Disclaimer
What follows is a draft chapter which will integrate the book *Transformational Evaluation for the Global Crises of our Times,* edited by Rob D. van den Berg, Cristina Magro and Marie Hélène Adrien, to be published by IDEAS and expected to be launched in the second half of 2021. This piece, therefore, may differ from the final version. The book will be accessible with open access on IDEAS website: ideas-global.org.

A Complexity-based Metatheory of Action for Transformation to a Green Energy Future

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Abstract

This chapter draws from complexity science to present a metatheory of transformation that can be applied to discrete theories of change that are constructed to guide model building, methodology, and data interpretation for the evaluation of individual change efforts. The focus is on six specific behaviors of complex systems – stigmergy, attractors, emergence, phase transition, self-organization, and path dependence. These can be invoked singly or in combination to understand pattern, predictability, and how change happens. The importance of both "explanation" and "prediction" is woven into the discussion. A definition of "transformation" is offered in which a qualitatively new reality becomes the default choice that constitute a new normal. Indicators of transformation include measurable ranges (as opposed to specific values) for level of energy use and the time over which the change endures. Because complex systems behave as they do, the recommended theory of change is sparse – it has few well-defined elements or relationships among those elements. There is already good progress in the application of complexity to the evaluation of transformation. An argument is made that these efforts should be strengthened by deliberately incorporating what is known about complex system behavior, and that by so doing, both prediction and explanation would better serve the purpose of practical decision making.

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Why a Complexity-based Metatheory of Transformation?

Typical theories of action are made up of discrete elements connected by symbols showing relationships among those elements – 1:1, 1:many, many:1, and many:many, feed-forward, and feedback. In those theories of action, semantic content matters. A box labeled: "consensus among government agencies" means something different from a box labeled "consensus among funding agency and citizen interest groups".

What follows is not that kind of a theory of action. Rather, it is a theory about commonalities among theories of action, no matter how different those theories may be with respect to semantic content and arrangement of their elements. Or put differently, I will articulate a theory about theories of action, i.e. a metatheory. The principle underlying the metatheory is that regardless of specifics, many different theories of action will have commonalities with respect to how change happens, what aspects of change can (and cannot) be measured, ability (or lack thereof) to identify detail, and what inferences can (and cannot) be made by analyzing empirical data.

The metatheory I will present will draw heavily on complexity science and will focus on transformation to a green energy future. The discussion will present many notions about action, measurement, and causality that you may find uncomfortable, or at odds with common sense, or both (Morell, 2017). I hope to convince you that despite the discomfort and the challenges to common sense, the metatheory I am about to present is worth taking seriously.

Individual theories of action for transformation to green energy will differ depending on how transformation is being pursued; where transformation is being pursued; who the funders are; what stakeholder coalitions are involved; what technologies are being pursued; which social and funding mechanisms are employed; the energy mix that is defined as "green"; and the mix of the goal of "energy transformation" and other social ends, to name but a few. No matter the details, the theory's value will depend on three criteria.

- Predictive power
- Explanatory power[1]
- Value as a useful guide to practical action

We do evaluation for instrumental and conceptual purposes. Success at both requires thought and action based on theories that respect the complex nature of change [2]. To show why this statement is correct I will proceed through three broad topics:

- concepts from complexity science that are relevant to evaluation theories of transformation,
- the characteristics of "transformation", and
- how the previous two topics come together to form a metatheory of transformation that can be applied to context-specific evaluations of transformation.

[1] "Explanation" and "prediction" are by no means simple and obvious. For the purposes of this article it is reasonable to accept their meaning at face value. For rigorous treatment of that they mean and how they are different, see: Ilkka Niiniluoto, 2019, Galit Shmueli, 2011

[2] It is worth noting that the argument made here is part of a larger literature that draws on complexity to drive social science theory and methodology. For instance, Russ Marion, 1999 Reinterprets many well-known organizational theories using a chaos and complexity framework.

Complex Behavior, Not Complex Systems[3]

Evaluators need to make operational decisions. How should program theory be represented? What form should a logic model take? What methodology should be employed? What data should be collected? How should the data be analyzed? How should the data be interpreted? They also need to make fuzzier, but nonetheless critical decisions. How to communicate to funders and other interested parties about realistic expectations for program outcomes? How to help people understand the causal dynamics that drive programs? How to explain the boundaries of what can and cannot be known about a program's consequences? Just knowing that a program is part a complex system does not help to formulate answers to these questions. What's needed is a perspective on complexity that can guide practical decisions about models, metrics and methodologies. That perspective resides in knowing how complex systems *behave*, not what complex systems *are*.

The field of complexity is vast, both with respect to the number of disciplines it encompasses, the theory it has developed, and aspects of the world it has touched (Castellani, 2014, Castellani, 2009). It would be no more appropriate to say that "complexity" is relevant to the evaluation of transformation than it would be to say that "statistics" are relevant to the evaluation of transformation. Both statements are true. Both statements are useless. What matters are the aspects of complexity that are useful under which circumstances. Different people are certain to have their own opinions as the what is relevant.[4] There is no single good answer. There is only opinion. This article contains mine.

Despite the diversity and range of research and theory that encompasses "complexity", it is possible to discern three themes that cut across much of the complexity landscape: 1) pattern, 2) predictability, and 3) how change happens. The rows of Table 1 contain the complex behaviors that I believe are most useful for evaluating transformation to green energy. The columns are there to remind us that each of these complex behaviors may have implications for understanding pattern, predictability, and how change happens.

Table 1: Cross reference, complexity themes and complex behaviors that are useful in evaluation

	Theme in Complexity Science		
Complex behavior	Pattern	Predictability	How change happens
Stigmergy			
Attractors			
Emergence			
Phase transition			
Self-organization			
Sensitive dependence			

The word "each" in the previous sentence is misleading because it implies that constructs making up the rows in the table can be understood in isolation. This is true for the purposes of explaining the construct, but it is not true with respect to understanding how complexity is needed to understand transformation. How these constructs can be combined to understand transformation will become clear as the discussion proceeds.

[3] Three sources are particularly useful as entry points into the domain of complexity: 1) New England Complex Systems Institute, *2020*, 2) Santa Fe Institute 1, *2020*, 3) Systems Innovation 1, *2020*
[4] For another classification that is well worth considering, see: Joanna Boehnert, *2020*.

Complex Behaviors that can be Useful for Understanding Transformation

How do complex behaviors provide insight about pattern, predictability, and how change happens? What are the implications for understanding transformation? To answer these questions, I will start by providing intuitive explanations for each row in Table 1. After each explanation I will discuss the evaluation implications of each complex behavior. I will end by showing how complex behaviors come together to help understand pattern, predictability, and how change happens.

