Submitted to Sustainability Science journal
Version: October 27, 2020

Root cause analysis as a foundational tool of sustainability science

Jack Harich[1], Montserrat Koloffon Rosas[2,3], Michael Hoefer[4]
[1]Thwink.og, Atlanta, USA. jack@thwink.org. Corresponding author.
[2]Vrije Universiteit Amsterdam, Amsterdam, Netherlands.
[3]Thwink.org, Atlanta, USA, montse@thwink.org.
[4]University of Colorado Boulder, USA, michael.hoefer@colorado.edu.

Revisions since submission: Fig. 4 had an error. It was missing (1) and (2). Added note (3) for clarity. Added two sentences in Conclusions, beginning with "As long as a…".

Abstract

Despite immense attention from scholars and others, solution strategies have failed to address the sustainability challenge, particularly the environmental pillar. We propose the central reason is that due to the extreme dynamic complexity of the problem it cannot be solved without root cause analysis (RCA), which was not used to develop past solutions. While RCA has long been a core tool for solving difficult business/engineering problems, application to social problems remains hindered because no suitable version of the tool exists for difficult social system problems, which differ radically from non-social problems. How then can RCA be adapted to solve difficult social problems, particularly environmental sustainability? To address that question our research iteratively developed an RCA-based process for difficult social problems while simultaneously applying the process to the environmental sustainability problem. We conclude that adaptation of RCA to fit difficult social problems is possible and has the potential to transform the sustainability problem from insolvable to solvable.

1. Introduction

Ever since classic works like *Silent Spring* (Carson 1962) and *The Tragedy of the Commons* (Hardin 1968) brought the environmental sustainability problem to the world's attention and *The Limits to Growth* (Meadows et al. 1972) defined the problem in sufficient detail using a series of stunning simulation scenarios, scholars have moved to increasingly sophisticated problem-solving methods. These include a long history of integrated global modeling (Costanza et al. 2007), ecological economics for balancing the eco/economic relationship (Costanza et al. 1997; Daly and Farley 1997), world system analysis (Hornborg and Crumley 2006), resilience theory as the basis for automatic adaptive governance (Folke et al. 2010), the many frameworks of sustainability

transitions (Markard et al. 2012), the single research framework of earth system governance (Burch et al. 2019), and proposals to structure sustainability science research itself (Jerneck et al. 2011). Eight Earth Summits from 1972 to 2019 culminated first in the Brundtland Report's widely accepted definition of "sustainable development" in 1987 (World-Commission 1987) and later the solution mechanism of governance by goal-setting (Biermann et al. 2017), with adoption of the Millennium Development Goals in 2000, followed by transition to the Sustainable Development Goals (SDGs) in 2015.

While there have been some gains, such as in local pollution and stratospheric ozone depletion (due to low change resistance), "decades of scientific monitoring indicate that the world is no closer to environmental sustainability and in many respects the situation is getting worse" (Howes et al. 2017). Such lack of progress indicates something in these methods, and hence the solutions they produce, is deeply flawed.

In an increasingly urgent effort to find those flaws and correct their methods, scientists closed ranks and began building the new field of sustainability science (Kates et al. 2001; Takeuchi and Komiyama 2006; Clark 2007). As Kates announced, "A new field of sustainability is emerging that seeks to *understand the fundamental character of interactions* between nature and society," with the intent of developing "society's capacity to guide those interactions along more sustainable trajectories."

We propose that understanding can be achieved by taking the transdisciplinary shortcut of adapting a *business* tool to fit *social* problems. A widely used, proven choice is available for understanding the fundamental interactions of any causal problem: root cause analysis (RCA). RCA can provide sustainability science with the knowledge structuring, problem-solving orientation, and generic research platform identified by Jerneck et al. (2011) as critical for the field to have the capacity to solve the sustainability challenge. Miller et al. (2014) contend that "sustainability science must link research on problem structures [which this paper calls essential problem structure] with a solutions-oriented approach." RCA provides the missing methodology for that link.

RCA originated with the "King of Japanese Inventors," Sakichi Toyoda, in the early twentieth century when he formalized how he applied the method with the justly famous Five Whys, where starting at the symptoms one asks "Why does this occur?" until the root causes are found (Ohno 1988, p. 77). For example, why won't a car start? Because of a dead battery. Why does that occur? Because of a bad alternator, which fails to charge the battery. The intermediate cause is a dead battery. The root cause is a bad alternator. Replacing or charging the battery will solve the problem temporarily. Replacing the alternator solves the problem permanently. Here only Two Whys were needed to find the root cause.

Today, RCA serves as the foundational paradigm of widely used, highly refined business processes with high process maturity like the ISO 9000 family of international quality standards (Tummala and Tang 1996), lean production (Womack et al. 1990), and Six Sigma. The ubiquitous leader is Six Sigma, used by 100% of aerospace, motor vehicle, electronics, and pharmaceutical companies in the Fortune 500 and 82% of all companies in the Fortune 100 (Marx 2007).

Industrial RCA revolves around the concepts of defects and root causes. RCA is used to maximize the quality of solutions to customer's problems. Anything that displeases the customer is a defect. Defects arise from root causes. Six Sigma, an RCA-based process for radical improvement of core business processes, routinely cuts defect rates by an astonishing three orders of magnitude, from roughly 6,210 defects per million transactions to 3.4 (Pyzdek 2003, pp. 5 & 60). RCA has become so central to quality management and problem solving that "Root cause analysis is an essential process for any organization that wants to continue to improve and is willing to engage in serious introspection and analysis" (Dew 2003).

The RCA paradigm rests on several axiomatic concepts. Drawing from a diversity of sources, e. g. (Ishikawa 1986; Pyzdek 2003; George et al. 2005; Tague 2005; Andersen and Fagerhaug 2006; Okes 2019), a root cause is the deepest cause in a causal chain (or the most basic cause in a feedback loop structure for more complex problems) that can be resolved. A causal problem occurs when problem symptoms have causes, such as illness or a car that won't start. Examples of non-causal problems are math problems, scientific discovery problems, information search/organization problems like criminal investigation, and puzzle solving. All causal problems arise from their root causes. The sustainability problem is a causal problem. It can therefore only be solved by resolving its root causes, whether root cause terminology is used or not. RCA is the systematic practice of finding, resolving, and preventing recurrence of the root causes of causal problems. RCA employs hundreds of supporting tools and techniques. RCA is generic and for institutional use is normally wrapped in a process tailored to the problem class.

