrew, 1986:157). Ethnicity extends the 'lingua franca', the structural homologies and also increases trade, interregional communication and the sense of a shared identity. Ethnicity development seem historically to be the strongest when peer polities share the same language (Renfrew & Bahn, 1991/2016:388). Mycenaean Greece is a clear example of ethnicity development (see also box 4.2). Finally, the development of supra-institutions sanctions a prolonged peer polity interaction (inferred from Renfrew in Cherry & Renfrew, 1986:158 and Johnson, 2004:124, 127-8). Supra-institutions are entities that allow meeting, exchange, mediation in neutral ground at the cluster-level. Supra-institutions can also work as ceremonial, religious or ideological centers. Supra-institutions can take the form of informational clearinghouses, contest arenas, communication and diffusion platforms (to make a cluster-wide appeal), displaying facilities and arbiters of neutral kind. In the latter case, supra-institutions stand above any other polity. Despite their neutral nature, supra-institutions do not escape peer polity dynamics. Hosting a supra-institution or building inside of it can be the object of intense competitive emulation, as the prestige of the supra-institutions would then be associated with the polity name. Supra-institutions can also emit recommendations or initiate directions. These serve as to guide the cluster evolution and reduce divisions between polities (inferred from Snodgrass, 1986: 53–56). For instance, the Vatican has played such a role in the peer polity configuration of the medieval and renaissance states.

4.4 Reactive Processes

Reactive processes (Tainter, 1998) subsume the previous approaches and proposes a simple and effective framework to analyze sociocultural change and complexity evolution. Previous developments were necessary to specifiy and integrate both symmetrical and asymmetrical polity interactions in a coherent model. Reactive processes have three functions at this point. First, they

[35] This indicates a theoretical impasse in the case of prolonged convention withdrawal pertaining to the conduct of war. Such a situation can only be reversed by the military defeat of the incriminated polity, which exposes the potential coercitive polities to more unpredictability and losses while doing so.

connect the central selection principle (and by extension, generalized evolutionism) to the polity interaction model. Second, they clarify the overall evolutionary context of societies. And third, they provide a central summary of the conditions and drivers of complexity growth in an evolutionary context.

Reactive process might be best characterized by what they produce: history. As Tainter puts it (1998:174), "history is substantially a chronicle of reactive processes". Reactive processes describe how societies respond to immediate pressures to ensure their continuation (inferred from Tainter, 1998:174-5)[36]. These pressures can arise from the need to ensure territorial, economic or political integrity, the imperative to deter a potential adversary, the urgency to increase resource production, the necessity to reinforce legitimacy, etc. (Tainter, 1998:174-5). While peer polities tend to react to other peer polities, subordinated polities tend to react to the expansion, domination, and meddling of dominant polities (Tainter, 1998:176). Pressures determine much of the possible reactions, as failure to do so effectively could mean termination or prolonged hardship for a polity, its ruling class or its institutions, etc. Reactions to different pressures display remarkable regularities throughout history. This makes them predictable to an extent (Tainter, 1998:174-5).

As events and processes can be mainly explained in terms of reaction to previous events and processes (Tainter, 1998:174-5), reactive processes define much of the context and direction of evolution. This is compounded by the effect of selection. Reactive processes indicate how adaptive and competitive polities were eventually selected at the expense of others. Fit organisms, as 'fit' polities solve the "enduring conflict between surviving today at the expense of tomorrow and providing for tomorrow while accepting extinction today" by choosing the former (Tainter, 1998:175). This simple reality has vast implications for complexity. Tainter summarizes it best (Tainter, 1992:106): "*When complexity does emerge it is for reasons of compelling need or perceived benefit. Complexity evolves under pressures from within a society; or pressures from without; or because peer polities emulate the organizational and technological developments of their neighbors*." This framework explains much of the development of complexity in complex societies, from the apparition of hierarchy (Tainter in Freedman, 2012, 06:57)[37] to the evolution of polities all over the world in the last 5000 years (Tainter, 2003d:71).

Reactive processes have significant implications for the evolution of complexity, complex societies and sustainability. These implications will be deepened in chapter 5.

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[36] The concept of reactive processes is partly reminiscent of Toynbee's 'challenge-response' model Toynbee & Somervell, 1946/1987). A recent work in sustainability studies (Schmandt & Ward, 2000:1) presented the concept as such: Tonybee "looked for the underlying cause that explained societal success or failure. By "challenge" Toynbee meant some unpredictable factor or event that posed a threat to the ways in which a group of people had made their livelihood in the past. [...] "Response" was the action taken by the same group of people to cope with the new situation. A challenge would arise as the result of many things – population growth, exhaustion of a vital resource, climate change. [...] Toynbee reserved the terms "challenge and response" for major threats and actions that impacted the well-being of the entire population. "Challenge" threatened the very survival of the existing system. "Response" would range from inaction to major change in the living conditions of individuals as well as the group. It could embody new technology, social organization, and economic activities, or a combination of various factors. "Response" was never predictable, and its outcome could only be known over time. This was the risk humans took – resulting in success or failure."

[37] As response to environmental pressure (rising population or other) requiring complexity growth (Tainter in Freedman, 2012, 06:57).

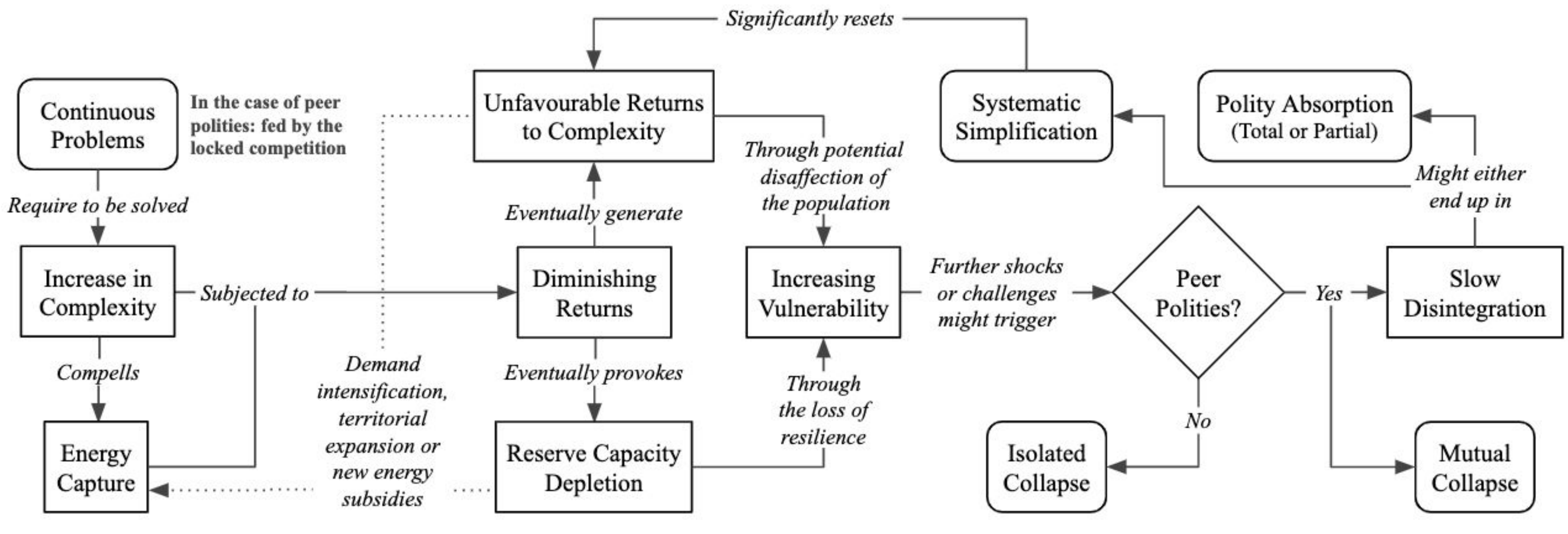

Figure 5.3. Synoptic summary of the evolution and termination of societies according to Tainter's framework. Figure by the author.

Trajectory	Political Situation	Discontinuity Requirements	Discontinuity Consequences	Examples
Isolated Collapse	Primary state with no neighboring organized polities	Diminishing returns and increasing vulnerability; outer political vacuum	Collapse (isolated); statehood disappearance; durable loss of complexity in the region	Cahokia, Old Egyptian Kingdom
Empire Collapse	Significantly higher complex and powerful polity dominating the other polities of the interaction sphere	Diminishing returns and increasing vulnerability; no peer competitor capable of filling the void	Collapse; replacement by smaller, less powerful and less complex polities	Western Roman Empire
Peer polity Collapse	Clusters of polities of equivalent complexity (in political, economic and technological terms)	Cluster-wide locked competition; overall diminishing returns and increasing vulnerability;; no external power capable of filling the void; impossibility to increase high gain energy* capture (territorial expansion or concentrated energy subsidies)	"Simultaneous"** mutual collapse (cluster-wide); statehood disappearance; durable and drastic loss of complexity	Maya and Mycenaean Cities-States
Polity Recovery	Polity surrounded by more powerful (but not dominating) peer competitors (militarily, economically, etc.)	Existential threat perception (Increasing vulnerability and peer competitors capable to fill the void) followed by imposition of systematic simplification	Reset of the cost-benefit ratio in complexity; state survival and recovery (militarily, economically, etc.)	Middle Byzantine Empire
Polity Disintegration	Polity surrounded by more powerful peer competitors (militarily, economically, etc.)	Increased (military) vulnerability and continuous military, territorial and economic loss to expanding competitors	Partial or total absorption by one or several peer competitors	Late Byzantine Empire, Ottoman Empire
Subsidized Peer Polity Competition	Clusters of polities of equivalent complexity (in political, economic and technological terms)	Cluster-wide locked competition with technological innovation ; overall diminishing returns ; possibility to increase high gain* energy capture (through territorial expansion or concentrated energy subsidies);	Dramatic increase in energy capture; sustained continued cluster-wide competition	Medieval and Renaissance European States

Table 5.3. Possible evolutive trajectories of complex societies. Remark: "Early State Collapse" and "Empire Collapse" are the only non peer polities trajectories. Notes: * High gain: Abundant and affordable ready-to use energy; ** Duration: generations to a century. Adapted or inferred from Tainter, 1988/1990:200-3, 212-4, Tainter, 1992:104; 2003d:75-7, 2012:120-3.

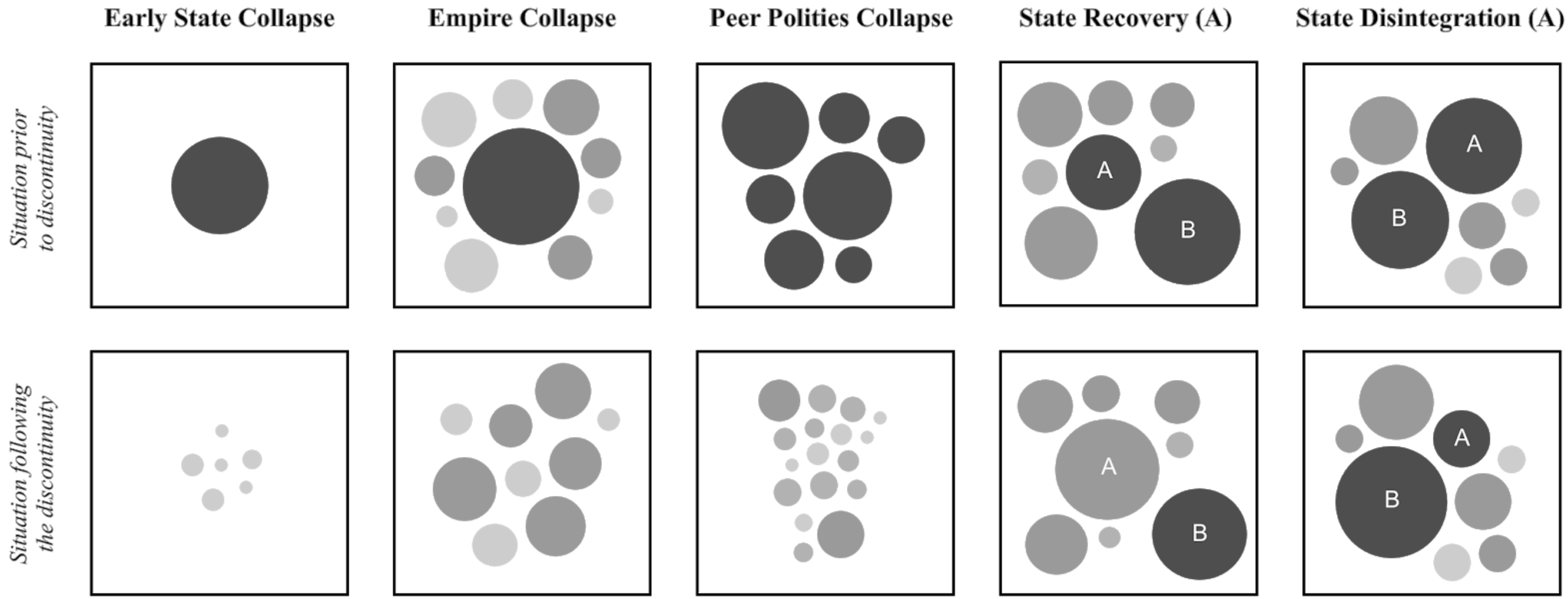

Figure 5.4. Symbolic visualization of the possible evolutive trajectories of complex societies. Each square illustrate an interaction sphere and each circle represent a different polity. The shades of grey correspond to the complexity of each polity, from low (light grey) to high (dark grey). The circle size indicates territorial control. In the "State Recovery" and "State Disintegration" trajectories, the "A" refers to the polity experiencing the trajectory. The "Continued Competition" trajectory is not represented because it mainly experiences an increase in complexity without significant configuration change in the dynamic of the interaction sphere. Its evolution could however be pictured by a transformation of the "Peer Polities Collapse" trajectory (situation prior to discontinuity) from a lighter to a darker gray. Inferred from Tainter, 1988/1990:175.7, 201-2, 214, 1992:104; 2003d:75-7; 2012:120-

5 Long-Term Evolution

Complex societies follow different trajectories in the long-term. These can be subsumed as such: societies ensure continuation, societies disappear and finally societies collapse. These trajectories are contingent to both fixed and variable factors. Fixed factors refer to legitimacy requirements and the bounded rationality of actors (this point having already been emphasized in the last chapter; it won't be elaborated in this one). Variable factors include the evolution of the return to complexity, energy gain and their polity situation. The first part of this chapter examines these drivers and their long-term impact, whereas the associated trajectories are explored in the second part. The third part concludes with some reflexion on sustainability.

5.1 Evolution Drivers

5.1.1 Diminishing Returns

As explored earlier, the evolution of complexity is subject to the law of diminishing returns. The simple fact has important implications. In the evolution of complexity, societies eventually reach a point where increased investments in complexity fail to yield a proportionate return. Costs rise then faster than benefits, which can even become negative at some point. As long as the society is standing, problems must be solved and thus complexity cost increase (1999a:994). Over the long-term, this situation has the following implications: the depletion of the reserve capacity of the society and the alienation of its support population (Tainter, 1998:127; 2013b).