It will become clear that complexity reveals operations of the world that are neither comfortable for the purposes of planning and allocating funds, nor compatible with our common-sense reasoning. It is those disjunctions, more than methodological difficulties, that impede our ability to apply complexity to the evaluation of transformation.

Stigmergy

Stigmergy is a concept that was first developed to understand insect behavior (Theraulaz and Bonabeau, 1999) but has since been generalized to many human-scale situations where changes in an environment serve as cues to direct the behavior of subsequent actors (Parunak, 2006). In a sigmergent process, even though there is no direct interaction with previous actors, and there is no overall plan that any actor follows, goal directed-type pattern is manifest. This happens because the "plan" is embedded in the history of activity that is encountered by independent actors.

Evaluation Implications

If sigmergent behavior is operating, goal directed activity that appears to be elaborate and deliberately planned, may in fact be the result of independent entities who survey their environment and make local decisions that are only relevant to their constrained needs. Thus it may be an error to assume that a goal-directed theory of action must include deliberate planning. An alternative approach would be to construct a setting in which independent actors react in specific ways to their environment, resulting in activity that looks as if it were centrally coordinated. A Stigmergic theory of change is particularly relevant to long timeline social changes that require multiple activities, by multiple actors. This is because deliberate coordination among these actors is neither practical nor desirable (Morell, 2018). Evaluation would serve transformation well if it used a methodology that could determine if, how, and how well, stigmergic processes were operating.

Attractors

"Attractors" are complexity's way of identifying where systems like to be. "Where systems like to be" is a loose anthropomorphic term that will not get us very far as we get in a rigorous discussion, but the term does provide an intuitive and accessible definition. More technically,

> In the mathematical field of dynamical systems, an attractor is a set of numerical values toward which a system tends to evolve, for a wide variety of starting conditions of the system. System values that get close enough to the attractor values remain close even if slightly (Systems Innovation 2, 2020).
>
> Social attractors define a specific subset of states that a social system may take, which corresponds to its normal behavior towards which it will naturally gravitate. When we look at many different types of social systems we see distinct patterns of clustering, distinct substructures that have synchronized their states, if we look for example at the distribution of ethnic groups across many multicultural cities we will see these distinct recurring clustering patterns of the different cultures. We would also see this clustering within the distribution of political opinions across the different regions of some country, or again the clustering of traditional dialects (Systems Innovation 3, 2020).

Three important themes appear in these definitions: 1) dynamic, i.e. change of state with time, 2) evolution to a definable state, and 3) return to a definable state when disturbed. It is critical to appreciate that there does not always have to be an attractor. Whether there is or not is an empirical question.[5]

Evaluation Implications

Here are two versions of the same question.

- What outcome will the program have?
- What attractor space describes the program's outcome?

Both questions focus attention on the consequences of a program, but the attractor version leads in directions that do not fall naturally out of "outcome" version.

- The attractor perspective focuses attention on the behavior of an outcome rather than its value. Conceptualizing outcome as a value within an attractor leads to curiosity about the range of values the outcome can take (boundaries of the attractor), and what effort is needed to effect a change from one set of outcome values to another (topography of the attractor, AKA sustainability, AKA resistance to change).

- Attractors provide a way to kick understanding of program outcome up a level of abstraction, and thus, provide insightful comparison among seemingly dissimilar programs. This is because similar outcome attractor spaces for seemingly dissimilar programs raises the suspicion that maybe those programs are not so different after all.

As a simple illustration, imagine evaluating a program designed to increase cooperation between a regulatory agency and industry as a means of improving safety. We know that neither enforcement alone nor cooperation alone is sufficient to assure safety (Sparrow, 2000). We also know that high profile accidents push agencies to become more punitive. As a result, the behavior of regulatory agencies can be visualized as a pendulum, with swings over time between excessive cooperation and excessive enforcement. What does this dynamic mean for understanding sustainability in a program that has very successfully improved safety by increasing cooperation? It means that the more successful the program, the more likely the agency is to reach the "swing back" point. Note that this scenario has said nothing about which regulatory agency is involved, or about any of the details of the safety program. Rather, it described the attractor shape for many different organizations and programs. It allows us to consider similarities among many settings that exhibit that attractor.[6]

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[5] Understanding whether systems converge to an equilibrium or diverge in unpredictable ways is a major theme in the field of complexity. Two dynamics drive unpredictability. The first is sensitive dependence, which can lead a system on a trajectory out of equilibrium. The second is the fact that a large number of low probability events may cause a major disruption in a system. For a dramatic example of these processes in geopolitical affairs, see Donald Rumsfeld, "Predicting the Future," ed. Depatment of Defense (Washington DC: 2001). For an analysis of the high probability of a member of a set of low probability events, see Nassim Nicholas Taleb, 2010. This kind of behavior is one of the main reasons that evaluators must pay attention to unintended consequences Jonathan A. Morell, 2010.

[6] In my work with regulatory agencies I have found it productive to think in terms of a simple pendulum attractor. However, the real situation is more complicated because both enforcement and cooperative innovations take place simultaneously and moves toward and away from cooperation and enforcement take place at different rates.

Emergence

The whole is different than the sum of its parts. This truism has special meaning in complexity. Imagine a cylinder in the internal combustion engine and an automobile. I can explain what a cylinder is – how it is constructed, what it does, how it fits into an internal combustion engine, and so on. That explanation would be meaningful even though the automobile may be different from the sum of its parts. The uniqueness of the cylinder in the system called an "automobile" would remain. The cylinder would retain its identity. The same reasoning holds for organs in a human body, the function of a graphics card in a computer, or the spring characteristics in a pair of tweezers.

Now think of a beehive, or a traffic jam, or an economy, or the vitality of living in a dense urban area. It is *impossible* to explain a beehive in terms of the behavior of each bee. It is *impossible* to understand a traffic jam in terms of the velocity of each car. It is *impossible* to understand an economy by breaking it down into the actions of each person and firm that makes up the economy. It is *impossible* to explain urban vitality by analyzing the behavior of each person living in a city. In all these examples, the whole is different from the sum of its parts in the sense that the parts lose their unique identity. When you see that, you see emergent behavior.

Evaluation Implications

Emergence matters for evaluation because it touches on the question of what should be measured. It is natural to think of change, and of the consequences of interventions, as made up of constituent parts, each of which can be measured. This is a comforting thought because it implies precision in the change process, the ability to measure intermediate change, and the warm feeling of knowing one has made progress toward a goal. But if what matters is the emergent property of many interacting parts, it may be difficult, or even impossible, to conceptualize an outcome in terms of the aggregate consequences of small achievements. There are consequences for program theory, for methodology, and for data interpretation.

Phase Transition

Phase transitions are about qualitative change that results from small quantitative change.