From the vantage point of quality management, where all problems are seen as forms of unacceptable quality of solution of a customer's problem (note that citizens are customers of their governments), the business/engineering world has concluded that RCA is the only known core method for solving difficult causal problems reliably and efficiently, e. g. (Tague 2005 pp 338-47, The Quality Improvement Process). Other core analytical methods, such as experimental trial and error, forms of statistical analysis like comparative and factor analysis, and simulation modeling[1], can sometimes eventually solve difficult causal problems. But they cannot do so reliably and efficiently, because the essential causal structure (defined in the next section) of the problem remains hidden. In this paper, difficult social problems are those that have remained unsolved after continued solution attempts for a generation (twenty-five years) or more and are large-scale (macro), involving social systems of millions of people.

However, RCA was developed by business to solve difficult business and engineering problems. No suitable version exists for difficult social problems, which differ so radically from non-social problems that they are wickedly difficult and "seem to defy conventional strategies for public policy interventions designed to address them" (Newman and Head 2017). Consequently, to our knowledge RCA has never been effectively applied to difficult social problems. This offers a clear, unifying explanation

[1] Simulation modeling can reveal some essential causal structure. However, if RCA is not employed to construct the model, the model will tend to include only the intermediate (proximate) causes and omit the root causes.

of why past solutions to the sustainability problem have largely failed: None were based on a suitable version of RCA, so the solutions were unknowingly directed toward intermediate rather than root causes.

That no suitable version of RCA exists for difficult social problems, particularly the sustainability crisis, reveals an enormous gap and an equally enormous opportunity for establishing a workable foundation for sustainability science. The research challenge is precisely this: How can the powerful *business* tool of root cause analysis be adapted to solve difficult *social* problems, particularly environmental sustainability?

The remainder of this paper reports on our answer to this question. Over a seven-year period, a generic process based on RCA for solving difficult large-scale social problems was iteratively developed while simultaneously applying the process to the environmental sustainability problem. The result was the System Improvement Process (SIP) and process application results.

2. The critical importance of essential causal structure

Sustainability science seeks "to understand the fundamental character of interactions between nature and society" and use that knowledge to solve the sustainability problem. The problem exhibits high dynamic complexity, making those interactions enormously difficult to understand. Sterman (2000, p. 22) lists ten reasons dynamic complexity can arise in social systems. All are present to a high degree in the sustainability problem:

1. The system is constantly changing.
2. Tight coupling.
3. Agent behavior is governed by a multitude of feedback loops,
4. System behavior is nonlinear.
5. System behavior is history-dependent.
6. Self-organizing behavior.
7. Adaptive agent behavior.
8. Counterintuitive behavior.
9. Policy resistance.
10. Interventions lead to trade-offs.

Sterman then explains how feedback loop simulation modeling is required to correctly understand system behavior when dynamic complexity is high. The unaided human mind lacks the capacity to mentally identify, organize, and simulate the very complex causal structures involved.

Yet the sustainability problem *has* been extensively modeled with feedback loop integrated global models. Costanza et al. (2007) reviewed seven of these models, which are met to "investigate what might happen if policies continue along present lines, or if specific changes are instituted." Integrated global models are widely used for scenario analysis in global environmental assessments to develop response options (van Vuuren et al. 2012)

What's missing in these models? Why have they not led to successful solutions?

A clue to what's missing lies in the intent of these models. Their goal is only to simulate probable system behavior under different policies, as the three editions of *The Limits to Growth* did with their twelve, thirteen, and ten scenarios.

Missing in these models, as well as the other methods listed in the first paragraph of the Introduction, is the concept of *essential causal structure*. This is the nodes, relationships, and interacting feedback loops that provide a sufficiently complete model of how problem symptoms arise from their root causes and where the *high leverage points* are for effective solutions. Causal problems can be solved only by resolving their root causes. It follows that if the analysis of a causal problem lacks the correct root causes, analysis users will be unable to reliably solve the problem, because solutions will tend to be directed toward resolving intermediate causes rather than root causes.

3. The search for a method for finding high leverage point solutions

Gooyert et al. (2016) argue knowledge of high leverage points is required, since "A sustainability transition [which we call the desired mode change] can be understood as a transformation in a complex system consisting of several feedback loops. With this understanding, successfully managing a sustainability transition becomes a matter of identifying *high leverage points* in those feedback loops that can support the progression of the transition, thereby overcoming policy resistance".

While the sustainability literature has long advocated high leverage point solutions, scholars (including Gooyert et al.) have offered no suitable RCA-based methods for finding them. Neither Donella Meadow's (1999) widely cited essay on *Leverage Points: Places to Intervene in a System*, nor her later work (2008) on *Thinking in Systems* offers such a method.

The strongest RCA-based attempt we could find, an analysis of *The Root Causes of Biodiversity Loss* (Wood et al. 2000) employed a four-step process based on the "chains of explanation" approach of political ecology: literature review, development of conceptual model, data collection, and revision of conceptual model. The process produced linear node diagrams for most of the ten cases studied (e. g. pp 24, 25, 193). Three cases employed causal loop diagrams (pp 291, 296, 302), which were not organized into feedback loops. While this is a strong step in the right direction, neither diagram type can be simulated and are thus incapable of understanding the problem's high dynamic complexity and revealing its essential causal structure. Root causes were defined as "the set of factors that truly drive biodiversity loss, but whose distance from the actual incidence of loss, either in space or time, makes them a challenge to identify and remedy. …we have reached a root cause when we have found a point at which we can successfully intervene in order to alter the loss of biodiversity." (pp 3, 32) While this definition is another strong step in the right direction, compared to the one presented later in this paper it is too weak for productive use.