Reserve capacity depletion can be associated with fiscal or military weakness and vulnerability to stress surges (Tainter, 1988/1990:127, 203; 2000b:18). A depleted reserve capacity means loss of resilience (Tainter & Taylor, 2014:1). This means that the society has no means left to adequately counter major adversities (Tainter, 1995:400). In parallel, as the cost of complexity increases, the support population becomes increasingly disaffected as people feel their investment is no longer proportional to their return (Tainter, 1988/1990:205). As a result, independence velleities develop among the population, which increasingly seeks to pursue its own goals rather than to serve those of the hierarchy (Tainter, 1995:400). In the Western Roman Empire case, this disposition can even lead to the population welcoming invaders as liberators, for their presence means termination of the unbearable imperial taxation (Tainter, 1988:145-8, 188).

5.1.2 Energy Gain

The economics of energy gain, whether high or low, also follow the law of diminishing returns (Allen et al., 2009:586) as resource extraction operates according to the best and least effort principles. It is thus inevitable for the costs of production relative to gain to eventually rise (Tainter & Allen, 2015:3). This means that a greater part of the society resources must then flow into energy production, which can have two consequences: compelling intensification and depriving other domains of resources. In practical terms, this implies higher taxes, more work, lower standards of living, etc. (Tainter et al., 2003:2). However, there are two situations where this might not materialize: first, the system finds energy subsidies in the form of either higher-gain resources or significantly lower-gain resources. Second, more effective production technology compensates (or even reverses) the tendency. This latter case is also subject to the law of diminishing returns (Tainter & Allen, 2015:4). But, if better technology (or production practices) might postpone for a time the effect of diminishing returns, resource production won't eventually escape the reality of resource depletion. This only way out it to find high-gain energy subsidies.

5.1.3 Polity Situation

Polities in a core-periphery situation evolve significantly differently than polities in a peer polity situation (Tainter, 1988/1990:201). Polities eventually either disappear or collapse. Dominant-subordinate polity relations are much less dynamic than their peer counter parts. As a result, the long-term dynamic of the polities evolving in a core-periphery configuration is significantly simpler: a prolonged period of diminishing returns increases their weakness and thus their vulnerability to collapse. On the converse, the same situation in a peer polity situation does not only increase the overall weakness and vulnerability of the polities, but makes regime change, slow disintegration and mutual economic exhaustion likely (Tainter, 1988:202-3).

This major difference is the result of the fundamental divergence in the evolutionary dynamic of the two polity configurations. As mentioned earlier, peer polity interaction tends to generate a competitive spiral, which compels ever more complexity growth (Tainter, 1988/1990:213). In such a configuration, peer ascendency is to be avoided at all costs, peer polities constantly need to ensure the means to protect their independence. This result in continued investments in organization, technology and military capacities among a permanent pressure to innovate. Polities that wouldn't be selected out by absorption. Soon, the competition becomes locked, as each polity doesn't want to suffer the risk of domination and independence loss (Tainter, 1988/1990:122, 214, 1998:177, 1992:106).

As each breakthrough is either rapidly imitated or countered by competitors, societies experience an increasing 'Red Queen Effect'[38], that is, ever more investments only to maintain the *status quo* (Tainter, 1988/1990:214, Tainter & Patzek, 2012:205). This stalemated competition eventually pressure societies under considerable diminishing returns. This is, however, compensated by an intensification of resource production and human work. In such a situation, there might be no advantage of winning, but there is certainly an imperative of not losing (Tainter, 1992:122). Therefore, collapsing is not an option. Collapsing would open the gates to absorption, which is to be avoided at all costs (Tainter, 1988:201-2). Figure 5.1 summarizes this dynamic. At some point, however, peer polities come close to mutual economic exhaustion unless they have access to energy subsidies (Tainter, 1992:103).

5.1.4 Legitimacy Requirements

Elites must constantly reinforce their legitimacy (Tainter, 1988/1990:27). Legitimacy refers to "the belief of the populace and the elites that rule is proper and valid, that the political world is as it should be" (Tainter, 1988/1990:27). This need determines much of what the elites should to do stay in power as ruling requires some sort of popular support. Therefore, ensuring legitimacy requires constant legitimizing activities and investments. Legitimizing activities range from ensuring basic stability (ensuring defense and local order) to providing for the population (redistribution, local funding; Tainter, 1988/1990:27). While effectively 'solving' these kinds of problems increases legitimacy, failure to do so weakens legitimacy (Redman et al., 2007:141). Legitimizing activities can also be considered as investments operating alongside the law of

[38] Named so in reference to a line of dialogue between the Red Queen and Alice in *Through the Looking Glass*, "Here, you see, it takes all the running you can do, to keep in the same place" (cited in Tainter & Patzek, 2012:205).

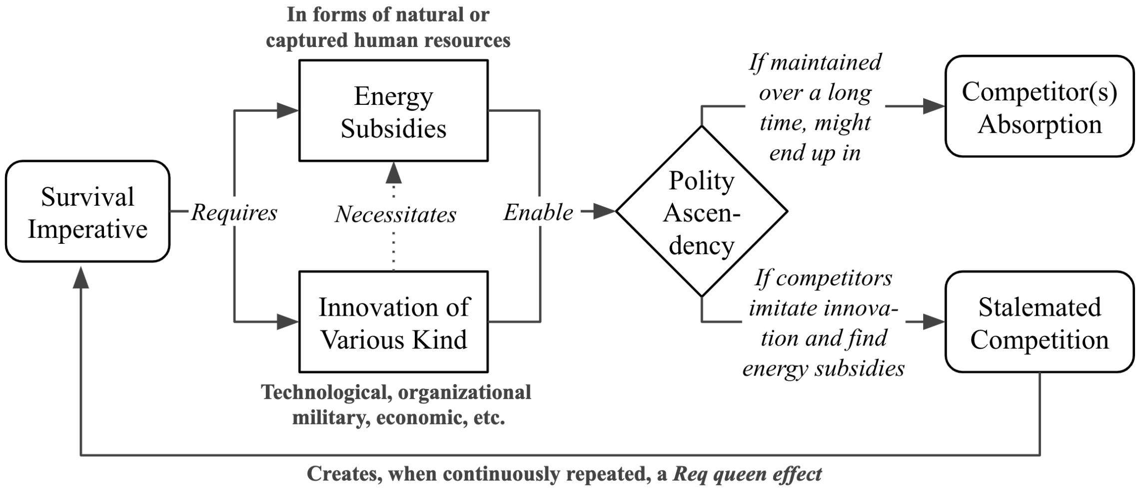

Figure 5.1. Peer polities competitive dynamic and possible outcomes. Data aggregated from Tainter, 1988/1990:122, 214, 1998:177, 1992:106; Tainter & Patzek, 2012:205.

diminishing returns (Tainter, 1988/1990:116–117) in a ratchet effect. When legitimizing activities and investments either become recurrent or are used to secure specific support (rather than building up on current supports), they quickly come to be considered normal elements of a proper rule as populations become used to them. Thus, as times goes by, the cost of normal and extraordinary legitimizing activities grows (1988/1990:117) while its elite benefit stays stable. This is reminiscent of the 'Red Queen effect'.

Legitimizing requirements being unending in nature (Tainter, 1999a:993), this aspect illustrates how difficult it can be for elites to scale down population benefits in time of resource scarcity. This reality underlines the little agency that elites enjoy. Even if elites might be convinced of the necessity to cut down costs to ensure survival, it is likely that such a project will never materialize as it threatens the very political survival of the current elites. Should the project be carried out and the elites lose sufficient support to be ousted out, how likely would such a project be carried out by the next elites? There is, however, one historic case of such a trajectory, but it required specific conditions (see § 5.2.3.2).

5.2 Long-Term Trajectories

As mentioned earlier, there are three main trajectory categories: disappearance, collapse and continuation. The following sections deepen each of these categories. Tables 5.2-5.4 and Figures 5.2 and 5.3 provide synoptic summaries of the different trajectories.

5.2.1 Disappearance

Disappearance is one of the two eventual end states of polity evolution. Disappearance should be considered separately from collapse. Disappearance results from absorption through disintegration or abandonment.

5.2.1.1 Disintegration

This case is the classic disappearance through conquest, like the story of Carthage or Macedonian Greece. Disintegration designates the gradual loss of power of a polity. It can lead to absorption by a competitor. One should not confound disintegration with collapse. Collapse entails to a rapid complexity loss, whereas disintegration refers to the polity weakening and possible absorption. Table 5.1 specifies the principal differences between disintegration and collapse.

	Slow Disintegration	Rapid Collapse
Complexity	No sudden loss	Rapid loss, later lower complex polities, either temporary or persistent for a long time
Territory	Slow and continuous loss to expanding competitors until absorption	Remains stable up to collapse, later is divided and occupied by polities of lower power and size
Power	Slow loss and increased weakness until absorption	Remains stable up to collapse, terminated after the collapse
Historical duration	Centuries	A few decades to a few generations (max. 100 years)
Examples	The late Byzantine Empire, the Ottoman Empire	The Greek cities-states of the Mycenaean period, the Warring States in ancient China, the Mayan City-states

Table 5.1. Differences between (slow) disintegration and (rapid) collapse. Adapted or inferred from Tainter, 1988:202, with formatting and additions by the author.

Disintegration can happen in both core-periphery and peer polity configuration. Disintegration means gradual political and military weakening. Disintegration followed by absorption can occur in both configurations: first, in peer polity competition, when a polity eventually becomes weaker than one of its competitors and slowly disintegrates as a result until it is absorbed; and second, in core-periphery configuration, a subordinated polity can also slowly lose power and then be absorbed as a result. When disintegration operates in a peer polity context, the competitor can acquire energy subsidies by conquest. Besides that, there are two other cases involving disintegration. The first one is partial disintegration, that is, disintegration that eventually stops. There is evidence of this case in a peer polity configuration, but its application might be broader. This case relates for instance to the gradual territory and power loss of the Ottoman Empire, which eventually stopped as Turkey became a modern nation state. The second case is disintegration followed by recovery. This case is explored in § 5.2.3.2.

5.2.1.2 Abandonment

Abandonment is the classic case of the Norse leaving Greenland (Tainter, 2006a:64). Abandonment refers to reduction in polity complexity and displacement. It is a rare case of polity evolution and tends to happen most in isolated and remote contexts. Abandonment is not collapse, as there is no polity and complexity left behind. Furthermore, abandonment followed by displacement can in fact be a strategy of continuation, as it might ensure conservation of a way of life (Tainter, 2005c, 87, 90–93).

5.2.2 Collapse

Collapse is the other of the two eventual end state of polity evolution. “Collapse is a rapid, significant, loss of an established level of socio-political complexity” (Tainter, 1999a:989). It usually happens within two or three generations (Tainter, 2000a:332). One particular trait of collapse, according to Tainter, is that collapse can economically make sense as the least costly option which apparently reconnects costs and benefits (Tainter, 1988:201).

5.2.1.1 Isolated and Empire Collapses

This case is the classic collapse of early states such as the Old Egyptian Kingdom and Empires as the famous collapse of the Western Roman Empire. It affects states that are in a core-

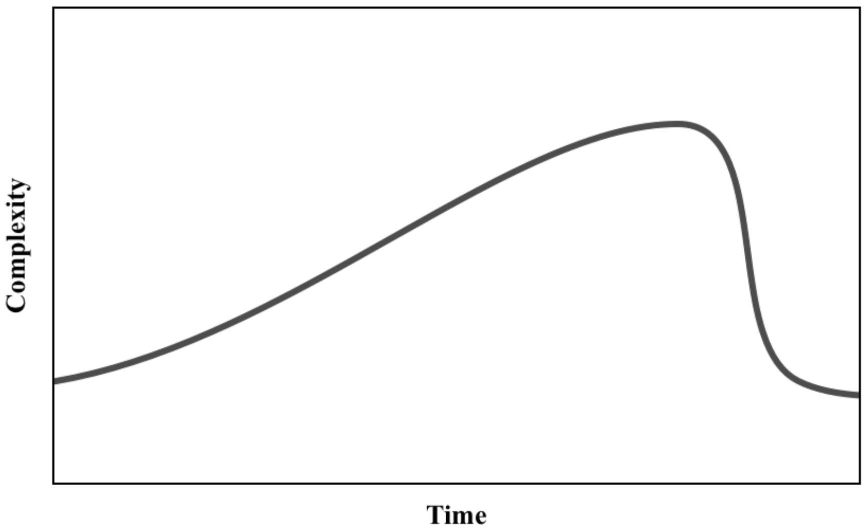

Figure 5.2. Schematized representation of collapse. Redrawn from Renfrew, 1979:485.

periphery situation. Once a prolonged period of diminishing returns has weakened the polity, collapse becomes a matter of "mathematical probability" (Tainter, 1988/1900:127), which is triggered as some point by either a shock or a tipping point in the disaffection of the population.

5.2.1.2 Mutual Collapse

This case relates to the collapse of the Maya and Mycenaean Cities-States (Tainter, 1992, 1998). This case only applies to peer polities. Polities that evolve as peers also collapse as peers[39] (Tainter, 1988/1990:213-4). Peer polity collapse requires a supplementary condition for the collapse to happen: a power vacuum. A power vacuum is a relative notion. It refers to the inability of any neighbouring polity to seize power should the weakened polity collapse. As the costs of peer polity competition become enormous, competing polities eventually reach a point of mutual economic exhaustion (Tainter, 1988:201-2, 213). When this point is reached, then collapse also becomes a "mathematical probability" (Tainter, 1988/1990:127), if it is guaranteed that collapse would be mutual and simultaneous (Tainter, 1988/1990:202). Peer polity collapse can be explained by two factors: First, once peer polities are economically exhausted, they have no reserve capacity left and therefore cannot seize a neighbouring territory. Second, collapse could happen in a fashion reminiscent of symbolic entrainment. The collapse of one polity could trigger

[39] Tainter is in fact not the first to make this point: Renfrew made it in the 1986 collective work on Peer Polities (in a description rather than explicative way though). Although Tainter includes Renfrew and Cherry's 1986 volume in his bibliography, he doesn't cite any chapter except for Sabloff's contribution on the Maya collapse. This is surprising, as the introductory and concluding chapter by Renfrew and Cherry in the volume are of central importance: Renfrew refines the core characteristics of peer polities and their interaction and then develops a theoretical embryo of peer polities collapsing together. It might be that Tainter did not read these chapters, which is puzzling if we consider that the final argument on collapse involves the mutual collapse of polities or its corollary – the impossibility of in a non-political vacuum (see further in text). This might be explained, however, if we consider the time necessary to conceptualize and then write the book. Tainter says that it took him two years of hard work to complete the book (Tainter, 1988/1990:xiii), which he began conceptualizing four years prior (personal conversation, 6 April 2019). During that time (therefore before the publication of Renfrew and Cherry 1986 collective work), he might have also conceptualized that Peer polities collapse together. One can however wonder why Renfrew, which was the series editor, didn't ask Tainter to include those two references in the final product (as at the same time, Tainter strangely cited the second series editor – Sabloff – for his contribution in the 1986 volume). What is probable is that Tainter didn't read the introductory and concluding chapter of the 1986 Renfrew and Cherry collective book, and that Renfrew wasn't obfuscated since his 1982 origin contribution was cited. What remains sure is that Renfrew's contribution to the fields of the evolution of complexity and the analysis of collapse have been significant – and predominant for Tainter's theoretical framework. This counts for the consequences of collapse (Renfrew, 1979:482-5), the definition as a rapid loss of complexity (Renfrew, 1979:485), the development of the peer polity concept (see Renfrew, 1982:286-9, 1986:1–18; Renfrew in Cherry and Renfrew, 1986:154-8) and the application of the Law of diminishing returns in archaeology (Renfrew, 1982:265-72).

other collapses for three reasons: first, the absorption threat disappears and thus a costly competitive apparatus isn't justifiable anymore; second, economic interdependencies would make collapse irresistible and third the collapse would be imitative (Renfrew in Cherry & Renfrew, 1986:155).