> A phase transition may be defined as some smooth, small change in a quantitative input variable that results in an abrupt qualitative change in the system's overall state. The transition of ice to steam is one example of a phase transition. At some critical temperature, a small change in the system's input temperature value results in a systemic change in the substance after which it is governed by a new set of parameters and properties, for example, we can talk about cracking ice but not water, or we can talk about the viscosity of a liquid but not a gas as these are in different phases under different physical regimes and thus we describe them with respect to different parameters (Systems Innovation 4, 2020).

Evaluation Implications

While the term "phase transition" has its roots in the chemical and physical properties of matter, it can also be applied to human-centric contexts, as for instance the brief time it took the Republican Party in the United States to transform itself from a long history of pro-free trade, pro-immigration, internationalist inclinations, to a USA-centric political philosophy as Donald Trump rose to prominence and position.

I will leave it to others to debate whether the dynamics that drive physical state changes bear any deep similarity to those that drive human-centric state changes. What is unarguable though, is that social phenomena often show state change-like behaviors. If such behavior were to exist with respect to program outcomes, program theory would have to identify when and where sudden change might occur, and planners would have to come to terms with the possibility that an effective programs may have no observable impact for a protracted period of time.

Self-organization

Self-organization:

> Self-organization is a process in which pattern at the global level of a system emerges solely from numerous interactions among the lower-level components of the system. Moreover, the rules specifying interactions among the system's components are executed using local information, without reference to the global pattern (Santa Fe Institute 3, 2020).
>
> Ability of a system to spontaneously arrange its components or elements in a purposeful (non-random) manner, under appropriate conditions but without the help of an external agency (BusinessDictionary, 2020).

The key insight in each of these definitions is that there are scenarios in which a system forms pattern without "instruction" from the outside world. This does not mean isolation from the outside world. It does not mean that external events cannot perturb the system. It does mean that outside events do not control the system. It means the system can form and maintain its pattern *only* through interaction among elements within the system.

Evaluation Implications

Key to the concept of self-organization is the notion of system boundaries because in a sense, everything is connected to everything else, and everything is part of a self-organizing mega-system. From an evaluation point of view the questions are whether, for the boundaries set: 1) Is self-organization a possibility? 2) Is self-organization present? 3) If a system is perturbed, how long does it take to evolve back into equilibrium? 4) Does the system go back to where it started from, or only near where it started from? 5) Is self-organization desirable? (After all self-organization may be good for sustainability, but it may be awful for bringing about change.)

Sensitive Dependence on Initial Conditions

Most of us have been schooled to worship at the altar of the general linear model. We have been taught to think in terms of groups – their means, variances, and distribution shapes. Everything we do is focused on eliminating the influence of individual data points. We scan for outliers. We make sure our samples are representative of carefully defined sets. We endeavor to keep our variances tight. We base inference on the belief that error across observations will sum to zero. This is a powerful analytical lens, but complexity offers an alternative, one in which local variation among elements of a system can affect the long-term evolutionary direction of the whole system.

> A system's sensitivity to initial conditions refers to the role that the starting configuration of that system plays in determining the subsequent *states* of that system. When this sensitivity is high, slight changes to starting conditions will lead to significantly different conditions in the future (Santa Fe Institute 4, 2020).

> … refers to the idea that current and future states, actions, or decisions depend on the sequence of states, actions, or decisions that preceded them---namely their (typically temporal) path. For example, the very first fold of a piece of origami paper will determine which final shapes are possible; origami is therefore a path dependent art (Santa Fe Institute 5, 2020).

Evaluation Implications

The message given by "sensitive dependence" is that a system's overall behavior can be understood in terms of how small changes within the system influence long-term trajectories as systems evolve over time. Because of sensitive dependence, it cannot be assumed that a sequence of relationships that exist at one point in time will repeat. Thus while a causal path can be traced in retrospect, knowing that says little about what the next path will be.

Combining Complexity Constructs to Explain Outcomes

The previous section dealt with individual complex behaviors. Here I will illustrate how these behaviors can cluster to produce an intellectual orientation to pattern, predictability, and how change happens that is different from what we are accustomed to. (Later I will return to this topic with a specific focus on a theory of transformation.)

Stigmergy and self-organization convey a sense that elaborate, seemingly deliberately planned, goal-oriented behavior need not have central direction. Both stigmergy and self-organization speak to the ability of a system's parts to "direct themselves" to develop in particular ways and to evolve to an equilibrium. One implication is that program theories based on deliberate planning may be incorrect portrayals of how coordination takes place. A second implication is that because methodology is guided by theory, evaluation will not provide data on the coordination process that is at play.

Phase transitions and emergence convey a sense that qualitative change can take place in constructs that have solid quantitative identities. Phase transitions imply that conditions can remain little changed over an extended period and then change suddenly to take on radically different characteristics. Emergence implies that parts of a system lose their identity. Prior to emergence, it made sense to observe and measure constituent parts. After emergence, the identity of those parts loose their meaning.

Complexity-based Explanation

Much of the discussion so far has inclined heavily in the direction of instrumental action. If I know that emergence is happening, I should measure at the aggregate level. If I can identify an attractor, I should use the knowledge to assess resistance to change. If I suspect that there is sensitive dependence, I should only track outcome chains retrospectively. And so on. There is a "predictive" sensibility to what I have been saying. "If I implement this program, what will happen?"

Evaluation is steeped in this predictive mindset. After all, the whole field is based on the belief that social science can give planners guidance for spending public money in ways that will achieve socially agreed upon goals[7]. We care about helping people know what will work, not helping them understand whether their beliefs about why things work are true. Our work is technological, not scientific (Morell, 1979) "The aim of technology is to be effective rather than true, and this makes it very different from science" (Jarvie, 1983).

But what happens when the technology fails, i.e. when the predictive ability of evaluation fails to provide guidance to decision makers? Then the need arises to delve into explanation, i.e. to understand the science of why events occur (Feibleman, 1983). When that need arises, complexity provides a productive framework.

What is our modus operandi when we turn our attention to explanation? Typically, we begin with a mechanistic model of programs and outcomes, and layer upon that understanding the uncertainties that flow from interactions and from unknowable environmental change. Or put differently, we layer a veneer of complexity over our non-complex reasoning. It is something else to begin with complexity as the initial frame. I am convinced that doing so leads to theories with different kinds of explanatory power. The best I can do is to provide a metaphor for why I believe this. Translating from English to French, no matter how good one's ability to translate, is different from beginning with French. I can't articulate it any better than that. The initial frame makes a difference.

I am by no means arguing that all evaluation of transformation must be based on complexity. I am only arguing that "all models are wrong, but some models are useful" Box (1979), and that complexity-based models are useful in ways that should not be ignored when transformation is being evaluated. What would a theory of transformation to green energy tell us if we invoked a complexity framework?

[7] Donald Campbell's classic piece on this topic is always worth reading Donald T. Campbell, 1991.

What is Transformation?