Wood's analysis found a set of eight main root causes (p62) shared to varying levels by the ten cases. The first four root causes are population growth, poverty, immigration, and inequality. All have deeper causes and can affect each other, such as population

growth frequently increases poverty. From the point of view of RCA as we understand it, these four root causes, as well as the rest, are in fact intermediate causes.

Scholars are beginning to recognize the need for an RCA-based method for finding high leverage point solutions. In a review of the needs of sustainability science and the problem-solving potential of Donella Meadows' leverage point hierarchy, Abson et al. (2017) concluded "sustainability science needs to engage with the deep, or ultimate, causes of unsustainability" and proposed that "a research agenda centered on the concept of deep leverage points can provide a coherent framework for engagement with the root causes of unsustainability." We concur and will return to this proposal later.

Current methods are unable to generate high leverage point solutions because no suitable version of RCA exists for difficult social problems. Let's turn our attention to how that gap can be filled.

4. A method for understanding fundamental interactions

4.1. Social force diagrams

To make finding the essential causal structure of a problem as systematic and reliable as possible, analysis starts by creating a visual diagram called a "social force diagram," using the standard format of Fig. 1. Social force diagrams show at a glance the high-level causal structure of a problem and the desired mode change (explained later). The tool provides a standard vocabulary and analytical framework especially suited for difficult social problems. Social force diagrams serve as roadmaps to the much more complex feedback loop models behind them. The diagrams and models capture the complex cause-and-effect relationships comprising a problem's essential causal structure.

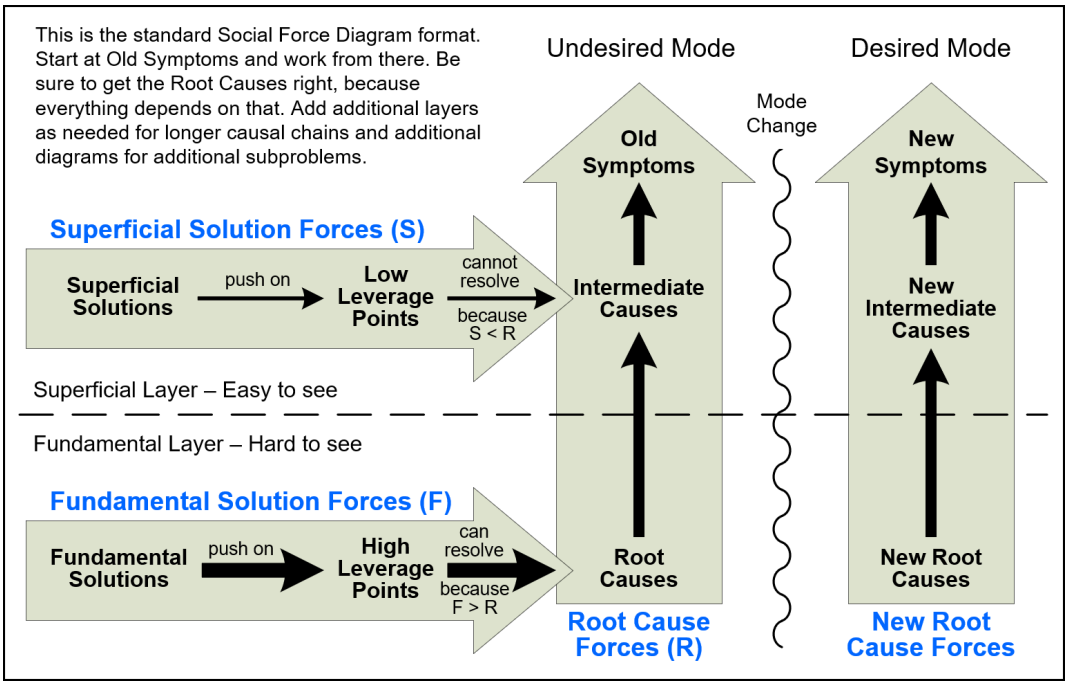

Fig. 1. Standard social force diagram for capturing the high-level essential causal structure of a single problem and its solution.

Social force diagrams simplify difficult social problems to their three main forces. The first is the *root cause forces* (force R) causing the problem. In difficult problems this systemic force is so strong it causes current mode lock-in and inherent high resistance to mode change. A mode is a general pattern of system behavior. Mode change occurs when the new mode differs distinctly from the old mode, such as when a person has recovered from an illness or a nation has industrialized. Systemic means "originating from the system in such a manner as to affect the behavior of most or all social agents of certain types, as opposed to originating from individual agents." (Harich 2010)

The central role of lock-in in the environmental sustainability problem has long been noted, such as by Hardin (1968) in *The Tragedy of the Commons*: "Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited." Lock-in occurs in all difficult systemic social problems. An unsolved problem is locked in the undesired mode (the wrong mode), while a solved problem has switched to the desired mode (the right mode). Non-difficult problems, like local pollution or susceptibility to flooding, usually require no mode change, making them much easier to solve.

Working backward from the old symptoms, research in the social sciences has traditionally identified what is believed to be the causes and then develops solutions based on that assumption. If it's a difficult problem the solutions fail because they are *superficial solution forces* (force S) attempting (in vain) to resolve intermediate causes. This is the second type of force.

Using traditional methods, only the superficial layer of the sustainability problem has been uncovered. By welcome contrast, with RCA-based methods problem solvers can penetrate to the fundamental layer and see the problem's complete causal structure, which contains the root causes and their high leverage points. This allows sustainability scientists "to understand the fundamental character of interactions between nature and society," which, we argue, has the potential to change the sustainability problem from insolvable to solvable.

Once the root causes are known the third type of force can be employed. *Fundamental solution forces* (force F), if properly designed, resolve the root causes by changing the feedback loop structure of the system such that a new homeostasis (dynamic equilibrium) becomes more attractive. Lock-in to the present mode ends, causing the system to quickly transition to the desired new mode. The system stays locked into the new mode due to the new root cause forces arising from the new feedback loop structure introduced by the fundamental solution forces. If analysis and solution convergence testing are done well, the solution force will solve the problem rapidly and relatively permanently, in the same predictable engineering manner by which so many difficult business/engineering problems have been solved using RCA.