5.2.1.3 Post-collapse societies

Collapse is sometimes followed by abandonment, and sometimes not. It cannot be generalized. Postcollapse societies however present regularities (Tainter 1988/1990:4, 1999a:1021-7; with labels inspired by Cochet, 2011:2).

- Destratification: societies exhibit a lower degree of stratification and social differentiation;
- Despecialization: individuals, groups and territories become economically and occupationally more generalized;
- Destructuration: societies become less integrated and less centralized on the organizational, political and economic level;
- Disorganization: behaviour becomes less controlled and regulated;
- Prioritisation: societies invest less in monumental architecture, artistic and literary achievements, and the like;
- Disconnection: the flow of information between individuals, between political and economic groups, and between a center and its periphery;
- Disengagement. less sharing, trading, and redistribution of resources;
- Disaggregation: less overall coordination and organization of individuals and groups; a smaller territory integrated within a single political unit.

Postcollapse societies are also characterized by a romanticisation of pre-collapse societies, which are seen as a 'golden age' (Tainter, 1999a:1029; Taylor, 2013:66).

Category	Associated Processes	Trajectories	Example(s)
Core-periphery situation			
*Continuation**	Diminishing returns, acquisition of an energy subsidy (perhaps), low-gain resource transition (perhaps)	Continuation	N/A as transitory
Disappearance	Increasing vulnerability	Abandonment	Méma, Chaco
Collapse	Increasing vulnerability, legitimacy loss	Isolated collapse	Old Egyptian Kingdom
		Empire collapse	Western Roman Empire
Peer polity situation			
*Continuation**	Diminishing returns, continuous competition, absorption (perhaps), acquisition of an energy subsidy (perhaps), low-gain resource transition (perhaps)	Peer polity competition	N/A as transitory
		Recovery	Middle Byzantine Empire
		Subsidized competition	European Medieval & Renaissance States
Disappearance	Increasing vulnerability	Disintegration	Carthage
Collapse	Increasing vulnerability, legitimacy loss	Mutual collapse	Mycenaean and Maya Cities-states

Table 5.2. Synthetic view of all the possible long-term trajectories of sociocultural evolution Note: * until disappearance or collapse. Synthesis by the author.

5.2.3 Continuation

Societies which continue over a long time do so by subsidizing their competition or redefining the relation with their resource base and their institutions of problem-solving.

5.2.3.1 Subsidized competition

Subsidized competition is mainly the story of European peer polity competition (Tainter, 1988/1990:175-7). Subsidized competition refers to the capture of energy subsidies to finance the growing costs of locked peer polity competition subjected to diminishing returns (Tainter, 1988/1990:201, 214). This capture of energy subsidies can happen through territory capture of exploitation of high-quality resources. In the case of European peer polity competition, these energy subsidies were colonies first, and then fossil fuels. Securing energy subsidies ensures continuation of the peer polity, without restraints that the availability of this energy subsidy (Tainter, 1992, 1998).

5.2.3.2 Polity Recovery

Polity recovery is a case of internal reorganization and effective avoidance of disintegration. Recovery implies a systematic redefinition of the societal relation between the problem-solving institutions and the societal resource base. This redefinition requires a polity-wide systematic simplification, that is, a controlled reduction of complexity in all domains and levels. This controlled reduction of complexity resets the cost/benefit ratio of complexity in positive terms. The conditions of this case are however strict: First, the polity in question (and especially its elites) should clearly understand the existential nature of the threat (disintegration) and second, it seems that some sort of autocratic, centralized decision-making authority is necessary as to coerce internal actors that might be opposed to the loss of privileges, which are associated with systematic simplification (inferred from Allen, Tainter & Hoekstra, 2003:132-6: Tainter & Patzek, 2012:120-3).

This case is so rare in history that there is only one documented occurrence: the recovery of the Middle Byzantine Empire. In the late 7th century, the Byzantine Empire lost half his territory in about 10 years. This desperate situation required desperate measures. As the state coffers were empty, the empire leadership couldn't pay the army anymore. The decision was harsh, but effective. Citizens were given a portion of terrain in exchange or hereditary military service. Where before the empire had to maintain an important infrastructure to collect and redirect taxes, the new solution allowed to directly sustain the army from the fields. The reforms proved effective, as the empire better resisted attacks, and then went again on the offensive (Tainter, 2000b:24-27).

5.3 Consequences for Sustainability

The previous trajectories provide great lessons for sustainability. Sustainability can be defined by its converse (Krumdieck, 2013:313; 315)[40]. The converse of sustainability is unsustainability. Unsustainability eventually leads to extinction. Historically, the extinction of societies occurred through collapse or absorption. Collapse and absorption result from the failure to solve existential problems. Existential problems are problems of continuity (Tainter, 2014a:202). Continuity problems are historically of two types: unstable low-gain systems associated with unfavorable returns to complexity and incapacity to simplify (e.g. the Western Roman Empire); and upwards-spiraling competition associated with insufficient energy subsidies

[40] Krumdieck, writing in inspiration from Tainter, remarked that sustainability is a self-defining term. A self-defining term is a "term that is defined and measured by its negative" (Krumdieck, 2013:313, 315). Thus, sustainability can be defined by unsustainability, which is failure to survive (i.e. to be sustained). Continued survival is therefore central to sustainability.

(e.g. the Maya). The converse of collapse or absorption is continuation. Continuation is achieved by solving problems, especially existential problems. Prolonged continuation produces sustainability. Thus, *sustainability results from continued success in problem-solving, with an emphasis on existential problems* (Tainter, 2001/2009:386, 2013b:3). This realization has several implications on categorical, structural, and dynamic levels. While most of them were hinted in Tainter's work, only some of them were articulated as such[41]. The sections below elaborate them further in detail.

5.3.1 Categorical Implications

Categorical implications refer to the nature of sustainability.

5.3.1.1 Sustainability Consists of a Succession of Short-Term Adaptations

Continuation equates short-term survival. Short-term survival is constrained by selection and selection is conditioned by immediate pressures. Adaptation enhances the likeliness of being selected. Adaptation is achieved by effective problem-solving. Thus, sustainability consists of a succession of successful short-term adaptations (Tainter, 2019b:73) to immediate pressures through effective problem solving.

5.3.1.2 Sustainability Is the Product of a Series of Tradeoffs

Ensuring continuation often implies a central trade-off. This tradeoff is between surviving today at the expense of tomorrow[42] (Tainter, 1998:175). This trade-off is often expressed in several variants, such as: developing necessary solutions or institutions of problem-solving, while not being able to afford them or cope with their future cost (inferred from Tainter, 1998:175 and 2000b:37); Intensifying resource production to finance further resolutions of problems through complexity growth, while creating new problems provoked by this very intensification (inferred from Allen, Tainter & Hoekstra, 2003:9); raising revenues today, while undermining future productive capacity (Tainter, 2004b: 531); and increasing the rate of renewable resources consumption, while this very rate ensures future depletion (inferred from Tainter, 2014b:145). As sustainability implies prolonged continuation, sustainability is the product of a series of trade-offs. Eventually, these trade-offs might endanger sustainability itself (see § 5.3.3.3).

5.3.1.3 Sustainability Is an Active and not a Passive Condition

Sustainability is achieved through a succession of short-term adaptations. Sustainability demands deliberate action. It is therefore an active condition and not a passive condition (Allen, Tainter & Hoekstra, 2003:12). Societies remain sustainable as long as they are successful at solving problems. Sustainability cannot be a consequence of consuming less, with exception. This exception is systematic simplification. Systematic simplification resets the cost/of problem-solving while consuming less resources and successful solving new problems. This option is, however, subjected to constraints (see § 5.3.3.2).

5.3.1.3 Sustainability Measures the Long-Term Past and is Produced in the Short-Term Present

While the analytical scale of sustainability is the long term, its actionable scale is situated in the short-term. Whether a society is sustainable can only be measured in the long-term past. Societies are sustainable until they cease to be able to ensure continuation. Successful short-term adaptation ensures continuation and a prolonged period of continuation produces sustainability. Sustainability is thus the product of present adaptations. This emphasizes the permanent tension between the certainty of sustainability in the past and its present uncertainty.

[41] This is why some sections don't have cited works in them, as they rely exclusively on the synthesis.

[42] The converse, providing for tomorrow while going extinct today seems never to have been historically chosen. Selection effects might have played a role. This option implies deselection of the entity, which reduces the likeliness of developing and leaving remains identifiable in the archaeological record.

5.3.1.4 Sustainability Can Never Be Durably Secured

Future Sustainability can never be durably guaranteed. There are three reasons for this: the future is likely to be different from the present; the perception of existential problems is subject to cognitive and social impairment, and adaptations may fail. Adaptation failure might occur as the result of insufficient adaptation, delays in adaptation, misperceptions of selective pressures, or selective pressures rapidly changing. This highlights a critical feature of sustainability: while failure at being sustainable can happen at any time, success in sustainability consists of ensuring continuation (Tainter, 2006d:100). This success can only last a short-time, as new problems arise.

5.3.2 Structural Implications

Structural implications pertain to the (fixed) requirements of sustainability.

5.3.2.1 Sustainability Requires Positive Returns to Complexity and Sufficient Resources

Sustainability requires continued success in problem-solving. Effective problem-solving is determined by two factors: first, increasing or stable returns to complexity, and second, abundant and affordable energy (Tainter, 1996a). In other words, institutions of problem solving require solutions that deliver a proportionate return to their investment and sufficient resources to finance it.

5.3.3.2 Sustainability Almost Always Requires Resource Consumption to Increase

Sustainability requires effective problem-solving. Problem-solving generates complexity, which in turn requires more energy. A continuous stream of problems compels a proportionate complexity growth to be adresse and thus a corresponding increase in resource consumption. While simplification might solve problems (see below), bring better returns to complexity and decrease resource consumption, the rarity of this occurrence posits that sustainability almost always requires resource consumption to increase (Tainter, 2006d:99).

5.3.2.3 Sustainability Necessitates Resilience, and Resilience Requires a Reserve Capacity

Sufficient resources are associated with reserve capacity. A reserve capacity is critical to sustainability, as it allows a society to rapidly mobilize resources to face existential problems (Tainter, 2013b:10). As a corollary, a reserve capacity makes a society resilient, as it has the resources to recover from shocks (Tainter & Taylor, 2014:1). Societies without reserve capacity might never recover from major shocks and threats and eventually become unsustainable.

5.3.3 Dynamic Implications

Dynamic implications are related to the (variable) evolution of sustainability.

5.3.3.1 Sustainability Might Be Enhanced by Competition

Competition is associated with collapse avoidance to maintain independence, as not to be absorbed by a competitor. Collapse avoidance as to maintain independence generates new constraints. These constraints compel greater participation of the population in the competitive effort and increase the threshold for population alienation. Thus, these constraints can make diminishing returns to complexity and greater costs more acceptable than in a non-competitive situation. Where an isolated or dominant polity would long have collapsed, a competitive polity is likely to continue as to ensure its independence. As longer continuation is produced by competition, competition might enhance sustainability.

5.3.3.2 Sustainability Might Arise Through Systematic Simplification (Within Constraints)

Continuation, thus sustainability, can theoretically arise from systematic simplification. Systematic simplification implies a significant polity-wide reduction in complexity. This reduction produces a better return to complexity as fewer resources are needed, which enhances polity recovery. However, the only documented case of systematic simplification suggests specific conditions for a successful recovery: first, an existential threat must be perceived polity-wide (especially by the elites); second, the returns to complexity or available resources must be judged insufficient to cope with the threat; third systematic simplification must be identified as an option (out of necessity or through evaluation); fourth, the society must have the hierarchical means to impose the systematic simplification (as complexity reduction is associated with privilege losses and lower living standards); fifth, the transformation should maintain or increase the legitimacy of the ruler; and sixth, post-transformation problem-solving *must* be adequately able to solve existential problems, including problems of competition. Failure to meet any of these conditions will very likely result in ineffective systematic simplification and terminated either by absorption or collapse. This underlines how systematic simplification by itself does not constitute sustainability. Continuation after systematic simplification produces sustainability.

5.3.3.3 Sustainability May Make Societies Eventually Unsustainable

A prolonged succession of trade-offs indicates sustainability but also amounts to greater challenges. As complexity grows, so does its cost. There eventually comes a time when the return of complexity becomes significantly low, where resource production is insufficient, where the societal reserve capacity is depleted, etc. Every one of these problems is the (direct or indirect) result of past complexifications through problem-solving. At each problem-solving iteration, higher complexity and higher costs may have appeared to be incremental and affordable. However, their cumulative long-term effects are typically unforeseen (Tainter, 1995:402). There might come a point where the situation becomes so deteriorated that collapse occurs. This constitutes one of the great dilemmas of sustainability: a society can be destroyed by the long-term cost of ensuring its sustainability (Tainter, 2006d:99).

6 Critiques

Tainter's theoretical framework has been criticized by a variety of authors. This criticism ranges from minor corrections (either factual or conceptual) to confronting the whole framework. Most of the praise, or criticism, revolves around Tainter's 1988 original publication of *The Collapse of Complex Societies*[43]. The reviews published shortly after the book release constitute the overwhelming part of all (Chapman, 1988; Whitehouse, 1988; Jones, 1989; Kardulias, 1989; Knapp, 1989; Myers, 1989; Rousselle, 1990; Rule, 1989; Blanton, 1990; Bowersock, 1991). The other reviews are either late (Ahuja, 2012) or related to the release of the book's French translation in 2013 (Potkine, 2014 and Dousset, 2017). Most of the reviews are academic in kind, with few exceptions of sufficient elaboration to be taken into account (Ahuja, 2012; Potkine, 2014; Dousset, 2017). While both *Supply-Side Sustainability* (Allen, Tainter & Hoekstra, 2003) and *Drilling Down* (Tainter & Patzek, 2012) seem to have been widely appreciated by the public[44], the books respectively didn't generate academic reviews pertaining to the theoretical framework[45], or didn't generate any review at all.