My intuitive understanding of "transformation" is as a transition to a "new normal", which I understand as a default set of conditions that shape how we live.[8] Here are some examples that come to mind.

- Wood to coal
- Animal to steam power
- Mercantilism to Capitalism
- Horse to horseless carriage
- Long distance fast communication, starting with the telegraph
- Mechanized transportation, starting with railroads and steamships
- The nation-state as a unit of relationships among geopolitical entities
- Income taxes as a legitimate method (at least in the U.S.) for a government to raise revenue.

There were times before these new normals, e.g. when people thought that a nation's wealth was defined by national surplus, when it was inconceivable that a human could move 50 miles per hour, and when information took weeks to move over long distances. What changed?

Let's take the example of the transition from wood to coal in England between the 17th and 19th centuries (Allen, 2013, Rhodes, 2018). (Yes, it did take a long time. Thirty five percent in 1660, sixty four percent in 1760, and ninety three percent in 1860.) What needed to be present to effect this change? Steam power had to be available to drive engines that could keep mines dry. Heating demand due to urban density (itself driven by a host of economic conditions) denuded local forests. Patent law and the ratio of labor to capital made invention appealing. The building boom in London was conducive to developing new chimney designs. And much else besides.

Of course, it is important to identify each of these factors, to assess their behavior and to determine their interactions. That story will be unique. But another useful perspective is to view these changes as a transition from one attractor regime to another. I.e. from one equilibrium condition that brought many factors together to favor wood, to a different equilibrium state that favored coal. Within each attractor, any force that perturbed the attractor would be counteracted by the self-organizing capacity of activity within the attractor. That's a perspective that leads to speculation about the shape and depth of the attractor. I'm not sure if that kind of speculation would lead to *better* strategies to effect change, but I do know that it will lead to *different* strategies to effect change.

Why would it lead to different strategies? Because it would affect our theories of action. A complexity argument would claim that within the attractor, it *may* be possible to identify all the relevant components, but that it is *impossible* to understand the attractor in terms of relationships among each of those components. Why? Because the equilibrium condition that defines the attractor is an emergent phenomenon. It may be possible to know what the parts are, but it is not possible to identify the specific

[8] "Default" is the operative word that makes "transformation" different from "sustainability", or at least, a special kind of sustainability. One can think of this in terms of system maintenance. Does energy have to be put into the system to maintain it, or are equilibrium and self-organizational dynamics at play? Transformed systems are the "low energy" conditions. There is an extensive literature on evaluating sustainability George Julnes, ed., *Evaluating Sustainability: Evaluative Support for Managing Processes in the Public Interest*, vol. 162, *New Directions for Evaluation* (NY: Wiley, Josse-Bass, 2019). To understand transformation through, the concept of default conditions, and the reasons they may or may not arise, needs more attention than it gets.

role of each part. Moreover, if we believe in sensitive dependence, we believe that each time the attractor is perturbed, the self-organization dynamic might be different. All we can say is that the attractor is deep enough relative to self-organization capacity, that when the attractor is perturbed, it returns to its equilibrium condition. Whatever theory of action might result from this kind of thinking, it would not be something that could be explained by identifying unique elements, and defining change in terms of a combination of 1:1, 1:many, many:1, and many:many relationships among them.

Defining the Outcome. What is Green Energy Transformation?

The complexity view from the previous section tells us that what we know about transition to green energy is that many different factors have to come together, that we don't know (and probably cannot know) what they all are, and that whatever they are, they can come about in different combinations. How to evaluate a scenario like this? A good place to begin is by defining the desired outcome. That means taking a stab at a set of conditions that are likely to be somewhere within the new attractor state. At least it's a place to start.

How to make this stab? Choose a level of green energy use at which it's hard to believe could exist without deep change in how energy is bought, sold, generated, and used. Or put another way, answer the question: How much use of green technology is needed to make it the default choice for the foreseeable future?

How much green technology is needed to make it the default choice for the foreseeable future? It would be nice to have some empirical data to help make this decision. I don't think there will be anything definitive, but I can see data that might be enlightening. E.g. adoption curves for relevant technologies; regulatory targets for alternative energy generation, or projected rates for cost /Kilowatt.
But when all is said and done, a great deal of opinion not based on empirical data would have to be relied on. Why? Because good data are sure to be sparse or untrustworthy, and because even if good data existed, making the transformation happen in a social/political process that requires a reasonable level of agreement among many diverse interests.

Here is an example of what might work as a definition of the transformation: "We know that transformation has happened if in geopolitical boundary X, about 80% of energy use (plus or minusa 10%) comes from green sources and has remained at about that level for five years." I like this form because it includes different dimensions of the whatever attractor space constitutes a green energy new normal, as shown in Table 2.

Table 2: Elements of the Green Energy Attractor	
Geopolitical boundaries	"Geopolitical boundaries" implies a reasonably large geographic area. It is a proxy for availability of equipment, businesses and expertise to install and maintain systems, cost, political consensus, the reach of regulation, and peer pressure.
Level of energy use:	"Eighty percent" is a level of energy use that would be truly different from the old way of doing things. It could only come about from a profound change in energy sources and their supporting constituents. Some of its supporting factors are shared "geopolitical boundaries". Other factors are unique to the "level of use" category. For instance, a high market share will be supported by the intellectual capital needed to innovate technological improvements to the infrastructure, and businesses based on that R&D.
Time	"Five years" acknowledges that an indicator of profound change requires assurance that the construct it reflects will endure over time. It indicates that the attractor is stable, i.e. that whatever forces may develop to disturb green energy use will not overcome contrary self-organizational capacity.

Table 2: Elements of the Green Energy Attractor	
Imprecision	The definition acknowledges that there is a range that defines the boundaries of the attractor. It does not say what kind of geopolitical entity must be involved, or precisely what the market penetration needs to be, or exactly how long a timeframe is required. It recognizes that there is a range, and that we can say very little about what that range is.
Measurement	Everything in the definition can be measured. That matters if we are doing evaluation.

What if the definition turned out to be wrong? What if our definition of the new normal danced about more than we would wish? Or in techie terms, what if small perturbations were enough to change the equilibrium state? Getting the definition wrong would be OK from the point of view of evaluation. After all, that definition of transformation came from a program theory that was articulated by stakeholders. If they were wrong, that would be fine as long as evaluators could report on it accurately and provide guidance as to how to do better.

Complexity-based Models

Any analysis, no matter what its methodology, requires an exercise in willful ignorance (Weisberg, 2014). This is because for any phenomenon we wish to research, there will always be relationships we care about that are enmeshed in a multitude of relationships that complicate and obscure what we want to know. Therefore, any research enterprise, evaluation included, requires a model, i.e. a simplified version of reality that specifies the relationships we care about. It articulates a theory of what's worth measuring. It is a guide for inquiry that reflects our understanding of the truth we are seeking.