Why exactly do superficial solutions work only partially, temporarily, or not at all? Because the superficial solution forces can never exceed the root cause forces. The diagram shows this law of physics with **S < R**. The equation means "S is always less than R." By contrast, fundamental solution forces work because **F > R**, meaning "Fundamental solutions can succeed because they can be designed such that F > R."

The basis for these two equations was discovered long ago by the inventor of system dynamics, Prof. Jay Forrester of MIT. In a groundbreaking study of the US urban decay problem, then its top national problem due to mass urban rioting, Forrester's (1969) simulation model showed that of the four most common solution policies, none made the problem better and some made it worse. The most popular solution, low cost housing, increased urban decay the most. Forrester explained why: (Forrester 1971, pp. 94–95)

> "The intuitively obvious 'solutions' to social problems are apt to fall into one of several traps set by the character of complex systems. ...people are often led to intervene at points in a system where *little leverage exists* and where effort and money have but slight effect.
>
> "...social systems are inherently insensitive to most policy changes that people select in an effort to alter behavior. In fact, *a social system draws attention to the very points at which an attempt to intervene will fail.* Human experience, which has been developed from contact with simple systems, leads us to look close to the symptoms of trouble for a cause. But when we look, we are misled because the social system presents us with an *apparent cause* that is plausible according to the lessons we have learned from simple systems, although this apparent cause is usually a coincident occurrence that, like the trouble symptom itself, is being produced by *the feedback loop dynamics of a larger system*."

Forrester's "apparent cause" is what we call the intermediate cause. "Little leverage exists" if people assume the apparent cause is the root cause because that leads to pushing on low leverage points, where S < R. Instead, one must understand "the feedback loops dynamics of a larger system," where the root causes and high leverage points may be found, and where F > R is possible.

4.2. Two social force diagram examples

To illustrate how social force diagrams work, consider one of history's most intractable problems: autocratic rule by countless warlords, dictators, and kings. The Autocratic Ruler Problem was eventually solved by invention of modern representative democracy. This took thousands of years and much painful trial and error because the root cause was unknown. However, now it is known, allowing the upper diagram in Fig. 2 to be constructed.

The upper diagram shows why superficial solutions failed to solve the problem for so long (bad rulers kept reappearing once one was removed), why the fundamental solution worked (good leaders now tended to appear), and why, once the mode change occurred, the institution of democracy automatically spread (it was now much more attractive due to the new symptoms). Democratic systems have tended to stay in the new mode due the new root cause force of rule by the people, supported by the right new feedback loops: voter feedback, checks and balances, government transparency, etc. If these loops become weak the new mode will regress to the previous mode, as it threatens to do today in many nations with corrupt or authoritarian leaders.

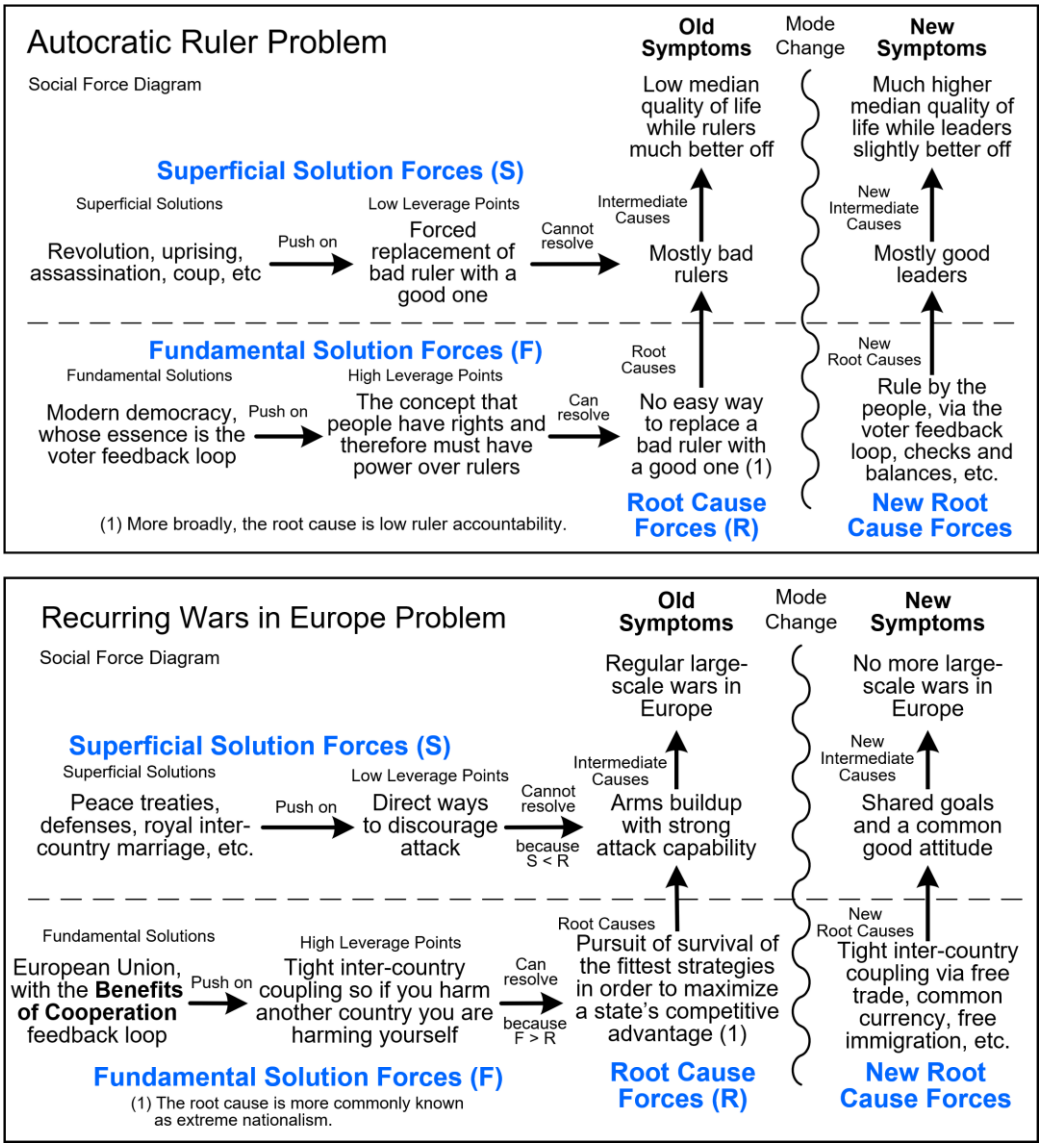

Fig. 2. Two retrospective social force diagrams.