This is why the quasi-majority of the criticism is crystallized around *The Collapse of Complex Societies*. Aside from the reviews, there are relatively few instances of criticism in the literature (Gregory, 1994; Van der Leeuw & De Vries, 2003; Diamond: 2004/2006; Middleton, 2008, 2017a, 2017b; Johnson, 2017; Storey & Storey, 2017), however wide the searches. Only few authors seem to have read other papers (Middleton, 2008, 2017a, 2017b). Storey & Storey, 2017). This is unfortunate, for Tainter's contribution on sustainability is significant and deserves discussion. As a result, the collected critiques can only allow a partial discussion of Tainter's work. Concepts such as energy gain, resources transition, sustainability (and its critique), and even complexity won't be confronted.

If the examination scope of the theoretical framework is narrower as one might wish, the collected critiques are rich and diverse for the most part, with a few exceptions. The majority of the critiques are directed at six points: an overreliance on process and structure; the outsized role of diminishing returns; his failure to effectively explain collapse; its dismissal of several relevant factors, such as shocks, resource depletion and overshoot, historical circumstances and actor behaviour; and finally, the economic bias of the model. This section also discusses the Western Roman Empire, as the case does critique Tainter in an indirect way. As to give sufficient context, the first section of the chapter briefly presents the reviews to *The Collapse of Complex Societies*. A synthesis of the praise for the book follows, while the third section discusses most of the points introduced above. A final evaluation summarizes the previous points and concludes the chapter.

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[43] The reviews were not easy to find. Collection was performed via multiple Google Scholar searches and through two former reviews aggregations (Middleton, 2008 and Vespertine, 2018).

[44] See the ratings on the online review aggregator Goodreads ("Supply Side Sustainability," 2019; "Drilling Down: The Gulf Oil Debacle and Our Energy Dilemma," 2019).

[45] Two reviews have been found for *Supply-Side Sustainability* (Czech, 2004; Jeffers, 2004). Both focus on the main concept of the book (supply-side sustainability) and do not discuss relevant elements of Tainter's theoretical framework (although present in the book in form of useful summaries and additions).

The first two sections are merely descriptive, whereas the rest (save for the evaluation) tries to be interactive. This interaction can take the form of the author agreeing or responding to the critiques according to Tainter's theoretical framework.

6.1 Reception of *The Collapse of Complex Societies*

The Collapse of Complex Societies generated more than ten academic reviews in the three years following its release and thirteen in total. This number testifies of the 1988 book's reach and significance. In order to adequately contextualize the reviews, this section proceeds with a short description of the reviews, then summarizes the appreciation of the reviewers, followed by a short assessment of the reviews and finally briefly comments some selected reviews. Three reviews (Chapman, 1988, Myers, 1989; Knapp, 1989) also cover *The Collapse of Ancient States and Civilizations*[46] (Yoffee & Cowgill, 1988/1991) while the others are solely focused on *The Collapse of Complex Societies*. A majority of the reviews are brief (four under one page; three under two pages, three over two pages[47]), with one lengthy exception (Knapp; 1989). Consequently, elaborate criticism is either concentrated and elaborate, or diffuse and generic. This results in most reviewers only criticizing a part of the book.

While the majority of the reviews give mild or high praise of the book, others were notably more polarized. Aside from Chapman's review (1988), which is almost only descriptive, the others can be classified as follows:

- Praise with acknowledgment of minor flaws: Whitehouse (1988), Kardulias (1989) Jones (1989) and Russel (1990). Ahuja (2012) and Potkine (2014) also fall into this category;
- Praise with a critique of the totalizing, simplistic and abstract nature of the model: Myers (1989). Rule (1989), Knapp (1989). This position is also adopted by Dousset (2014);
- Little praise and heavy criticism pertaining to various aspects and specifically insistent regarding the interpretation of the Western Roman Empire case: Blanton (1990) and Bowersock (1991).

The majority of the reviewers seem to have understood the book well, but some appear to have grasped its contents only in part[48]. This seems to be reinforced when the reviewers focus their (strong) criticism on peripheral elements of the model, while seemingly missing the central point of the book (in parts, Jones, 1989). Some reviewers use a completely different wording in their review for some concepts while not mentioning other relevant information of the book (e.g. Rule, 1989, who confuses polities for empires). Some give much appreciated contextual information (e.g. Kardulias, 1989:601, on the tension within processual archaeology; Myers, 1989:1065, on Tainter's position in the formalist-substantivist debate; and Jones, 1989:634, on the structuralist bias of the model).

All reviewers approach the book from their own disciplinary perspective, and only few seem to be able to navigate outside of it. As a result, a portion of the reviewers engage in some unsubstantiated criticism. It seems, however, that they didn't understand elements which they criticized in the first place (e.g. Whitehouse, 1988 and Blanton, 1990, who apparently didn't understand the nature of diminishing returns). This is problematic, as are some cases of unspecified criticism. These are particularly unhelpful, as they do not indicate what point triggered a reaction and cannot therefore be either debated or corrected. Two reviews exemplify

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[46] In an interesting twist of events, *The Collapse of Complex Societies* and *The Collapse of Ancient States and Civilizations* were coincidentally published the same year. Although the two books greatly differ in perspective (see Knapp, 1986:199-206), both are now considered classic and key readings in the field of collapse (Middleton, 2017b:424).

[47] Effective space allotted to the review of *The Collapse of Complex Societies* (subtracts the spaced used to review *The Collapse of Ancient States and Civilizations* if relevant) : ¾ page: Chapman (1988), Jones (1989), Myers (1989) and Rousselle (1990); 1 ¼ page: Blanton (1990); 1 ½ page: Kardulias (1989) and Rule (1989); 2 pages: Whitehouse (1988) and Bowersock (1991); 9 pages: Knapp (1989).

[48] This suggests that some reviewers only skimmed the book or hastily read it (as Chapman, 1988).

this behaviour (Blanton, 1990, Bowersock, 1991). Their authors were apparently so crystallized on a few contention points that they missed the bigger picture. The following section presents some reviews illustrative of the trends introduced above.

Of all the reviews, Kardulias's (1989) stands out. It is the only one addressing the mechanism of collapse constrained by peer polity competition. It is also the only review to discuss the relevance of the book for the future. This aspect seems to have been so remote from the other reviewers as none comes close to it. Knapp's review (1989) is the longest, but also the most carefully crafted. It also covers Cowgill & Yoffee's book (1988) as well. Knapp adequately balances the two and weights their strengths and weaknesses. His impressive scholarship allows him to put things in perspective like no other reviewer or subsequent critique could (with a loose exception for Middleton). Knapp and Kardulias are the only reviewers to show signs of Peer polity Interaction[49] understanding. Being particularly respectful and knowledgeable, it is probable that most authors would prefer Knapp's type of treatment when subject to criticism.

Blanton (1990) and Bowersock (1991) expressed much discontent, although it is not sure that they fully understood the whole model before beginning their reviews. Both of their reviews are more critical than constructive. Blanton finds Tainter's partially successfull in building "a state-of-the-art theoretical framework", as he could have used more "systematic thought and editorial guidance" (p. 422). He concludes that "anthropological archaeology could do a better job with such an important topic" (p. 423) but does not specify how and why. Bowersock's review is witty and amusing, as bad reviews tend to be (Vespertine, 2018) but unhelpful as a whole. It seems that the author was significantly annoyed by Tainter's treatment of the Western Roman Empire. Bowersock spoke with the authority of an eminent Roman historian (Vespertine, 2018), which just covered the topic in Cowgill's and Yoffee's *Collapse of Ancient States and Civilizations* (Bowersock, 1988). The reviewer was a member of the school of 'Late Antiquity', the prevalent historical view of its time. The school of 'Late Antiquity' stressed the 'continuation' and 'transformation' of the Western Roman Empire. This view has been, however, severely questioned (see § 6.4). As a result, Bowersock was convinced of the accuracy of this representation and probably aggressively and repeatedly admonished Tainter for what appears wrongthink. The contention must have been significant, as Bowersock tries to dig as many inconsistencies as possible to discredit the model, and cites nonexistent definitional shortcomings. The reviewer seems keener to chastise Tainter than to improve his scholarship. This brings confusion and doesn't advance knowledge, both of which are of no use for the present exercise. Most of Bowersock's review should thus be cast aside[50].

6.2 Praise

Various commentators were quick to observe how Tainter (1988/1990) found in the study of collapse an important gap in the literature which pressed him to organize a coherent framework to address it (Whitehouse, 1988:789 and Jones, 1989:634). The book was met with repeated praise. This praise pertains to three categories: The book as a whole, Tainter's decisions and Tainter's framework.

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[49] In fact, Knapp reviewed Cherry and Renfrew's 1986 collective work (Knapp, 1986).

[50] Bowersock's treatment is illustrative of a bigger problem at play. This problem is the tendency for specialist to become so entrenched in scholarly niches that they become prisoners of their disciplines. An obsession for precision tends then to produce narrow-thinking, which in turn might feed a posture of righteousness. At some point, discussion with non-specialists becomes impossible as specialists seem only willing to be challenged by peer scholars (which tend to disappear as specialization grows). This drive for precision, and in some measure, for power, replaces a drive for relevance. Therefore, the conversation stops where it could become relevant, because Bowersock seems incapable to think abstractly and outside his area of expertise.

6.2.1 Praise on the Book

Kardulias (1989:601) deemed this scholarship remarkable. Rule (1989:73) found it considerable and wide-ranging. Knapp (1989:206) stressed it as a 'new impetus' and Blanton, however critical, recognized it as a 'methodological "hammer"' (1990:421). Its arrangement was judged extensive and eloquent (Knapp, 1989:205), the arguments and data thoughtfully presented and well-written (Myers, 1989:1066). The literature review was perceived as ambitious (Blanton, 1990:421) and thus only partially successful for some (Blanton, 1990:422), while others found it welcome and valuable, especially the introduction to the different theories of collapse (Jones, 1989:634) and its effects (Middleton, 2008:58). The presentation of the debate on state emergence was praised for its impartiality (Dousset, 2017) and Tainter's approach to complexity was perceived competence (Myers, 1989:1066).

The whole enterprise was lauded for its "deft handling of a large amount of material" (Kardulias, 1989:600), which provided "much useful historical and archaeological information on empires" (Rule, 1989:74). As a whole, the book was found lucid, stimulating (Whitehouse, 1988:789; Bowersock, 1991:119), and thought-provoking (Rousselle, 1990:543)., as its "endless raw material" could provide much for reflexion (Ahuja, 2012). The book multiple ideas (Jones, 1989:634) made it very interesting (Dousset, 2017), prompting reviewers to recommend it widely (Whitehouse, 1988:789) in the humanities as a whole (specifically in archaeology, anthropology, (economic) history, historical sociology (Knapp, 1989:206).

6.2.2 Praise on Tainter's decisions

Kardulias commended the decision to conceptualize complexity as a continuum and sanctioned the correct identification of the schools of state emergence as inadequate (1989:600). Reviewers felt that competing collapse theories were given "fair and objective representation" (Myers, 1989:1065) and agreed with Tainter that none are adequate (Kardulias, 1989:600 and Jones, 1989:634), especially mystical theories (Whitehouse, 1988:788). However praised was the coverage of competing collapse theories, others found it much too long (Knapp, 1989:202). The inclusiveness of the model, which avoids single cause explanation was commended (Jones, 1989:634). Finally, the interpretation of collapse as a possible adaptive strategy met scholarly agreement (Kardulias, 1989:600).

6.2.3 Praise on Tainter's Framework

The framework was found solid for several reasons: "the broadness of its terms of reference" (Whitehouse, 1988:789); its large applicability, which is largely accommodating for all levels of complexity and evidence (Whitehouse, 1988:789); the relevance of diminishing returns (Dousset, 2017), a flexible and universally applicable mechanism (Kardulias, 1989:600-1) that "cannot be faulted" (Knapp, 1989:206). These characteristics made the whole model attractive and elegant and indicated strong relevance for its contemporary transposition (Kardulias, 1989:600-1; Storey & Storey, 2017:36).

6.3 Critiques

The critiques addressed to the framework can be summarized as: an overreliance on process and structure; the outsized role of diminishing returns; his failure to effectively explain collapse; its dismissal of several relevant factors, such as shocks, resource depletion and overshoot, historical circumstances and actor behaviour; and finally the economic bias of the model.

6.3.1 Overreliance on process and structure

The model of society evolution and collapse is structuralist. Structuralism stems from system theory. System theory analyzes systems, including societies, which are integrated and regulated structures that adapt according to events and triggers. In this view, once a certain level of instability is reached and a triggering event materializes, a society is forced to reorganize—i.e. collapse (Middleton, 2017a:8). This view is seen as problematic by several commentators (Yoffee & Cowgill 1988:251–255, cited by Knapp, 1989:202; Middleton, 2017a:8, 61, 217) which critique its underlying presumption—high integration and regulation of societies. Furthermore, structuralism "reduces dynamic human action to motiveless structure" (Middleton, 2008:217). Authors who consider agency, decision-making and unique historical circumstances to be key factors of the evolution of societies will inevitably reject a structuralist model like of Tainter's (Middleton, 2008:61-2). Tainter is in fact a structuralist. He doesn't believe in the capacity of personal agency to significantly alter the course of evolution (personal communication, 5 April 2019). However, if the converse might be proven, that is, that the whole system dynamic can be changed through time and space, then the model should be adapted. Until this point, it seems that personal agency and unique historical circumstances (competitive dynamics excepted) can at best account for increasing or reducing the speed of the process, not its trajectory.

6.3.2 Outsized Role of the Diminishing Returns

After having criticized single-cause explanations, Tainter's almost does exactly the same by explaining most of the collapse by the role of diminishing returns (Potkine, 2014). The resulting model should be synthetic as it combines all possible causes into one (Ahuja, 2012). However, it has also been perceived as emphasizing only a single cause (Rule, 1989:73). This outsized role attributed to one factor (Johnson, 2017:69) has been criticized as excessive (Dousset, 2017), monolithic and misguided (Middleton, 2008:61). This approach supposes that similar causes will always produce a analogous results (see § 6.3.3, which casts doubts that the model actually explains collapse; Rule, 1989:73). While recognizing the role of diminishing returns in explaining collapse, scholars advocate for a multifactorial approach which takes into account specific and unique (local or historical) circumstances in explaining collapse (Middleton, 2008:62; Johnson, 2017:6),

This criticism is partially iconic, because Tainter selected diminishing returns as a synthetic account of multiple factors (Tainter, 1988/1990:3, 5). There are several explanations why this aspect wasn't understood by contrarians: First, it may not have been stressed enough, second readers may have not paid sufficient attention or third, the criticism holds because it addresses another underlying conception of the model: its economic perspective. Economic perspectives have long been criticized, as they are incomplete and fail to account for intangible factors (Van der Leeuw & De Vries, 2003:255, see § 6.3.6 for a critique of Tainter's economic leanings).