The above paragraph conjures images of deterministic, linear reasoning along the lines of traditional evaluation logic models. That image would be wrong. Or at least, it does not have to be right. The key is the relationship between "our understanding", and the "truth of what we want to get at". "All models are wrong, but some are useful"(Box, 1979). Complexity-based models are wrong, but more useful than our traditional ways of depicting program theory and program action. The act of developing and working with models serves as an opportunity to probe our understanding of how a phenomenon works and what it will do (Jordan, 2010). Using the language of complexity allows us to explore that understanding with respect to unfamiliar, but very powerful principles.

Comparing Complexity Based and Non-complexity Based Models

If we think in terms of complexity, discovering "the truth we want to get" will require models that reflect complex behavior. As it turns out, those complexity-aware models are far less elaborate than the models we are used to. Scenarios 1, 2, 3, n, and A in Error! Reference source not found. Illustrates w hy this is so.

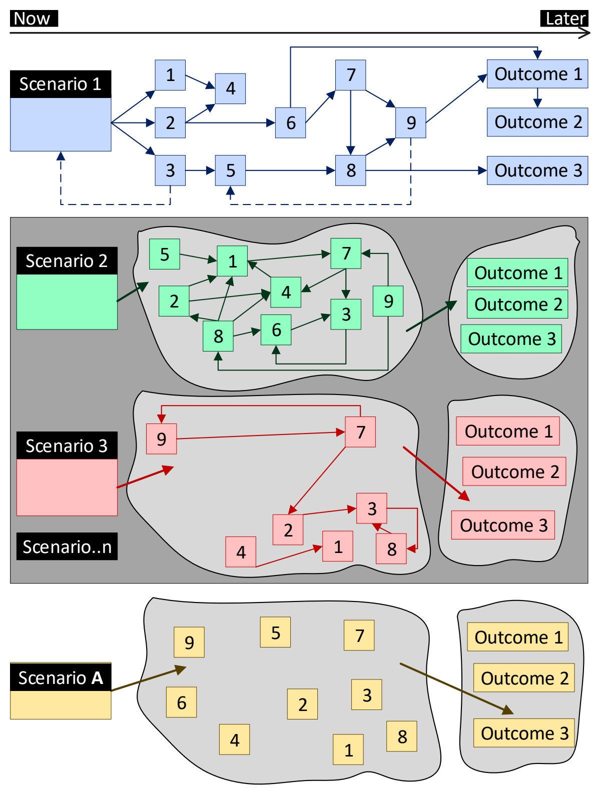

Figure 1 Modeling Complex Behavior Might Require a Sparse Model

<u>Scenario 1</u>

One reason I don't believe it is because it's hard for me to believe that we know enough about a program and its outcomes. Another reason, however, is that Scenario 1 is based on a theory of action that ignores complex behavior. It's not that we don't know enough to specify the model. It's that we cannot know enough.

<u>Scenarios 2, 3… n</u>

These scenarios (gray field in Figure 1) depict different possible complex relationships between the program and its outcomes. What is the message in these scenarios? 1) There is a connection between program and outcome. 2) There is an exceedingly large number of paths that can elicit the desired outcomes. 3) Because of sensitive dependence, we cannot predict the precise path between program action and desired outcomes. 4) Not all the known relevant factors have to be equally important during each pass through the system. 5) No single intermediate factor leads directly to any of the desired outcomes. Rather, outcome stems from the emergent effect of all the networked intermediate elements.

So when designing an evaluation, which configuration should we pick? None. Why? Because whichever we choose, that configuration may be different in the future. All we can say is that in unknowable ways, the desired outcomes are an emergent consequence of all that is going on. This leads us to Scenario A.

Scenario A

Scenario A has a very simple logic: Do a lot here, and something will happen there. In a world driven by complex behaviors, this logic makes sense. I do not mean to imply that we can pick the internal elements of the model at random. It seems eminently reasonable to specify categories that need to be included, e.g. economic conditions, technological capabilities, regulatory structures, culture, and so on. After all, we do have domain knowledge based on experience, research, and theory. That work must be honored.

What I do not believe though, is that we have learn to be comfortable with a theory of program action that posits an emergent dynamic that can be relied on to appear because no matter what variation in paths results from sensitive dependence. These models may be predictive, but they are not predictive in the sense of being a deterministic consequence of many different individual elements.

Possibilities or Prediction

I overstated the case and left the impression that highly specified models cannot be predictive in a deterministic sense. This is not exactly true. What is true is that the broader the scope of a model, the greater the likelihood that complex behaviors will replace the role of specific relationships. Or put differently, a model might be everywhere correct locally, but incorrect globally.

Figure 2 Illustrates this point. It is drawn from Scenario 2 in Figure1. There are three regions. The simplest region (green rectangle) contains two elements connected with a single feedback loop, and two direct connections from the outside. The next larger region (blue) contains five elements. It also contains nested feedback loops and three direct connections from the outside. Finally, there is the entirety of Scenario 2.

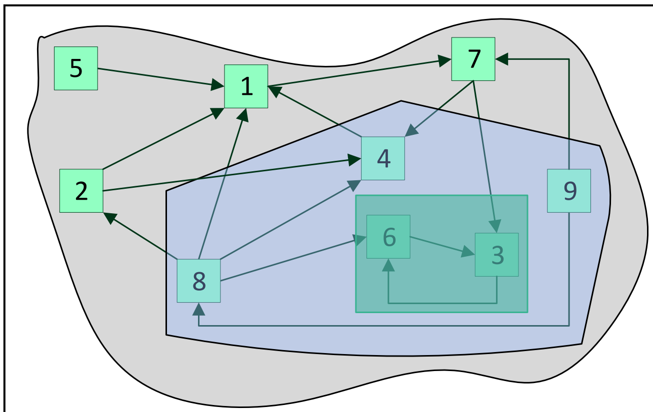

Figure 2: Global / Local Model Correctness

I do not know how to quantify degrees of complexity, or how to specify when complex behavior will manifest. But intuitively, I think it is reasonable to subject the green region to a traditional evaluation.[9] I'm not sure I would do it for the blue region, but I could be convinced. I know I would not accept that tactic for the entire Scenario 2. My assertion can be generalized. For a small enough region anywhere within an elaborate model, traditional modeling approaches can be trusted. As the boundaries expand, those approaches can be trusted less and less. Three other considerations matter. First, it is worthwhile to evaluate parts of an elaborate model. Second, as valuable as such an exercise is, one cannot aggregate those small-scale evaluations into a test of the overall model. Third, between the micro-level model testing and a complexity sensibility, evaluation can guide progress toward green energy transformation.