The lower diagram shows traditional solutions to the Recurring Wars in Europe Problem didn't work because they didn't resolve the root cause. But after the horrors of two successive world wars on European soil, problem solvers said never again and intuitively looked deeper for the root cause and its high leverage point. The resulting solution, the European Union, caused a permanent mode change. Today no member of the union would even consider war against another member since that would be terribly self-destructive.

The superficial solutions failed because they pushed on a low leverage point. All those peace treaties, military defenses, royal marriages between countries, and so on did little to resolve the root cause. The drive to maximize a state's competitive advantage was a much stronger force than the superficial solutions, due to S < R.

The fundamental solution worked because it pushed on a high leverage point, where F > R was possible. This resolved the old root cause forces and created new root cause forces, which emanated from the Benefits of Cooperation loop.

Social force diagrams are part of:

4.3. The System Improvement Process (SIP)

SIP is a comprehensive method for applying root cause analysis to difficult social problems. Surveying the business and academic literature, we found no such method was available so we were forced to develop one, a common occurrence on novel classes of problems. NASA (2013) encountered the same situation:

> After extensive review, NASA found that none of the commercially available tools and methods would support a comprehensive root cause analysis of all the unique problems and environments NASA faces on the Earth, in the ocean, in the air, in space, and on moons and planetary bodies. Existing tools were designed for a specific domain (e.g., aviation), a specific type of activity, a specific type of human error (e.g., errors of omission) or had a limited set of cause codes. The NASA RCAT [Root Cause Analysis Tool], a paper-based tool with companion software …was designed to address the shortcomings identified in existing tools.

SIP was developed from scratch to solve difficult large-scale social problems, particularly the sustainability problem. Fig. 3 summarizes how SIP works.

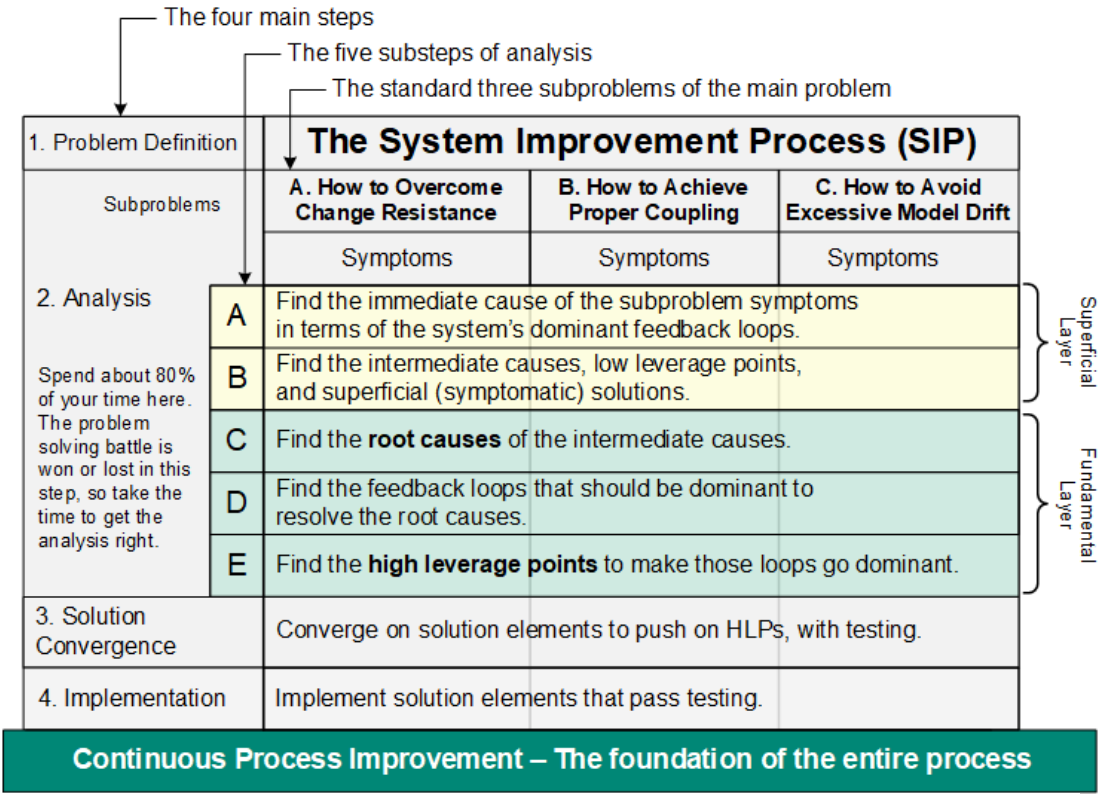

Fig. 3. The SIP matrix. Each subproblem employs a social force diagram and necessary models.

The matrix is *the* mental model of SIP. All work goes on inside a cell, so you always know where you are in the process and what to do next. SIP uses a step-by-step fill-in-the-blanks matrix, with one instruction per cell. A completed matrix contains one hypothesis and/or measurable result per cell.

SIP defines the problem in step 1. Step 2 decomposes the one big problem into carefully identified smaller and hence much easier to analyze subproblems. The three subproblems present in all difficult social problems are shown. Each subproblem is then analyzed using substeps A to E. Step 3 uses that information to converge on solution elements. Finally, step 4 implements those solution elements that have passed testing. The process is flexible and highly iterative. The four main steps work like this:

Step 1. Problem Definition – This defines the problem using a standard format: Move system A under constraints B from present state C to goal state D by deadline E with confidence level F. Moving from the present state to the goal state requires a mode change. SIP treats difficult social problems as social systems stuck in the wrong mode.