6.3.3 Failure to Effectively Explain Collapse

While Tainter's model may fairly well represent the structural evolution of societies, many scholars have argued that it doesn't really explain collapse. Detractors indicate that the framework cannot really account for proximate causes[51] (Knapp, 1989:206). It seems that the focus of the model on the underlying evolutionary dynamics relegates actual collapse processes in the background (Middleton, 2008:62). A complete collapse explanation, scholars emphasize, must identify a factor that precipitates collapse and describes the whole process (Johnson, 2017:5; Middleton, 2017b:11;184). Even if this identification might be of reduced value relative to the understanding, it is important, as it constitutes an essential part of the explanation and the narrative (Middleton, 2017a:8).

[51] At best, it integrates the possibility of disaffection of the population and the increased vulnerability to shocks. This can be hardly described as proximate causes (inferred from Knapp, 1989:206).

A similar critique has been expressed in the form of the model being too abstract, too simplistic and dramatic as it fails to account for the effect of variations on Collapse (Chapman's inferred criticism of Cowgill, 1988:22; Myers, 1989:1066; Inferred view of Yoffee & Cowgill from Knapp, 1989:206). As a result, the model could be irrefutable. This could be the price of some measure of explanatory coherence (Myers, 1989:1066). This critique and the previous one on causal pathway might be sorted out if when considering Tainter's model as a description of *how societies become increasingly vulnerable to collaps*e, rather than collapse in the first place.

6.3.4 Dismissal of Several Relevant Factors

The oversized role attributed to the diminishing returns has already been emphasized. There have been specific appeals as to take into account several other factors in explaining collapse: shocks, historical circumstances and actor behaviour (especially the role of agency and decision-making).

6.3.4.1 Dismissal of Shocks

Contrarians argue that some shocks might be of absolute greater magnitude than others, irrespective of the available reserve capacity of the society (Jones, 1989:634). There is certainly a need to account for mega-shocks that are beyond the adaptive capacity of any society. But these shocks didn't seem to have materialized so far in history. Advocates of this approach don't seem to have consciously read the 1998 book, for Tainter explained his refusal to consider this factor. When societies collapse under apparent shocks, proponents should explain why certain societies collapse and not others (Tainter, 1988/1990, 89, 198, 206; also: 1996c & 2012b).

6.3.4.2 Dismissal of Resource Depletion and Overshoot

Another variation of this criticism pertains to Tainter's failure to take into account resource depletion has been criticized by Diamond, which wasn't convinced of the former explanation for excluding the factor (2006:420). Tainter explained his refusal because of the divergent outcome of resource depletion: while some societies collapse, other actually increase in complexity through intensification. Therefore, susceptibility to collapse should better be explained in terms of internal differences rather than external factors (Tainter, 1988/1990, 89, 206; also: 1996c & 2012b example: 2000a:333-4). Besides his criticism of resource depletion, Diamond lamented that other scholars didn't consider the possibility of collapse by overshoot (2006). After having studied both the role of climate change (Tainter, 2000a) and overshoot (Tainter, 2006a) in collapse, Tainter concluded that evidence of both was slim, if nonexistent, in the archaeological record.

6.3.4.3 Dismissal of Historical Circumstances and the Role of Actor Behaviour

Other critiques voiced discontent at the absence or limited integration of personal agency & decision making and historical circumstances in the model. These factors have been recognized by some as key factors in societal evolution (Middleton, 2008:62). Middleton argues: "individual decisions and actions can and do shape wider and sometimes very profound events [. . .] empires or states as actors are fallible in executing policies (even good ones), can be very slow to respond to events, and may not always respond in the 'best' way" (Middleton, 2017b:187). One example of such mismanagement is the events leading up to the battle of Adrianople in the late Western Roman Empire[52].

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[52] "[In the second half of the 4th century,] the movement of the Huns toward the west put pressure on the peoples of eastern and central Europe who were not part of the Roman Empire. Because of the pressure of the Huns, in A.D. 376 the Goths, living in central Europe, petitioned to be allowed into the empire. The Roman government was always looking for recruits for the army, and so the emperor, Valens, allowed them in. But corrupt Roman officials began to cheat and enslave the Goths. Soon they were starving, and began to pillage Thrace.Valens assembled an army of perhaps 15,000 men to subdue them. The Roman army at this time was divided between mobile field forces and stationary frontier troops. [...] Valens took with him much of the eastern field army that could be spared from other duties. The two forces met at Adrianople in Thrace on August 9, 376. The result [...] was the worst Roman defeat since Cannae. About 2/3 of Valens' army was killed, as was the emperor himself. The core field army of the eastern empire was gone. The

Diamond also rebukes Tainter in that its model doesn't account for decision-making failure, which, Diamond claims, is prevalent in societies. This reproach suggests that Diamond didn't carefully read Tainter as the later states that the model sort of integrate mismanagement in two ways: he considers misadministration a normal, normal aspect of complex societies and thus integrates the incurred costs in the model and cannot believe that elites cannot act irrationally in the long-term as they put their survival at stake (Tainter, 1988/1990:72, 89; confirmed by personal communication, 5 April 2019; see also: 2000a:341).

While it is true that Tainter doesn't believe in the capacity of personal agency to significantly alter the course of evolution (personal communication, 5 April 2019), the real question should revolve on how personal agency and decision-making affect the dynamics of the evolution of societies. As of now, it seems that there is only one instance of a society avoiding collapse by reforming under tremendous pressure. Decision-making seems to have played an important role, but how comparatively to the society dynamic and the urge to survive? It should seem prudent for proponents of the agency approach to justify their claims by showing how decision making affected the long-term societal dynamic in the first place. If this influence only account for speeding, or reducing the process of collapse, then these factors are of little use. On the contrary, if it can be shown that they have significant impact and play a role in preventing collapse trajectories, then these factors would take on considerable importance.

6.3.5 Economic Bias

Tainter's economic leaning generated further reproaches, without stating how they might be wrong. It seems that most criticism stems more from a reaction to the inclusion of economic theory and its associated effects. The law of diminishing returns is a component of the theory of the firm. This inclusion provoked rebuke as contrarians accused Tainter of analyzing societies as firms (Rule, 1989:73), who see only complexity as an investment (Blanton, 1990:423). The use of economic theory to analyze society implies value-judgments and thus divides social scientists (Bowersock, 1991:120 and Middleton, 2008:61-2). As Myers notes, "the reader's position on the "formalist-substantivist debate" in economic anthropology is probably a strong predictor of his or her opinion on the validity of Tainter's [formalist] conclusions" (Myers, 1989:1065). The debate fundamentally opposes universalists who recognize shared patterns among societies, such as economic rationality and particularists and constructivist who advocate that economic rationality is culturally constructed[53]. If there is wisdom in cautioning the use of universal theories, contrarians should also admit that societies adequately capable of observing these much-denigrated principles of the formalist approach have been selected to dominate the world.

Another critique pertains to the nature of the 'returns'. According to Rule (1989:73), the synthetic and encompassing nature of the returns to complexity masks social inequality and tension. (Rule, 1989:73) Returns as such should be defined, he argues. As previously mentioned, it is uncertain whether Rule truly grasped the nature of diminishing returns. Diminishing returns refer to complexity growth, that is, elaboration of structure and organization. Should inequality affect the dynamics of the model, then contrarians should prove it. It is sure that elites tend to accrue the benefits of complexity at the top, but then the important question is: does it affect long-term trajectories?

Goths were free to devastate Thrace, which they proceeded to do. [...] The Battle of Adrianople marked a turning point in Roman history. [...] The balance of power was shifting in favor of the Germanic peoples of central Europe." (Tainter, 2013b:7)

[53] "Formalists (aka rationalists) [...] premise that all humans are rational and all behavior can be explained rationally. The desire to maximize profit is rational and universal. Depending upon [...] rules consistent with the "principle of least effort" and calculated self-interest that transcend culture, though the rules or protocols might be different for each level of development. Substantivists (aka culturalists or "romantics") view economics as a category of culture as a "sense-making system" that determine human behavior; economics is organized by domestic groups and kinship relations. Economic behavior is a "cultural construction." Our bourgeois economic values are not universal, argues Marshall Sahlins, they are a product of culture." ("The Formalist-Substantivist Debate," n.d.)

6.3.6 The Western Roman Empire

Did the Western Roman Empire collapse? If not, is it sufficient to reject Tainter's model as awhole? In 1990, the historical school of the 'Late Antiquity' was the dominant view of its time. The 'Late Antiquity' view stresses that the disappearance of the Western Roman Empire should be more accurately described in terms of 'continuation' and 'transformation'. This view was, however, later severely questioned (Ward-Perkins, 200; Middleton, 2008:188-9, 2012:263.4; 2017b:182-186, 193, 203; Taylor, 2013:61–65; Harper, 2017). Bowersock and others (such as Gregory, 1994) obviously think that proving Tainter's case study wrong equates effectively refuting his model or significantly weakening it. This, however, is not how it works: First, the question whether the Western Roman Empire collapsed or not is very debatable (and leans towards collapse when the observer lens shifts from symbolic continuation to actual living conditions, see the above-mentioned works). Second, should the Western Roman Empire have not collapsed, this only constitutes proof of a potential inadequate case study and not evidence of the model failure. Last, this criticism doesn't address the effect of prolonged diminishing returns.

6.4 Final Evaluation

Given the diffusion of *The Collapse of Complex Societie*s and later articles, it is safe to say that the bad reviews were not heeded. In fact, the balance between the praise and the criticism of the reviewers is positive. Yet, most of the criticism is justified and raises important points. The tension between structural explanations of sociocultural evolution is obviously not solved, and contrarians are right to caution against overreliance on processes and blind universalism. However, it seems that one shouldn't be over cautious, as contrarians have yet to prove how non-synthetic and particularist factors, such as personal agency, decision-making, historical circumstances really affect long-term dynamics. This point might be important for guiding further research. It has been widely demonstrated, it seems, that they surely have a significant short-term impact and can act as triggers of various reorganizations.

All things considered, there is, it seems, sufficient evidence to accept most of the construction and implications of the tainterian framework, within constraints. These constraints are that the framework doesn't explain how societies collapse, it indicates how vulnerability grows as societies solve problems and increase resource production, and how high complexity costs increasing vulnerability to collapse. Collapse may be inevitable and even unsurprising (Middleton, 2017b:184), but the diminishing returns can only account for vulnerability. As the extended tainterian framework covers actually much more trajectories than collapse, it would have been interesting to analyze some feedback. Sadly, there is close to none.

7 Contemporary Analysis

This chapter aims at analyzing contemporary societies in the light of the previously developed framework and identify their likely evolutionary course. While contemporary societies exhibit a series of both quantitative and qualitative differences with ancient societies, both operate within the overall same set of constraints. As a result, their evolutionary dynamics are similar in directions with differences in complexity, polity, population size and speed of the processes. This chapter is divided in four parts: the first part of the chapter describes the evolution towards modernity and compares ancient and modern societies, as to identify commonalities and differences; the second part evaluates the contemporary situation in terms of diminishing returns, energy gain, polity configuration, future problems; the third part discusses various sustainability options, including options proposed in sustainability discourse and the fourth part concludes by identifying the most likely trajectories of contemporary societies.

7.1 The Evolution Towards Modernity

Ancient and modern societies may be compared in five domains: complexity, energy technology, population and historical prevalence. In the last 12,000 years, societies have become in average ever more complex (Tainter, 1995:398). This complexity is now reflected in the profusion of parts and types of parts of modern societies. Table 7.1 summarizes the principal differences between prehistoric (and to an extent, antique societies) and western societies. The trend towards higher complexity, however, could not have been achieved ever more energy. While, energy per capita fluctuated in the past (with low-gain energy transitions and collapses), the global trend has seen an increase in total energy harnessed. Specifically, two revolutions have been instrumental in raising the total amount of energy available to human societies: the agricultural and industrial revolution. While the agricultural revolution relates to antique societies, the Industrial Revolution connects to modern societies. Then, a competitive process set the stage for world expansion and reaction. The three following subsections summarize them and the fourth assesses the major differences between ancient and modern societies.

7.1.1 The Agricultural Revolution

The agricultural revolution marked the end of high-gain hunting and gathering. Hunter-gatherers had reportedly a very efficient and leisurely lifestyle. In average, they spent only three to four hours per day (in average) to find and consume food, the rest left to leisure activities. However, selective pressures (likely population growth) made this lifestyle less and less reliable as the intensification of hunting and gathering depleted stocks faster than they could regenerate (Harari, 2015). Thus, a more reliable alternative was slowly selected in the form of agriculture. Agriculture is low-gain. It demands more work but can produce more in aggregate. Agriculture could engage in systematic "production beyond subsistence" (Renfrew, 1982:267-8), something hunter-gatherers couldn't have the luxury, as storage wasn't reliable enough (Kardulias,

	Prehistoric Societies	**Western societies (in 1983)**
Complexity	Low	Very High
Size	Small	Large
Power relations	Egalitarian relations	Class relations
Differentiation	Minimal	Large (social and economical)
Structure	Internally homogeneous	Heterogeneous
Social personalities	A dozen	Up to 1 million
Unique artifacts	3000–6000	+ 500,000 (in 1942)
Exchanges	Balanced	Asymmetric
Roles	Generalized	Specialized
Leadership	Ad hoc leadership	Full-time leadership
Energy per capita	Very small	Very important
Primary Energy Input	Sun and human work	Fossil Fuels
Power Generation	1/20 Horsepower per cap/year	100-1000 Horsepower per cap/year
Energetics	Closer from thermodynamic equilibrium	Farther from thermodynamic equilibrium
Prevalence	In most of human history	Is an "anomaly of history"

Table 7.1. Principal differences between prehistoric and modern societies. Data from or inferred from McGuire, 1983; Tainter, 1988/1990: 23, 27, 37–38, 91; 1996b:18; 2016b:1023; 2017:41.

1989:600; Harari, 2015). This production beyond subsistence constituted surpluses which could support non-productive members of society should the need arise. As societies slowly formed in response to reactive processes (Tainter, 1998), problem-solving institutions and specialists arose, such as craftsmen, religious Figures, soldiers and a ruling class. To the extent that agricultural production could be intensified, this non-productive class could be extended, likely to solve problems.

Agricultural production, however, is limited by the energy available from the sun and metabolic transformations. Up to 90% of energy is lost at each trophic transformation (Tainter & Patzek, 2012:124). This emphasizes the low-gain needs to aggregate a larger number of inputs. Thus, complexity growth was ultimately capped by the energy of the sun. Furthermore, as in all low-gain systems, temporal variations could quickly destabilize a system having depleted its reserve capacity to finance extra complexity. Within this low-gain period, a high-gain system developed: empires. As all high-gain systems, empires lasted only a relatively short-time. Box 7.1 summarizes why the economics of empire are unsustainable in the long-term.