The discussion above was a global/local perspective on how models can be used for prediction. Time horizons also matter. It is well known in the field of modeling that predictions lose their accuracy over time (Orrell, 2007, Parunak, et al., 2008, Pilkey and Pilkey-Jarvis, 2007). The opposite is also problematic. One often sees evaluation models that do not estimate the length of time needed between change in one part of a model and change in another Morell (2019), and as a result, imply that data collection and analysis of program action can take place within inappropriate timeframes.

[9] For the purposes of constructing evaluation models, the presentation here works. It is important to realize, however that the quantitative measure of complexity is a very deep technical subject. The Wikipedia article on this topic contains pointers to the vast literature on this subject **Wikipedia, 2020.** Also, seemingly "simple" models that contain only a single feedback loop can exhibit chaotic behavior. Go there for a demonstration: Bifurcation Diagram for Teh Logistic Map: Xn+1=Rxn(1-Xn), Santa Fe Institute / Complexity Explorer.org.

A Meta-theory of Transformation to Green Energy

Existing theories of transformation clearly engage complexity. Some of the theories engage complexity indirectly. These are scenarios in which complex behavior is recognized, even if the theory does not explicitly draw on complexity constructs. The second are cases where the theory of transformation does explicitly draw on complexity. I will give an example of each. Then I will make the case that theories of transformation should extend their efforts and draw from complexity science in a more systematic fashion than is currently the practice in evaluation.

Theories of Transformation that do not Explicitly Refer to the Field of Complexity

Reed and Jordan (2007) developed a systems theory for the U.S. Department of Energy's (DOE) Energy Efficiency and Renewable Energy (EERE) program. They confronted a classic complex system problem. EERE has the long-term goal to bring about a regime of efficient renewable energy. In doing so EERE runs many discrete programs that emanate from many different cubbyholes within the DOE, all of which have different short and intermediate term goals, and separate theories of action. With respect to the long-term goals, the theories of action employ the well-known logic: implement program --> accomplish short term goals --> magic happens --> achieve long-term goals.

Reed and Jordan's proposal was that all the diverse programs do evaluation based on Rogers' theory of innovation (Rogers, 2003). That theory is backed by extensive empirical research and contains a very well-defined logic. Moreover, the Rogers' theory's constituent parts are applicable to a wide range of settings, thus making evaluation findings comparable across diverse contexts. Individual programs may still need their own unique objectives, but by invoking Rogers, the diverse programs can also share goals. Because of this commonality, the strengths and weaknesses of separate programs that affect each other can be compared. Reed and Jordan do not discuss their efforts in terms of complexity, but it is clear that stigmergy, emergence, and sensitive dependence can provide complexity-inspired explanation about pattern, predictability and how change happens.

Stigmergy

Recall that stigmergy is a process in which a "plan" is embedded in the history of activity that is encountered by independent actors (Theraulaz and Bonabeau, 1999). In other words, it is a process that appears to be centrally coordinated, but which in fact occurs when independent actors make decisions as they engage an environment. Now consider EERE's dilemma. Their various programs have a common long-term goal, different short-term goals, and are embedded in a bureaucracy that makes tight coordination difficult and in many ways, counter-productive (Morell, 2018). Under these circumstances, evaluating overall progress toward a goal should include an investigation of whether, how, and why independent programs base their actions on the activities of related but independent activities.

By devising a process that generates common goals, Reed and Jordan have come up with a method by which centralized coordination *could* be more deliberate. After all, a centralized authority could use common evaluation findings to set policy. However, even without additional centralized coordination, Reed and Jordan's approach allows uncoordinated but connected efforts to make independent decisions account for what others have already done. Thus it becomes possible for all these EERE programs to act as if there was a mechanism for centralized coordination, even where none exists. Of course there is no guarantee that independent programs will consider what other programs have done. But by allowing visibility with respect to common goals, the theory of action makes it possible. Because stigmergic change is part of the program theory, it can be understood as the reason change occurs, and it can be evaluated.

Magic, AKA Emergence and Sensitive Dependence

Implement program --> accomplish short term goals --> magic happens --> achieve long-term goals. Emergence and sensitive dependence explain the magic. Consider the EERE scenario in light of **Error! Reference source not found.**. There are many different programs that inhabit the same ecosystem. For any pair, it is not unreasonable to hypothesize a directional relationship. Work out the details, and you will end up in the gray area of the figure, i.e. with a scenario somewhere between 2 and n. But which? Once all the relationships were worked out, would a careful look at the model lead one to conclude: “Yes, I know enough about these elements that I believe the relationships are correct? That the model is correct? You know that my answer is “no”. It is true that focusing on relationships among a small number of elements may be deterministic, and the more such evaluation takes place, the better. But for the model as a whole? What may be true is that sensitive dependence is operating to continually change the precise relationships among the model’s elements, but that as a whole, they operate within an attractor that produces the desired long-term goals.

What does this mean for evaluation? First, previous research must be taken seriously. Thus it is important to make sure that all relevant elements are included. The fact that one cannot specify exact relationships does not excuse omitting elements that are known to be important. It does matter that each element is done well, and thus deserves its own rigorous evaluation. Second, the “magic” is an emergent property (likely also showing a phase transition pattern) of elements that can interact in numerous different ways to produce the same result. One cannot specify a causal path and determine how far along the path one has traveled.

A complexity view yields the model depicted in Scenario A in **Error! Reference source not found.**. That scenario shows a theory that says: Given how the world works, the best we can say is that if we do a good job with enough of the relevant elements, we will get a transformation in which green energy becomes the default choice. Even though we know this, we cannot estimate how close we are to that transformation. Evaluation can tell us if we are doing the right things, but it cannot tell us how much progress we have made.[10] Funders, planners, and stakeholders may not like this model. They have good reasons to want a metric that indicates how much progress has been made toward a goal. But such a metric is unlikely to be available. Comfort must be taken in evaluation that: 1) shows that individual components are done well, 2) that many of those components are done well, and that 3) regions within the overall model are succeeding. That is a lot.

Theories of Transformation that Explicitly Refer to the Field of Complexity

There is considerable effort under way to draw on complexity when developing theories of transformation. Radical change is not needed. What is needed is a continuation of a line of thinking that is already being pursued. Four examples illustrate how current thinking about theories of transformation have drawn on complexity.[11]

[10] I do not mean to say that progress to a phase transition boundary cannot be measured. An obvious contrary example is the transition from water to steam, which takes place at well-known combinations of temperature and pressure. Our problem is that for the work we do, we are nowhere near having the scientific knowledge needed to make such determinations.

[11] There is nothing systematic about this collection. It came from examples I have been collecting, not from a thorough review of the literature. Also, my focus is specifically on “transformation”, not on development in

Example 1: Zazueta has proposed a theory of change that draws heavily on networking relationships, as illustrated in Figure 3. With respect to the behavior of the network, he identifies adaptive learning, feedback, and emergence. He also specifies that "agents" are operating, and notes the importance of domains, and scales of both space and time. The network is left deliberately vague. The graphic implies that there are nodes and edges, but precisely what they are, and how they are connected, is left undefined.