Step 2. Analysis – This step begins by decomposing the original problem into the three subproblems present in all difficult large-scale social problems, plus additional subproblems as needed. This decomposition can transform the original problem from insolvable to solvable, because you are no longer trying to simultaneously solve multiple subproblems and resolve multiple root causes without realizing it. During our research we found that without the right decomposition the sustainability problem was impossible to analyze.

A standard decomposition allows problem solvers to work more efficiently, by what we estimate is several orders of magnitude. Standard decompositions are the norm for mature RCA processes, such as the original four Ms of manufacturing: Materials, Methods, Machines, and Measurement (Ishikawa 1986, p. 19). The three standard subproblems are:

A. *How to overcome systemic change resistance.* Also called solution change resistance, lack of political will, inertia, defending the status quo, and barriers to action, systemic change resistance is the tendency for a system to resist particular solutions. The system dynamics literature (Sterman 2000, p. 5) uses the term "policy resistance", defined as "the tendency for interventions to be delayed, diluted, or defeated by the response of the system to the intervention itself." Change resistance is the most important subproblem to solve (in the short term) and must be solved first if possible.

B. *How to achieve proper coupling.* Proper coupling occurs when the behavior of one system affects the behavior of one or more other systems in a desirable manner, using the appropriate feedback loops, so the systems work together in harmony in accordance with design objectives. For example, if you never felt hungry you would starve to death. You would be improperly coupled to the world around you. In the environmental sustainability problem, the human system is improperly coupled to the greater system it lives within, the biosphere. Note how the definition of proper coupling immediately enforces a particular feedback loop pattern perspective. The original problem to solve is always a proper coupling problem. In the Autocratic Ruler Problem citizens were improperly coupled to their rulers. In the Recurring Wars in Europe problem a collection of states were improperly coupled to each other.

C. *How to avoid excessive solution model drift.* A solution is a model of understanding about how a system should respond when the solution is implemented. If the model is correct the solution works. Otherwise it fails. Excessive solution model drift occurs when a solution model works at first and then doesn't. The solution has drifted, due to change in the problem, change in how the solution is managed, etc. All social systems continually evolve, so solution model drift is the norm. To avoid excessive drift, solution managers must continually evolve solutions as the system evolves, or solutions must be self-evolving. This subproblem equates to the process control phase of industrial root cause analysis. After initial solution success, "…don't be too hasty to declare victory. The last battle has yet to be fought. The battle against creeping disorder, the battle against entropy. The battle to ensure the gains you made are permanent." (Pyzdek 2003, p. 649) In the long term this is the most important subproblem of them all, because if it's not solved a political system may eventually be overwhelmed by multiple problem recurrence.

These three subproblems are present in all difficult large-scale social problems: (A) High successful change resistance is present because prior solutions have failed. (B) The proper coupling subproblem is present because the original problem to solve is, we found, always best defined as one of improper coupling. (C) Excessive model drift is present because if it wasn't, the governance system would be able to solve the problem. Difficult social problems start small and gradually grow large. Solutions that worked when they were small, such as small manageable amounts of pollution, discrimination, and recession, no longer work when the problems grow large. The model drift subproblem reflects how difficult "Social problems are never solved. At best they are only re-solved—over and over again" (Rittel and Webber 1973).

Change resistance differs from lock-in in that change resistance is to particular solutions, as seen in the symptoms for subproblem A in Fig. 4. In mode lock-in, the feedback loop structure of the system locks the system into a particular mode of behavior, where certain agents behave in a similar manner and find it hard to behave otherwise. An undesirable mode creates a problem to solve, as seen in the symptoms for subproblems B, C, and D, and in the analysis model for subproblem A, which causes lock-in to systemic change resistance.

After problem decomposition each subproblem undergoes the five substeps of analysis. The substeps serve as a "cookbook" procedure for achieving a solid first iteration of the problem's essential causal structure in a standardized engineering manner.

As analysis proceeds a social force diagram and feedback loop model of the subproblem are constructed. A simulation model rather than a causal loop diagram is preferred, though the latter will suffice for simple subproblems. Model simulation allows rapid theoretical testing of the analysis via scenarios that would be slow, expensive, or impossible to test in the real world. For simulation modeling we recommend system dynamics due to its elegant simplicity, its emphasis on feedback loop structure, and its suitability for qualitative or quantitative modeling.

SIP utilizes a strong definition of root cause. A root cause is that portion of a system's feedback loop structure that, using the checklist below, explains why the system's structure produces a problem's symptoms. The checklist allows numerous unproductive root causes to be quickly eliminated. The five requirements of a root cause are:

1. It is clearly a (or the) major cause of the symptoms.
2. It has no worthwhile deeper cause. This halts the asking of "Why did this occur? What is its cause?" at an appropriate point.
3. It can be resolved, by pushing on its high leverage point(s) to initiate the desired mode change in complex problems, or to merely change the node with the root cause in simple problems. (Mode change versus node change)
4. Its resolution will not create other equal or bigger problems. Side effects must be considered.
5. There is no better root cause. All alternatives have been considered to the point of diminishing returns.

The requirements must be supported by a model of the essential causal structure of the problem with all important feedback loops clearly organized and named. For simple problems this can be a causal loop diagram. For complex problems a feedback loop simulation model is required.

Step 3. Solution Convergence – A high leverage point is a specific place in the causal structure of the problem to change (or "push on") to resolve its connected root cause. Pushing on the high leverage point with solution elements reduces the root cause force to an acceptable level or eliminates it altogether. A high leverage point description, such as "raise political truth literacy from low to high," summarizes a solution strategy that can be realized with one or more solution elements pushing on the high leverage point.

This step uses analysis results to rapidly converge on the few solution elements that could plausibly work. These become solution candidates and are then tested. Testing reduces the number of candidates to the selected few that will be implemented. Testing takes many forms, principally simulation model scenarios, laboratory studies, and real word studies such as pilot programs. This step ends when there is a high probability the selected solutions will work to initiate the desired mode change scenario.