7.1.2 The Industrial Revolution

While the agricultural revolution was low-gain, the Industrial Revolution is intrinsically high-gain. The Industrial Revolution actually arose in Britain from a series of positive feedback triggered in reaction to low-gain resource depletion. This low-gain resource was wood, whose supply became low as a result of population growth between the 14th and 17th centuries. With its most accessible reserves depleted, people turned to surface coal. Coal, as fossil fuels, is a highly concentrated energy resource. But at the time, coal was polluting, could only be extracted in a

Box 7.1. The Economics of Empire
Empires acquired high-quality resources (generally in the form of energy surrogates, such as gold) concentrated by low-gain society at a fraction of the price. This price was paid in military campaigns or raids. Successful campaigns could easily pay for themselves or for next campaigns. The dynamic of empire expansion was therefore perpetuating until all neighbouring low-gain polities had been looted or conquered, or until the size of the administered territory reached its maximum manageable size by land couriers.

After this point, empires had to bear the full costs of administering the seized territory (defense, public works, etc.) while only relying on low-gain agriculture for energy production. Eventually, most of these systems reached their limits and depleted their reserve capacity. When productive fluctuations and challenges became higher than usual, they became vulnerable to collapse (Tainter, 1988/1990:148-9, 2000b:19-20; Tainter, Allen & Hoekstra, 2006:47-8).

few places and thus required new distribution systems. All of this made coal less popular than wood, as it was less convenient and more costly. Without any credible alternative, its exploitation was necessary.

Soon, extraction had to be intensified through deep mining. Deep mining was difficult because of groundwater flooding. At the same time, the steam engine was developed. The solution was to use coal-fed steam pumps to allow more efficient mining. Then, steam engines were put on rails and distribution became even more efficient. Soon, a series of positive feedback made coal cheaper than wood, and especially convenient as it fueled economic growth. This allowed further specialization as new problems arose, but the overall productivity of the system still increased. This development illustrates a typical energy transition from low to high gain, where overall returns were first worse than the low-gain system, but quickly become better as appropriate technology was developed (Tainter, 1988/1990:98–99, 2000b:13-14; Allen, Tainter & Hoekstra, 1999:417).

7.1.3 The European Competition and Expansion

At the time, European states had been engaged in a continuous and incredibly costly peer competition. The competition produced a general military stalemate, as every military breakthrough became more costly and was soon effectively countered by other competitors. Power asymmetries were balanced by alliances, which often shifted. As to finance their ever costly competition, most European states resorted to overseas expansion to capture more territory where the energy of the sun fall. This process, however, merely extended the stalemate and soon new energy was required. Without it, it is likely that European states would have eventually collapsed under the huge costs of their competition. Thus, when Britain experienced its coal revolution and then Industrial Revolution, these developments quickly became imitated by competitors. The new sources of energy allowed even greater competition, and complexity grew exponentially as a result.

This process culminated in 1914. At the time, the European states and their offshoots controlled 84% of the earth's surface. The following war was unmatched in intensity and its use of technology. European peer polities came out of the conflict economically exhausted. The United States were, however, in a better situation and gradually took ascendency as a result. Contrary to Europe, which had huge reserves of coal, the United States had massive reserves of oil. So, when the Second World War came, the USA could energetically finance all of its allies, whereas Germany was energetically constrained. The war also produced considerable technological development. Oil eventually won the energetic war and propelled economic recovery in the western states in an unparalleled energetic-economic feedback. The war confirmed the ascendency of the United States, which then expanded all over the world. There is today virtually no territory that hadn't been touched by European or American expansion. As a result, most of today's states have been shaped to diverse degrees by reactive processes to European-

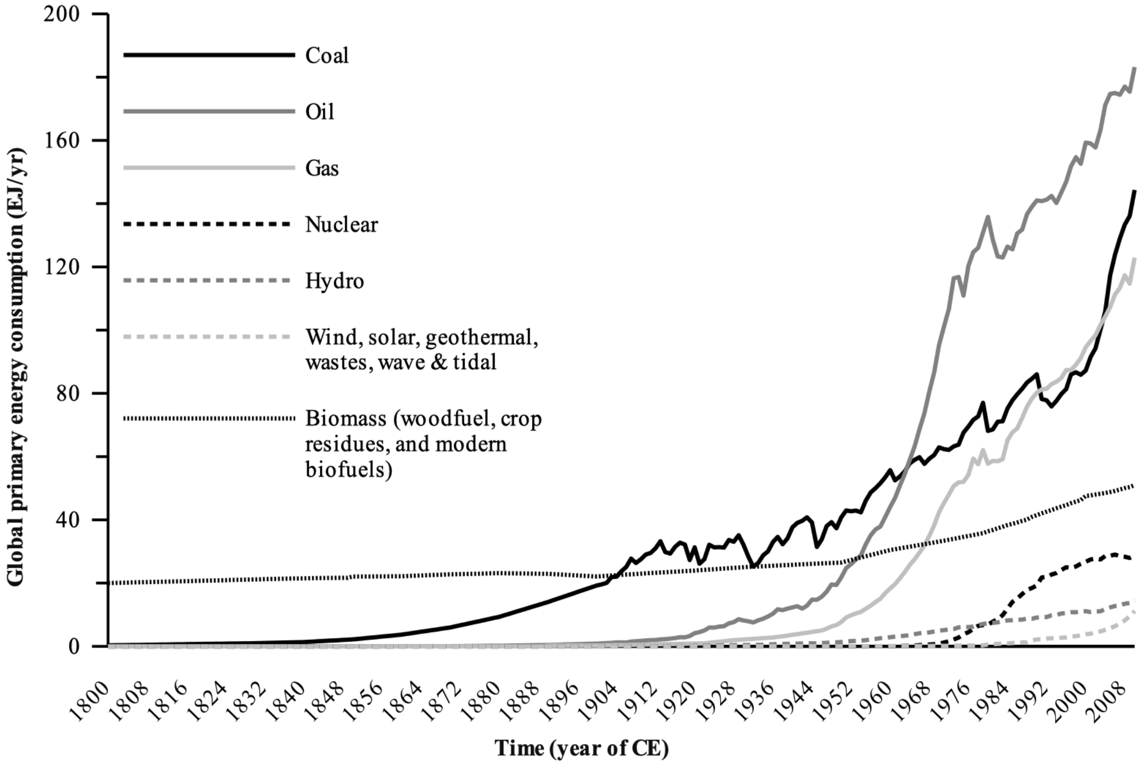

Figure 7.1. Evolution of the global primary energy consumption per primary energy type from 1800 to 2014. Original Figure from Court (2016), adapted from online data.

American expansion, domination and meddling (Tainter, 1992: 107-12, 120-4; 1998: 176-84; Auzanneau, 2016).

7.1.4 Comparison between Ancient and Modern Societies

The evolutionary course undertook by modern societies made them differ in five areas: complexity, energy, technology, population, and historical prevalence. Modern societies are highly developed thanks to cheap and affordable energy. The number of social roles in a western society had been estimated in the 1989 to average one million (McGuire, 1983). This number is probably much higher today. Hierarchies, counted in institutions and regulations, have grown exponentially. Ancient societies had much less social roles a tiny bureaucracy in comparison. Modern societies also differ in energy intake. This might be the most critical variable.

As a result of the positive feedback set in motion by the exploitation of fossil fuels in the Industrial Revolution and its worldwide energy use dramatically increased. Figure 7.1 shows this recent increase. Whereas the sun was the main energy source of societies in the past, fossil fuels constitute the majority of the present primary energy (81.4% in 2015, distributed 31.7% for oil, 28.1% for coal and 21.6% for gas, International Energy Agency, 2018:6). The difference is not only in energy source. It is also in energy quality and energy carriers (for the difference, see Allen, Tainter et al., 2017). Whereas the sun arrives at a rate of 0.04 calories/cm^2/minute[54] on Earth's surface, one liter of gasoline contains 8,245,698 calories (inferred from Tainter & Patzek,

[54] "Solar radiation reaches earth's upper atmosphere at a rate of 1.94 calories per square centimeter per minute. Thirty-one percent of this is reflected or scattered, and 23% is absorbed in the troposphere or upper atmosphere. The remaining 46% (about 0.9 calories) of the original solar radiation reaches the ground, or near it. Then, 34% of this is reflected back by snow or clouds. Forty-two percent goes to heat land and water. Twenty-three percent drives the water cycle, evaporation and precipitation. One percent drives wind and ocean currents. Of those original 1.94 calories, 0.023% is available for photosynthesis. That is 0.04 calories per square centimeter per minute [...]. Of those 0.04 calories, the plant needs some for itself, so humans and other consumers actually get less. [... Societies were built] on a small fraction of 0.04 calories per square centimeter per minute." (Tainter & Patzek, 2012:123-4)

	Antique societies (antiquity)	Modern societies (developed states)
Main energy sources	Sun and its derivatives (biomass)	Fossil fuels (and nuclear and hydro power to a lesser extent)
Energy form	Mainly slow fluxes with some stocks	Mainly stocks with some fluxes
Energy availability	Current on a local scale (little or no access to past energy)	Current and stored on a global scale (large access to past energy)
Energy subsidies	Rare (exception for capital cities)	Abundant and necessary
Land transport	Very costly (28 to 56 times more costly than by sea)	Cheap relative to the costs of fossil fuels
Supply area	Local or regional (practically constrained by the economics of land-based grain transportation)	Global (theoretically unconstrained)
Size and population	Limited by the energy falling on the territory, transport speed and food transport costs	Unlimited to the degree that fossil fuels and transport are cheap
City size (average and max.)	Small: 10,000–30,000; Rome: 1,000,000 (under Augustus)	Large: 1,000,000; Chongqing: 30,165,000 (2016)
Complexity	Lower and limited complexity	Much higher and extended complexity

Table 7.2. Summary of some selected differences between antique and modern societies. Data from or inferred from Tainter, 2019:86–87, with additions and formatting by the author.

2012:124)[55]. While the sun is a low-energy flux which must be converted in biomass and other products to be used, fossil fuel are (mostly) ready made resources. These differences are huge and explain a lot of the evolution of modern societies. Table 7.2 summarizes and extend these differences between ancient and modern societies.

The technological difference between ancient and modern societies is significant. It can be subsumed under three factors: almost total technical penetration into the processes of society, greater share of specialists assigned to technology and technical invention, institutionalized research and development (Strumsky, Lobo & Tainter, 2010:496) and the inscription of innovation as a truism of modern cosmology (Tainter et al., 2018). With huge energy subsidies and technology, food production has been able to growth to unmatched level to support the biggest population increase in human history. population, where modern societies registered the biggest demographic growth since the appearance of Homo sapiens 300,000 years ago; and historical prevalence. This last emphasizes the brevity (as to now) of modern society relative to ancient societies. Whereas the total population in 2000 BCE was 27 million, it reached 200 million in 1 CE, 458 in 1550, 2,525 billion in 1950, 4,061 in 1975, 6,127 in 2000 and 7,349 in 2015. This growth follows an exponential progression ("World Population," 2019). Historically, this period is, however, what Tainter's calls an "anomaly of history" (Tainter, 1988/1990: 24, 38, 193), that is, a major discontinuity with the evolution of Homo sapiens communities. The agricultural revolution happened just 12,000 years ago, while Homo sapiens have existed for 200,000 years. Recorded history dates back to ~ 3200 BCE. That is close to 5220 years from now. Modern states

[55] There is so much energy available per capita that some commentators argue that we live in a society powered by energy slaves. One liter of gasoline delivers the same mechanical work as a person working 117 hours. Calculation of energy slaves posits they work around the clock. With this reasoning in mind, each european can be assumed to possess around 50 energy slaves (Tainter & Patzek, 2012:67, with units conversion by the author, see also Nikiforuk, 2012).

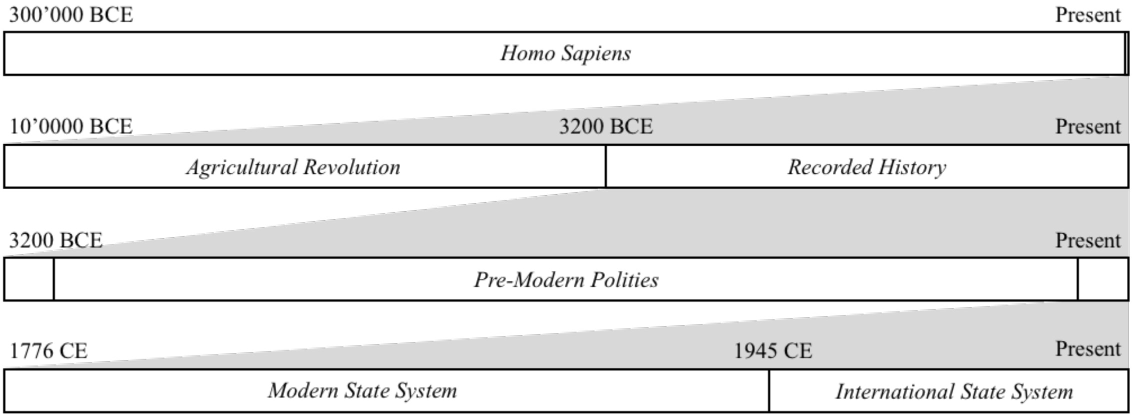

Figure 7.2. Human historical periods visualized. Data adapted from Tainter, 1988/1990:24 and Taylor, 2013:60. Figure by the author.

are almost 250 years old, and the contemporary world order has been established in 79 years from now (Tainter, 1988/1990: 24; Taylor, 2013:60), while complex societies have been around for 0.02% of human history and the current order only accounts for 1,5% of the duration of modern societies. Figure 7.2 presents a graphical representation of these durations.

7.2 Contemporary Situation Evaluation

The contemporary situation should be evaluated in three areas: diminishing returns, energy gain and inter-polity dynamics. These factors have proven to be of most importance in the past, even if today complexity, energy input, population and technological development have significantly changed. One fourth factor can be added: future problems. Future problems can be, to some extent, anticipated as knowledge and technology have grown in the past.

7.2.1 Diminishing Returns

Diminishing returns are widely experienced in the contemporary world. Tainter shows solid evidence of diminishing returns in foraging and agriculture; competition, warfare, and arms races; sociopolitical control and specialization; technology and innovation; research and development and economic growth (Tainter, 1988/1990:94–118, 1992:102-6; 1996a). This section does not aim to elaborate them but two: agriculture, as it shows the evolution of a system from increasing returns to diminishing returns; and technology is of paramount importance to offset the effect of both diminishing returns and resource depletion. The case of agriculture is fairly simple. In 1940, American farmers got 2.3 calories worth of food for every calorie of human labor they put in working the fields (Servigne, 2013:12). Their return to investment was positive. In 2000, this ratio had been inverted. For every calorie of food obtained, 1.6 calorie worth of fuel, pesticides, fertilizers, mechanical work, etc. had to be invested. The return had become negative. The total output of the system was, however, still increasing, an indication that the system has not yet entered the negative returns phase. The situation might be more worrying if the whole food chain from the producer to the customer is taken into account. In this case of full-cost accounting 7,3 calories have to be invested for every calorie of food put on the table (Heinberg & Bomford, 2009:4).