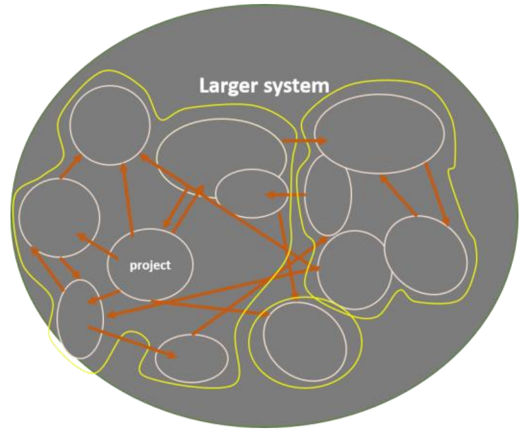

Figure 3: Theory for Transformational Development –

Example 2: Figure 4 is the theory of trasformational change proposed by the SDG Transformation Forum (2020). It relies heavily on feedback loops and networks, but acknowledges that specific elements of success are unknown, hence the unlableled network nodes and the question marks which, presumably, are there to indicate uncertainty about network edges.

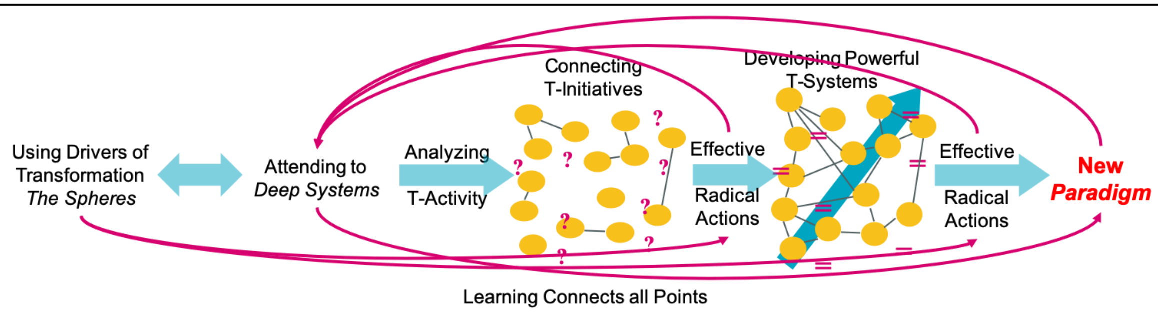

Figure 4: Theory of Transformational Change (SDG Transformation Forum, 2020)

general. For a good treatment of complexity in the evaluation of development efforts, see: Michael Bamberger, Leonardus Vaessen, and Estelle Raimondo, eds., *Dealing with Complexity in Development Evaluation: A Practical Approach* (Thousad Oaks CA.: Sage, 2015).

Example 3: Figure 5 is an adaptation of a model developed by Fisher and Roehrer (2020) to understand progress toward transformation. As Figure 5 shows, individual elemets ("incremental" inputs on the left side of graphic), undergo a network development process that trasform into "transformational" elements on the right, e.g. projects to portfolios.

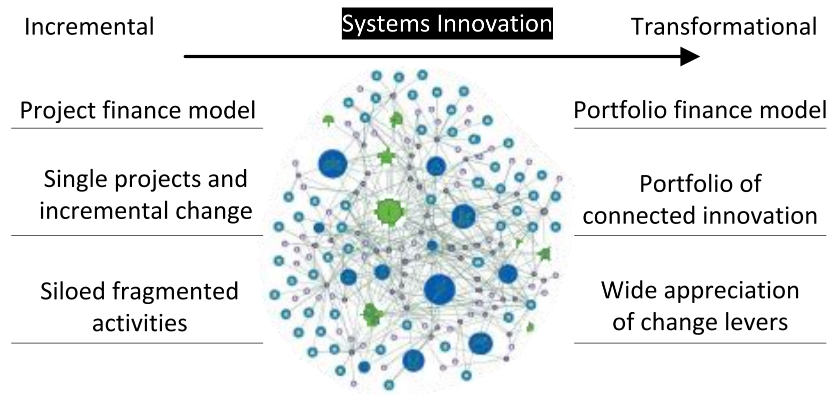

Figure 5: Model of Progress Toward Transformation (adapted from (Fisher and Roehrer, 2020)

Example 4: A report commissioned by the Climate Investment Fund identfied a time sequence of signals of transformational change (Climate Investment Funds, 2020). They offer a two-dimensional model constituting domains of change – systemic, scale, and sustainability; and chronological indcators for each – early, interim, and advanced indicators. Table 3 Table shows their logic. Each cell of the model contains lists of indicators. However, there is no specificity with respect to relationships among individual elements within each cell, nor of rationships among elements across cells.

Table 3: Climate Investment Fund Change Model

	Domain of Change		
	Systemic	Scale	Sustainability
Chronology			
Early			
Interim			
Advanced			

Examples one, two, and 3 specifically identify network behavior as key to transformation. All three use visual representation to acknowledge two domains of uncertainty – the specific identity of nodes (i.e. relevant variables), and the nature of relationships among these nodes, i.e. causal relationships as depicted by edges. Example four is unlike the others in that it does not propose a network. But it is similar to the others in that it does not hypothesize specific relationships among individual variables. Its message is that "if enough is done here, good things will happen there".

Extending the Application of Complexity in Devising and Using Theories of Transformation

I do not know what was in the minds of these model developers, but it's easy enough to appreciate the complex behavior that is implicit in their theories of transformation Table 4.

Table 4: Complex Behaviors Implicit in Existing Theories of Transformation

Complex Behavior	**Manifestation in Theories of Transformation**
Emergence	Emergence can account for reasons to avoid explaining transformation in terms of linear combinations of discrete variables.
Phase transition	Phase transitions are common (but by no means guaranteed) as edges grow in a network.
Attractor behavior	Attractors allow for the fact that despite the uncertainties of sensitive dependence, there are circumstances where if enough activities are done well, the specific outcomes can be expected.
Sensitive dependence	Sensitive dependence implies that even when a causal chain can be determined in retrospect, that same causal chain may not operate in the future.
Stigmergic and self-organizing phenomena	Stigmergic and self-organizing phenomena may drive activity in the direction of organized change even though tight central coordination is not present.

My argument is that the complex behaviors that are implicit in existing theories of transformation should be made explicit and considered in a deliberate manner. There is no reason to assume that each row in Table 4 will always be useful to each context-specific theory of transformation that may be developed. But transformation does involve complex behavior. Because of this, better theories of transformation will result from honing specific theories against a meta-theory of transformation that explains transformation in terms of the complex behaviors presented in Table 4.