As solution convergence proceeds the analysis is updated to reflect how pushing on high leverage points causes the system to behave. This way you always know why a solution *should* work, and eventually why a solution *does* work. If a solution doesn't work, the reason why is relatively easy to determine by inspection of the analysis and further iteration.

Step 4. Implementation – Here the most promising solutions become policy proposals and are implemented. Implementation tends to go smoothly, in an engineering-like manner with a minimum of surprise and solution adjustment, due to high predictability of how the system will respond. Any significant deficiencies in solution success cause iteration to step 2, analysis, where the analysis is first updated to reflect what was learned. The process then proceeds as before.

Underneath the four main steps lies continuous process improvement, the most important step of all. This step has taken SIP and the analysis, as well as countless other processes, to where they are today.

This completes description of SIP. Next, we examine the results of applying it.

5. SIP application results

5.1. Summary of Analysis Results

SIP was iteratively developed while applying it to the environmental sustainability problem. Fig. 4 summarizes analysis results.

The matrix of Fig. 3 was expanded in Fig. 4 to show key analysis results. The one big problem of environmental sustainability was decomposed into four smaller subproblems. The original problem is subproblem D. One additional subproblem beyond the three standard subproblems was found: subproblem B.

Summary of Analysis Results of Executing SIP on the Global Environmental Sustainability Problem

1. Problem Definition			How to achieve global environmental sustainability in terms of the desired system goal state				
2. Analysis	Subproblems		**A. How to Overcome Change Resistance**	**B. How to Achieve Life Form Proper Coupling**	**C. How to Avoid Excessive Model Drift**	**D. How to Achieve Environmental Proper Coupling**	
	A. Find immediate cause loops	Subproblem symptoms	Successful opposition to passing proposed laws for solving the environmental sustainability problem	Large for-profit corporations are dominating political decision making destructively	Inability to correct failing solutions (1) when they first start failing	The economic system is causing unsustainable environmental impact	Superficial Layer
		Improperly coupled systems	Not applicable	Corporate and human life forms	Not applicable	Economic and environment systems	
		Analysis model	Basic Dueling Loops of the Political Powerplace	Complete Dueling Loops model. This adds the Alignment Growth loop.		The World's Property Management System	
		Immediate cause dominant loops	The Race to the Bottom among Politicians		Intelligent Adaptation loop in evolutionary algorithm model	Industrial Growth and Limits to Growth (the IPAT factors)	
	B. Find inter. causes, LLPs, SSs	Intermediate causes	System acceptance of the fallacious paradigm that Economic Growth Is Good above all else	Strong resistance from corporate proxies to solving problems that corporations don't want to solve	Laws giving corporations advantages over people	Externalized costs of environmental impact	
		Low leverage points	More of the truth: identify it, promote it, magnify it	Logical and emotional appeals and bargaining	Citizens must directly reverse laws that favor corporations	Internalize costs	
		Symptomatic solutions	Technical research, environmental magazines and articles, awareness campaigns, marches, sit-ins, lawsuits, lobbying, etc.	Corporate social responsibility, green investment funds, NGO/corporate alliances, etc.	Media use, campaigns, lobbying to get bad laws repealed	Main solutions at system level are regulations and market-based. At agent level main solutions are 3 Rs and collective mgt.	
	C. Find the **root causes** of the intermediate causes		The inherent advantage of the Race to the Bottom, which causes that loop to be dominant most of the time (2)	Mutually exclusive goals between top two social life forms, *Corporatis profitis & Homo sapiens*	A high rate of defects in the political decision-making process	High transaction costs for managing common property sustainably	Fundamental Layer
	D. Find the loops that should be dominant to resolve root cause		You Can't Fool All of the People All of the Time	Alignment Growth	A Politician Decision-making Feedback loop of some kind	Sustainability Growth and Impact Reduction	
	E. Find the **high leverage points** to make those loops go dominant		Raise general ability to detect political deception (aka political truth literacy) from low to high.	Correctness of goals for artificial life forms. These must align with the goal of *Homo sapiens*.	Raise maturity of the political decision-making process from low to high.	Allow firms to appear to lower transaction costs for managing common property sustainably.	
3. Solution Convergence			Nine sample solution elements (3)	Corporation 2.0, *Corporatis publicus*	Politician Decision Ratings	Common Property Rights	
4. Implementation			No policy recommendations yet since process execution is incomplete.				

Fig. 4. Summary of Analysis Results. (1) to the environmental sustainability problem. (2) Also known as low political truth literacy. (3) One is Truth Literacy Training.

The results reported here should not be interpreted as *the* process, or *the* analysis, or *the* solution elements, but as a meticulously built, sufficiently correct first iteration demonstrating the potential of an RCA-based approach for truly difficult social problems. With this caveat in mind, the analysis matrix offers three major insights:

(1) The key insight, the one all the rest depend on, is that these four subproblems, or ones like them, in one stroke transform the sustainability problem from insolvable to solvable, because they allow radically more productive lines of analysis and solution strategies. This decomposition (and simultaneous development of the three subproblems found in all difficult social problems) consumed more analysis time than anything else.

(2) Superficial layer results reveal why the sustainability problem remains unsolved. Without realizing it, problem-solvers have been pushing on low leverage points with symptomatic solutions. All large-scale solution efforts fall into this pattern. For example, the SDGs, as well as earlier regimes like the Kyoto Protocol, are regulations and thus fit in symptomatic solutions for subproblem D. Misinformation correction, such as with fact checks and news/articles pointing out the truth, fits in with "more of the truth" symptomatic solutions for subproblem A.

(3) A pleasant surprise appeared when we uncovered the fundamental layer. If these or something like them are indeed the main root causes, then pushing on these high leverage points will lead to rapid solution of the sustainability problem due to transformational global mode changes for each of the four subproblems. Unlike the many solutions pushing on the low leverage points (where S < R), there are no large-scale solutions pushing on any of the high leverage points (where F > R is possible), suggesting that once problem solvers shift to RCA-based processes, the sustainability problem may be significantly easier and faster to solve than presently assumed.