The case of technology, namely the productivity of technological invention, is more controversial as human ingenuity is the only area which neoclassical economists exclude from the application of diminishing returns. However, recent quantitative research by Tainter and colleagues has examined the productivity of invention through the database of patents of the United States patents bureau (three million patents covering 1974 to 2012). The advantage of this

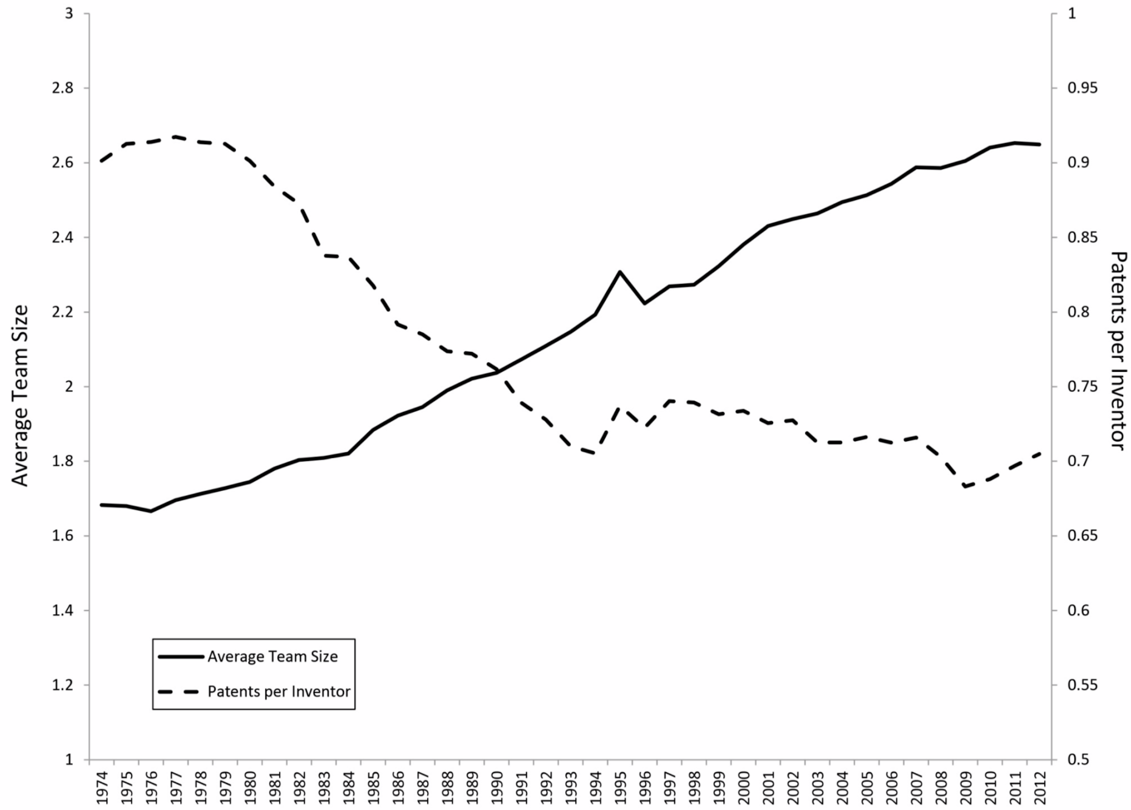

Figure 7.3. Evolution of the productivity of invention measured through patents per inventor and average team size. Data: Tainter, Strumsky et al., 2018 with the Figure from Tainter, 2019b.

database is that it is fairly representative, as half the patents are granted to non-US residents. The result of this analysis indicates a slight decline of the number of patents per inventor, and a steeper increase of the average team size. Over 39 years, the overall productivity of invention, measured in patents per inventors, declined 22%, that is, 0.56% per year. Figure 7.3 plots these evolutions. Even if measuring productivity in patent numbers has been criticized, the heavy trend of reduced patent per inventor and growing team size suggests an increased difficulty for isolated inventors to invent and a growing requirement for firms to put more people in research and development. These trends are observable in any technological branch, irrespective of the age of the branch and funding differences. This is a likely indicator of diminishing returns to technological invention (Strumsky, Lobo and Tainter, 2010; Tainter, Strumsky et al., 2018) and suggests that technological innovation won't be able to offset forever the effects of diminishing returns in other domains and resource depletion.

7.2.2 Energy Gain

Charles Hall, based on the works of Howard Odum, proposed an indicator to measure energy gain: EROI (see chapter 3). EROI calculates the energy return for each unit of energy invested. EROI and net energy are two perspectives of the same phenomena. Figure 7.3 shows the relation between energy invested and energy return. What is important to understand it the nonlinear relation between energy invested and energy return. When the proportion of energy invested goes above 10%, that is, one unit invested for 10 in return, the ratio then rapidly goes downhill. At 15% energy investment, only 7 units come as return, at 20%, only five, at 25 percent, 4, at 40%, 2.5, at 50%, 2 units. This phenomenon is called the 'energy cliff' (Murphy, 2014).

Specific EROI estimates are difficult if not utterly impossible to calculate, as defining a boundary for analysis is an unending challenge and the units of comparison might actually not compare (Allen, et al., 2017; Raugei, 2019). If specific assessments of one energy system at one

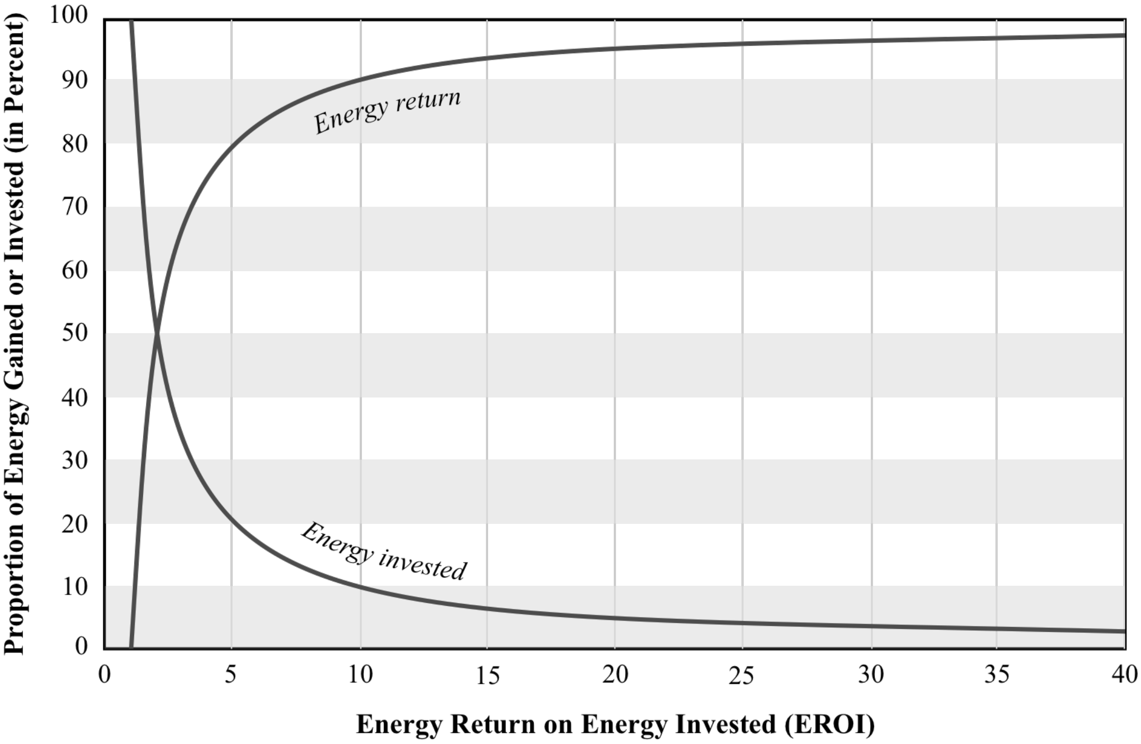

Figure 7.3. Relation between energy invested and energy return plotted with the proportion of energy gained or invested on the vertical axis and EROI on the horizontal axis. Inspired by Murphy, 2014. Figure by the author.

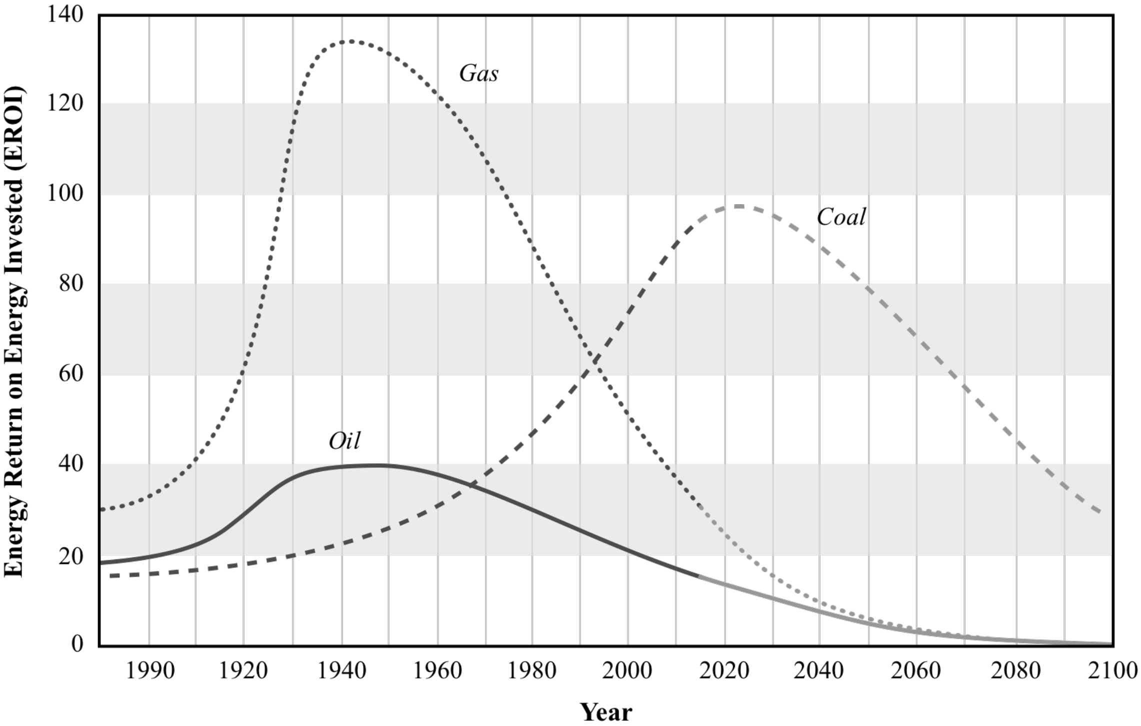

Figure 7.3. Simplified representation of the long-term evolution of the EROI of oil, gas and coal. The long-term EROI estimate of coal might be overstated (Ritchie & Dowlatabadi, 2017) Data from Court & Fizaine, 2017. Adaptation and Figure by the author.

temporal point are difficult, long-term trends are much more telling and subject to less controversy (Court, personal conversation, 21 June 2018). In this light, recent long-term estimates of fossil fuel EROI indicate a clear downwards trend for oil and gas energy gain, with the exception of coal in the long-term (Court & Fizaine, 2017). Figure 7.3 shows these trends. The long-term EROI estimate of coal might be overstated, as coal reserve estimates, technology and markets have not evolved since the 1980s (Ritchie & Dowlatabadi, 2017). Taken together, these trends indicate diminishing energy gain in the present for oil and gas, and diminishing energy gain for all fuel sources beyond 2025. The period between 2030–2040 will be particularly critical, as the EROI of oil and gas is projected to pass below the threshold of ten. Should these trends materialize, then any production beyond this point will bring less and less energy gain more and more rapidly. This represents a major challenge contemporary societies.

7.2.3 Polities Dynamic

The current polity configuration has been widely shaped by European peer polity competition. Nearly every territory has been affected by European and American expansion in the last 500 years. This dynamic had an enduring influence on states, for they primarily evolved as a reaction to expansion, dominance and meddling by more powerful polities. The world is, however, in an imperfect peer polity configuration. Most polities are unequal, and some might only be interacting on subordinate-dominant basis. But overall, alliances assure a relative balance and competition remains a major driving factor in international relations. Competition might be local, regional or worldwide. But polities might engage in worldwide competition indirectly, through alliances or discrete support. This is a major difference with past peer polity configurations: there might be several sub-clusters for the big worldwide cluster (Taylor, 2013:90). These subclusters might engage in inter-subcluster competition, as the Warsaw Pact and NATO countries did in the cold war (Tainter, 1988/1990:213). Other signs of worldwide peer polity interaction is the existence of supra-institutions. These institutions, like the UN and its affiliates, fill the functions of mediating, or promoting certain evolutionary courses (Johnson, 2004:129, see § 4.6.4).

However, the actual competitive polity configuration is locked in a competitive spiral (Tainter, 1988/1990:213). And unlike in the past, the world now is full: there are no territory left for territorial expansion without full-scale war; and there are no more power vacuums, that is, places where a polity could collapse as there was no threat of absorption by a competitor. The existence of failed states is, however, puzzling. Their existence today actually interacts with the peer polity dynamic and to a certain extent, is preserved by it. Box 7.2 explores the topic. Back to the contemporary situation, the consequence of both a full world and an overall competitive dynamic embedded in a peer competition is simple but blunt: should collapse happen in this configuration, then it would be global, mutual and simultaneous (Tainter, 1988/1990:213-4).

7.2.4 Future Problems

The problems of prolonged diminishing returns, continuous competition, energy depletion and reduced technological capacity to offset both diminishing returns and energy depletion are compounded by a series of future problems, some concrete and some abstract. Tainter identifies the following for industrial nations (Tainter, 1988/1990:213, Tainter & Crumley, 2007:71-2; Tainter & Patzek, 2012:200): pollution and population control; climate change adaptation; environmental transformations; growing costs of security; decaying infrastructure; aging populations and retirement funding (especially for the baby-boom generation); reluctance to tax; new energy sources development; continuing high military costs; continuing need to innovate.

The challenge, according to Tainter, will be to keep the standard of living leveled while solving the other problems as to not suffer from legitimacy problems (Tainter & Crumley, 2007:72). This might be however impossible. Furthermore, these are only a handful or problems. Further problems will have to be solved, such as biodiversity loss, agricultural yield decrease, less available debt, etc. Succeeding in this enterprise might be harder than everything previously experienced. As Tainter concludes: "solving each of these problems would represent a big cost, but it might be feasible. Our great difficulty is that all of these problems converge and will continue to do so for decades to come. We have to face all these problems at once" (Tainter in "Quand l'expansion expire," 2013, translation by the author).

Box 7.1. The Rationale Behind the Existence and Preservation of Failed States
Historically, failing states were states in disintegration which eventually were absorbed by competitors (Taylor, 2013:89). Today, failed states exhibit collapse characteristics and strong subpolity recovery. The territorial integrity and government of the former state is no more, but its political and territorial components often compete with each other while displaying functional 'non-state' hierarchies. But why can this happen in a peer polity configuration? Why aren't failed states absorbed anymore? There are several explanations.

First, the now century(ies)-long peer polity process produced conventions by which most states are held accountable, or should pretend to respect. These conventions and supra-institutions help to keep the internationally recognized existence of the theoretical statehood of the failed states, with respect to their external borders (Taylor, 2013:91-2).