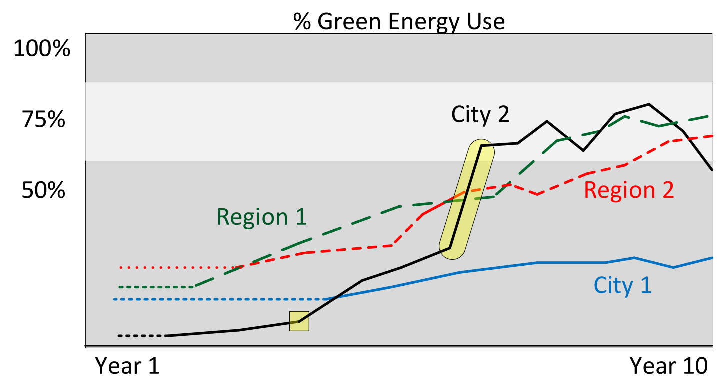

Figure 6: Illustration of Evaluation Data, Promotion of Green Energy Technology

To produce a theory of transformation it is necessary to begin by defining the outcome, in this case the criteria in Table 2: geographical boundaries, level of green energy use, geographical spread, range not point estimates, and make sure that it is all measurable. By defining outcomes in this way, it will be possible to produce data as depicted (in the entirely fictional scenario) shown in Figure 6. In the figure: Colors represent geographical entities. Dashed lines represent regions. Solid lines represent cities. Straight dotted lines show the time in each location prior to when any change might be expected. These data illustrate some of the complex behaviors that I have been discussing.

- For there to be a "new normal", geographical spread matters because geography is a proxy for availability of equipment, businesses and expertise to install and maintain systems, cost, political consensus, the reach of regulation, and peer pressure. The graph shows which locations are changing, and when the changes took place. If the data were paired with a map, evaluators would have a solid appreciation of how infrastructure support evolves.

- Complexity posits that even if change is defined as space within an attractor, there is still the question of the topography of the attractor – how well can self-organizing forces "hold" values within the attractor? Eyeballing the data suggests that the attractor seems stable for larger geographical areas, even if it may not be stable for smaller areas. That's a comforting finding.

- Look at the yellow square in the graph for City 2. There is a dramatic acceleration in the rate of change. It seems as if something might have happened with respect to the factors that are driving change. It might not be a bad idea to think about that time as the time at which emergent dynamics replaced the additive consequences of individual drivers of change. From the point of view of program theory, change management, and data analysis, it might be advisable to determine what that emergent behavior is, and what elements were involved in bring it about.

- The definition of success stated a range for percent green energy. Three of the four regions made it into that region. Still, they only made it into the bottom range, and one of those almost did not stay there. What it looks like is that the natural range for green energy use, under the interventions implemented, in the environment in which they were implemented, is lower than what was expected. This may suggest a change in program theory or an adjustment in our understanding of what realistic outcomes are.

- To say that about eighty percent green energy use is a new normal is to say that it is qualitatively different from lower percentages. This may be the case because all of the various factors that affect energy use come together in a networked fashion to yield a condition akin to a traffic jam, or an economy, or urban vitality, i.e. a condition in which its component parts lose their identity. Is this a case of emergence? And if it is, is our hypothesis correct that emergence takes place at about eighty percent green energy use? These are empirical questions that can be answered if our program theory has correctly identified the necessary components, and if have constructed a methodology that can measure those components.

- Complexity tells us that phase shift behavior is possible, i.e. that in terms of transformation, there may be a qualitative change from one state to another. But complexity does not tell us that there *must* be such change, or that the new normal cannot happen incrementally. See the yellow oval for City 2. It seems as if a phase shift may have taken place. Incremental change (albeit sometimes at a rapid pace) seems to be the case in the other scenarios. Of course, these kinds of changes are not like the state change from water to steam because the definition of the "new state" is debatable. We know when H_2O is water or steam. It's a judgment call that eighty percent green energy use, over a particular geographical area, for a particular period of time, is qualitatively different from what went before. In terms of our efforts to bring about green energy use, however, it matters whether we plan as if change is just "the same, but more" or if we conceptualize the desired state as different from what went before.

What complex behaviors would have to be built into the evaluation to allow us to interpret the data in complex terms? The answer is summarized in Table 5.

Table 5: Complexity as it Applies to Theories of Transformation	
Emergence	▪ Does the model identify what the emergent outcome is? ▪ Does the methodology consider the emergent behavior as its own variable? ▪ Does the theory of action recognize the importance of individual elements without assuming that the consequences of those elements can be "added up"? ▪ Does the model reflect when an emergent change will appear, or for how long into the future the change will persist?
Phase transition	▪ Does the theory postulate a non-linear change in which little happens for an extended period of time? ▪ Does the theory and methodology (not to mention stakeholder expectations) acknowledge that the concept of "intermediate stages of transformation" may not have much meaning? ▪ Does the model recognize timing, i.e. does it identify a window when the change can be expected?
Attractor	▪ Does the theory acknowledge that transformation may be defined as an attractor that can be explained as a condition in which self-organization resists changes to the status quo? ▪ Has any thought been given to how deep that attractor is, i.e. how enduring the transformation state is to outside shocks? ▪ Does the methodology consider the stability of the attractor? Or put in other terms, if the model predicts the appearance of an outcome attractor, for how long will that prediction remain accurate?
Sensitive dependence	▪ Does the theory specify relationships among discrete elements, or does it recognize the possibility of sensitive dependence, a condition in which multiple unpredictable chains of causation may lead to the same result? ▪ How does the evaluation engage this possibility in terms of a metrics that specify what needs to be measured, and a methodology that provides the logic of data interpretation?
Stigmergy	▪ Does the theory explicitly consider coordination among the actors that are involved in transformation activities? ▪ If so, does the theory consider the possibility of stigmergic processes in which independent choices are influenced to work toward a specific goal?

Over and above the implications of the specific complex behaviors described above, these characteristics of complex systems convey an orientation to thinking about how transformational processes behave. It's not a question of whether to invoke a particular complex behavior. Rather, it's the style of reasoning that results from thinking in terms of complexity. Table 6 Gives some examples. All of these examples speak to the themes in complexity that constitute the columns in Table 1 – what pattern we can expect, what we can and cannot predict, and how change happens.

Table 6: Examples of Reasoning that Derives from Combining Complex Behaviors

Emergence and phase transition	▪ combine to convey a sense that smooth incremental change is not typical behavior.
Sensitive dependence and attractors	▪ combine to convey a sense that clearly specifiable patterns should not be expected.
Stigmergy, attractors and sensitive dependence	▪ combine to convey a sense that even without high levels of process control, certain outcomes can be expected.

Finally, drawing on complexity can help at times when efforts at transformation fail. This is because the process of transformation is a complex system and therefor, the science of complexity is needed to explain success and failure when the technology of effecting change.

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