Second, as long as failed states don't pose an immediate threat, they might be left alone (Taylor, 2013:91-2). Sure, failed states aren't able to externally compete*, or even survive on their own. The threat might, however, be less of competitive nature and more about the instability risk carried by the absence of a strong polity-wide hierarchy. When they do, external polities tend to meddle through local alliances or intervene through 'humanitarian' missions in order to solve the problem of instability. This latter option might also be convened by a supra-entity to preserve the international order.

Third, the international system and the peer polity process of power balances might play an important role in preventing absorption in four ways: international and peer pressure against the invading candidate as to respect international conventions; transformation of the state in a symbolic competition arena through displays of humanitarian help for prestige gain; military deterrence as to prevent a competitor to acquire further territory; and finally, general economic disinterest for invasion. This general economic disinterest could be much explained in terms of available energy. With fossil fuels being unmatched concentrated forms of energy, territorial expansion might have become less energetically interesting, as securitization of fossil fuels supply works better and is less risky to acquire cheap energy.

* Although their 'non-state' components might engage in international competition, as the recent examples of the Islamic 'State' and Hezbollah shows.

7.3 Sustainability Options

Despite the cosmology telling them that they are unique, modern societies are subjected to the same processes that constrained ancient societies (Tainter, 1988/1990:216). In this sense, high complexity, continuous competition, diminishing returns, slowly falling energy gain and future problems might cause societies collapse worldwide and simultaneously. As mentioned earlier (§ 5.3.3.3), ensuring sustainability can make societies vulnerable to collapse. But can this eventuality be postponed? This section discusses several options discussed or inferred in the theoretical framework: capturing energy subsidies, low-gain energy transition, technological innovation.

7.3.1 Capturing Energy Subsidies

Today, capturing high-gain energy subsidies as a solution to diminishing returns is either not possible anymore or not durable (Tainter, 1988/1990:214-5). There are several reasons for this: first, the best energy subsidies have already been captured. Second, territorial expansion can't be successful because the world's configuration. Territorial expansion implies conflict. As there are no more polities of significantly lower complexity, expansion is likely be met with stiff resistance from the locals or other peer polities. Even in the eventuality of successful military expansion, the captured high gain energy subsidies (concentrated wealth and resources) can only last briefly relative to the size of the overall expanding system[56]. In the short-time, capturing high-

[56] As mentioned earlier, the evolutionary pace of modern societies is much quicker than in ancient ones.

gain subsidies could work, but the economics of empire dictate once seized, the cost of administering the lands eventually makes the whole enterprise unprofitable.

In modern times, this is compounded by the fact that captured lands alone can only produce low-gain energy fluxes. Thus, land capture doesn't seem to be a sustainable solution. Another solution, not mentioned by Tainter, could be to only raid or capture high-gain energy subsidies and then release control and retreat when seized or depleted. This solution could work in the short-term, but can only secure a brief respite in the face of the inevitable depletion of high-gain energy subsidies. Furthermore, as it is likely that such a strategy would follow a best first pattern, its cost would be increasingly likely to growth relative to its benefits.

7.3.2 Low-gain Energy Transition

Capturing high-gain energy subsidies seems to be either impossible or only effective in the short-term (see point above). Therefore, the only long-term rational course would be to transition safely to a low-gain system now. The classical type of a low-gain system is powered by renewables. This trajectory appears as the only way to ensure continuation of today's societies. A rational perspective in this sense would advocate to marshall all available resources and make use of all possible technologies to enable the necessary low-gain energy transition (Tainter, 1988/1990:215). This implies to utilize the society high-gain advantage to shape its low-gain aftermath, as countless species and some polities have done in the past. One cannot stress enough how transition should begin now for a low-gain transition to be successful. Recent research has shown that the average time from development to implementation and full integration of new energy technologies is 40 years (Gross et al., 2018). Transitioning to a low-gain system might, however, be fateful, as these systems require significantly increased complexity to work. This might make them more vulnerable to collapse in the long-term. This has to be compounded with the typical vulnerability of such systems to energy capture variations, which are likely to happen because of climate change.

7.3.3 Technological Innovation

As mentioned earlier, technological invention, and innovation can be used to offset the effect of depletion and diminishing returns, as it has been used effectively in the past. However, the dilemma of this solution lies in the convergence of harder and harder problems, overall diminishing returns (including returns of technical innovation) and diminishing energy subsidies to finance further innovation. This is compounded by the facts that technological solution take time to be effectively implemented (as stressed in Gross et al., 2018). Therefore, while technological innovation is and will continue to be useful, its overall return is probably going to decrease. For this strategy to make sense, it might be best to combine technological innovation focused on enhancing a low-gain energy transition.

7.3.4 Reduce Resource Consumption

Reducing resource consumption, either through voluntary simplification, market mechanisms or outright rationing is a popular option in sustainability discourse. This discourse is based on several premises, which turn out to be either weak or false on close inspection. The first premise is that resource consumption can be durably reduced. This premise assumes that no problem would arise in the period following the reduction, which would be historically exceptional. Otherwise, problem-solving would eventually force resource consumption to increase as to finance the further complexity (inspired by Tainter, 2011a:79).

The second premise is that competition problems won't affect the polity implementing resource consumption reduction. In a classic version of the tragedy of the commons, this premise is naive as to think that freed resources won't be consumed by other polities (even remote polities) engaged in competition with the polity in question or other polities. This premise is also dangerous for the sociopolitical sustainability of the society in question, as its reduced consumption of resources might make it weak and inviting for absorption, which may eventually ruin the efforts of such a strategy.

The third premise assumes that legitimacy isn't an issue and that population (especially elites, which communicate more horizontally than vertically) won't be stressed by the growing gap in living standards and conditions with other polities. This strategy might therefore need extensive political coercion to work. Without entering the debate whether the proponents of this approach would condone such a strategy, it should be noted that political coercion costs tends to make it ineffective (Tainter, 1988/1990:36, 117).

Thus, this strategy doesn't seem to be destined to succeed on a polity-wide level. The only option that might work is systematic simplification, whose outcomes include resource consumption reduction. This option, however, is subjected to specific constraints (see § 5.3.3.2).

8 Conclusions

Concluding this work can be can be approached in three perspectives: an evaluation of the overall work and its capacity to meet the objectives set in the introduction, some thoughts on sustainability and finally the identification of the lines of future research.

8.1 Work Evaluation

8.1.1 Academic Evaluation

This work began with a simple question: “what are the likely evolutionary trajectories of modern societies?” In light of previous chapters, it seems fair to say that the possible evolutionary trajectories of societies have been identified in Tainter’s work, as well as their components, drivers and evolutionary dynamics. The last chapter addressed the question of the likely evolution trajectory for modern societies according to Tainter’s framework, which is, continuation until worldwide mutual and simultaneous collapse. These elements answered most of the subquestions of this synthesis, with the exception of “what would be the conditions for sustainability today?” This question is addressed later.

At the beginning of this work, four objectives were set: identify a model of the evolution of societies; identify its limitations and robustness; identify a set of requirements for current sustainability according to the theoretical framework; identify conceptual weaknesses, literature gaps and objectives for future research. The first and second objectives appear to have been met. The third and fourth objectives have been partially met and will therefore be clarified in point 8.2 and 8.3.

Not all purposes of the synthesis have been met. This has to do probably with excessive ambition and might be corrected in later work. These elements in particular could be developed: insist on Tainter’s critique of mainstream sustainability; clarify misunderstandings, misrepresentations and misuses of Tainter’s work. The goal of inferring from various concepts has produced original elements that are consistent with the theoretical framework. One of these is the polity evolution model and its emphasis on the iron laws of generalized evolutionism (with the principle of selection, variation, transmission) and the second is the multiple tables and Figures which clarify much of Tainter’s thoughts. These two elements may be of most relevance in this work for other scientists interested in Tainter’s work.

8.1.2 Personal Evaluation

As mentioned in the introduction, this work could have used better planning, less objectives and ambitions. There are lessons to be learned from this experience. These can be grouped in two recommendations: Triple each time estimate as to account for the planning fallacy; set smaller and more specific objectives and built from them.

8.2 Thoughts on Sustainability

8.2.1 Critique of Mainstream Sustainability Discourse

This thesis has been a significant occasion to reflect on mainstream sustainability discourse. As to be fully transparent, the author has always felt unease with sustainability discourse (either of 'weak' or 'strong' orientation). There are several things to be said: Sustainability discourse is based on a cognitive fiction which denies evolutionary pressures; sustainability discourse shares the same structural flaws as neoclassical economics; sustainability discourse it mainly ignorant of the evolutionary dynamics of societies. Before deepening these points, it must be said that they are generalizations and counter-examples might be found. These generalizations might not be specifically accurate, but they reflect a wider experience of a student of sustainability.

Sustainability is based on a cognitive fiction which denies evolutionary pressures. Social science has had a hard time incorporating evolutionary theory (see e.g. Barkow, 2005; Mesoudi, Veldhuis, & Foley, 2010). There is a particular hubris characterizing social science, whereas agency is asserted as a core principle. However, the study of long-term history and biology indicates that this agency might be much reduced. Sustainability discourse has incorporated many recent scholarly contributions, ranging from ecological (or biophysical) economics to the study of far-from-equilibrium systems. But the openness to other ideas stops where elements challenge the possibility that agency, and therefore social change, might not be culturally shaped toward a desired future. Whereas such an objective is laudable, it doesn't constitute rigorous scientific work. It should be discarded as the *survival of modern societies might be at stake. This requires an objective assessment* to act upon. Evolutionary pressures should be incorporated in sustainability thought to become effectively operational.

The problem of the cognitive fiction of sustainability has much in common with neoclassical economics. While some sustainability scientists pride themselves to criticize neoclassical economic, the great irony is that their field suffer from similar flaws. These flaws are simple, yet destructive for these disciplines long-term relevancy. Neoclassical economics and sustainability discourse have developed very coherent discourses. However, these discourses fail at accurately representing reality. Neoclassical economics doesn't take into account the fundamental role of energy in life and wealth creation and treats it as a commodity instead. Sustainability discourse denies the existence of evolutionary pressures which might condition the long-term evolution of societies and the agency of its citizens. Neoclassical economics integrates a somewhat caricatural version of Darwinism, on the other hand. Both disciplines fail at accurately representing reality and refuse most of external criticism, “because the internal model works!” These disciplines should become more scientific and observe reality before constructing grand models and narratives.

This leads to the third and last point. Sustainability discourse cannot be operational if it doesn't understand the evolutionary dynamics of societal evolution. As Tainter says, “our historical ignorance stems from our historical arrogance-or vice versa” (Tainter, 1995:398). There is a great need to understand the evolutionary dynamics of societies, for historical arrogance—or hubris—might lead to termination.

8.2.2 Conditions for Contemporary Effective Sustainability

According to Tainter's theoretical framework, the conditions of sustainability equate the conditions for continuation. Continuation requires continuous success at solving problems, including problems of competition. Effective problem-solving institutions require sufficient resources and therefore reserve capacity. As long as societies are able to complexify, they will be able to continue, i.e. be sustainable in Tainter's sense. As problems are expected to intensify in the future, this capacity will be put under stress. Furthermore, continuous diminishing returns in various sectors are predicted to worsen, including in the productivity of invention. As mentioned earlier, invention is critical to offset the effects of resource depletion.

Therefore, both sufficient resources and an affordable and effective research and development system are critical to future sustainability. Should one of the above be less available, future sustainability will be compromised as societies will be less and less able to solve their problems. While it is true that systematic simplification could enable a society-wide recovery by redefining the complexity of one society relative to its resource base, this option is very constrained (see § 5.3.3.2). Based on the conditions for systematic simplification, the section below proposes some possible strategies to increase sustainability of the long-term while enabling continuation in the short-term.

8.2.2 Requirements for Effective Sustainability Strategies

As the tainterian framework suggests that mainstream or radical sustainability strategies either are ineffective or cannot be sustained in the long-term, this section explores how sustainability strategies could, however, work. These strategies could act at two levels: first, creating favourable ground to apply society-wide systematic simplification, and second, shaping the current environment to increase the likelihood of long-term continuation. While the first level aims at a system-wide reorganization, the second merely accommodates the current system to slowly change its direction.

The first level could consist of strategies to increase the degree of existential threat perception and to change the demands of the population for the legitimacy of the elites. Continuous lobbying might be of use, as maybe large-scale citizen campaigns. These campaigns should remain non-violent, as recent literature indicated that such movements are most likely to succeed compared to other political action forms (Abrahms, 2018; Chenoweth & Stephan, 2011). It should be noted that either lobbying or campaigns should not weaken the hierarchy of the state, which is then needed to compel society-wide simplification. Furthermore—and this is a point often overlooked by activists and other scholars—the systemic simplification must ensure that the problem-solving capacity is reset while maintaining the competitive potential of the polity. This might require multiple smaller simplifications, as a big one might weaken the state too much. A series of smaller simplifications could ensure power retention at gradual levels while neighboring states slowly disintegrate under the effects of diminishing returns and energy shortages.

The second level could work in the very short-term, *while using the dynamic of the system*. This dynamic is expressed in two requirements: ensuring continual competitiveness and legitimacy of the elites. Within these constraints, the challenge is to design policies, technical innovation and economic business model that ensure continuation today while increasing the likelihood of future continuation. There is today a growing number of institutions which try to reconcile the two, but it seems that no theoretical research has succeeded in proposing effective strategies to attain this goal. While first-level strategies might be the most desirable for long-term sustainability, the second level of strategy, should their application be effective, are probably the most promising because they 'swim' with the current rather than against it. That does not, however, mean that second-level strategies might be able to effectively avert an eventual collapse. But they might contribute in alleviating its future consequences and even postpone it for a time. If the first-level strategies don't work, second-level strategies might be the best possibility to reduce future damages and suffering. There is much need conduct further research to deepen these two strategic levels.

8.3 Future Research

Future research pertaining to Tainter's framework or implications falls in two categories: the measure of the extent of the influence of agency/decision-making/historical circumstances; the identification of short-term strategies which enhance long-term continuation.

As stressed in chapter 7, a potential weakness of Tainter's model is the lack of agency / decision-making / historical circumstances integration. The degree of influence of such factors is yet to be determined: are they capable of influencing the long-term dynamic or only the short-term events? The answer is very probably more nuanced, but knowing it is critical to orient future sustainability policies. This is especially important if agency is proven to be of significant importance, for it means that current trajectories could be effectively bent if behavior can be influenced.

The importance to identify strategies able to enhance long-term continuation while enabling short-term continuation has already been emphasized in the previous section. These strategies can be already identified is the behavior of a selection of actors. Theorization is, however, lacking and conceptualization might help these actors by reinforcing their legitimacy. There is probably a wide-range of sectors where there are no actors applying such strategies, which could be theorized in order to facilitate their future application. Finally, communication on these kinds of strategies should be researched, for their effect might be increased if they are widely disseminated and concentrate a wide array of societal actors.

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9.1.2 Polity Evolution Model

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