The structure of the summary matrix, the way it summarizes the essential causal structure of the *complete* problem (meaning all four subproblems), the models supporting the matrix, and the above insights illustrate how SIP can provide the "knowledge structuring" Jerneck et al. (2011) argue is necessary for structuring sustainability science into a successful discipline.

SIP provides a particular kind of structure: a comprehensive framework for structuring both the work of RCA and the knowledge produced, so as to maximize their efficiency and effectiveness. The framework is so comprehensive it meets the five requirements of Abson et al. (2017). Starting with the premise that "the failure of sustainability science" is partly (we would say largely) due to failure "to engage with the root causes of unsustainability" and building on the high leverage point work of Donella Meadows (1999), Abson et al. "propose that a research agenda centered on the concept of [1] deep leverage points can provide [2] a coherent framework for engagement with [3] the root causes of unsustainability. A leverage points framework to conceptualize [4] transformation in social–ecological systems will enrich the multiple fields and disciplines that it needs to draw on. Most importantly, such a framework has tremendous potential to help [5] reveal key, hitherto under-explored avenues to sustainability."

We have attempted in this paper to demonstrate that an RCA-based method like SIP meets each of these requirements. The first three requirements are addressed by social force diagrams and the SIP matrices of Figs. 3 and 4. Requirement 4, transformation in social–ecological systems, is addressed by engineered mode changes. Requirement 5, revealing innovative solution strategies, is demonstrated by the high leverage points and sample solution elements found in Fig. 4, insight 3, and the next two sections. No other method we are aware of can meet these requirements.

Once the main root cause of all four subproblems was identified, the analysis snapped into a productive whole since the resultant structure explained a baffling pattern of system behavior, one that had us stuck for several years. This led to a fourth major insight.

5.2. The Broken Political System Problem

After peeling through layer after layer of the environmental sustainability problem, a striking pattern emerged. That problem was not the only large social problem society has been unable to solve. There are many more, as the 17 SDGs suggest. There are also many problems society *has* been able to solve. The pattern is that all of these problems would benefit the common good if solved, but yet some invisible force was causing one group of problems to be solved and the other not solved. Patterns this strong do not happen by chance. What could explain this phenomenon?

Further application of the process led to an answer (Fig. 5). The diagram explains why society has been unable to solve so many common good problems. The root cause forces of subproblems A, B, and C combine to form a deeper problem, the Broken Political System Problem. Its side effects are that all three pillars of sustainability are weak. Therefore, the Broken Political System Problem is the real problem to solve.

The ideals of democracy and its pursuit of the common good pervade the planet, even in China (Wang 2007). In theory the world's nations *should* be intently focused on solving the eight unsolved problems and mostly succeeding, but yet in practice they are not. Why is this?

The reason, of course, is the Broken Political System Problem. The problem is so systemic it causes extraordinarily high change resistance to solving any problem that runs counter to the goal of what has become the dominant life form (Beder 2006; Korten 2015)

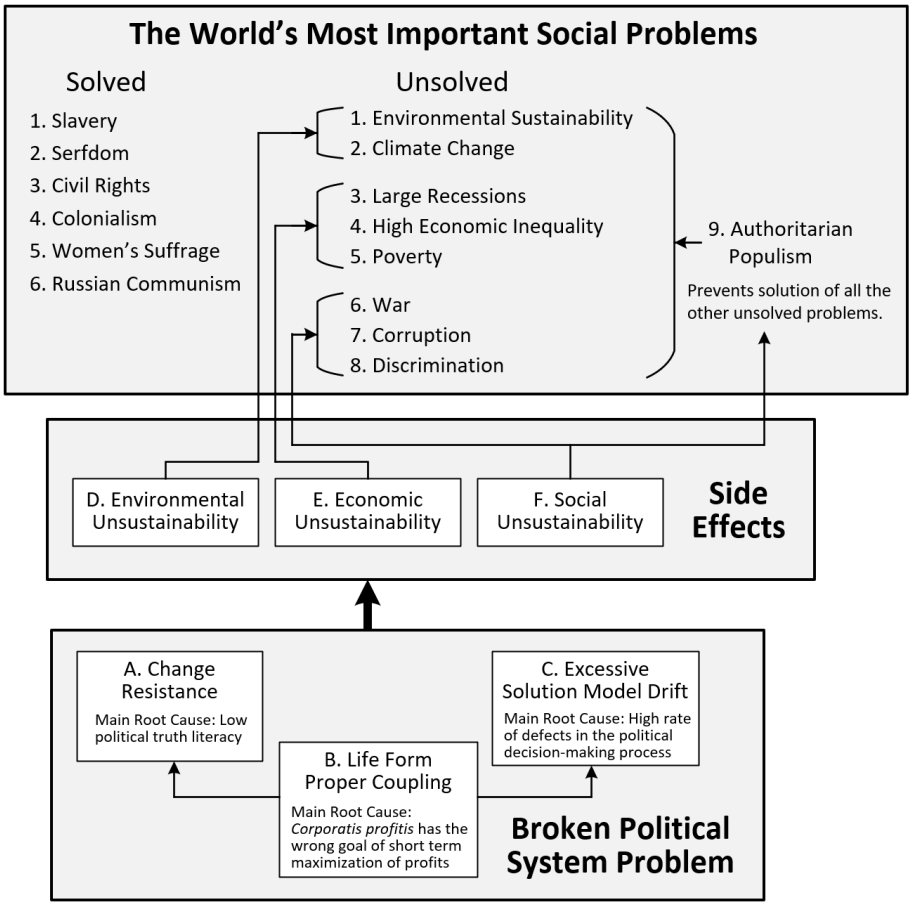

Fig. 5. High-level causal diagram of the Broken Political System Problem and its consequences. Subproblems E and F have been added to give all three pillars of sustainability. The lists of problems are not definitive.

in the human system, *Corporatis profitis*, better known as the large modern for-profit corporation. Like the way *Homo economicus* models the behavior of humans (a genetic species) as consistently rational, optimal agents in pursuit of self-interest and serves as a cornerstone component of economic theory (Ng and Tseng 2008), *Corporatis profitis* encapsulates the way large for-profit corporations (a memetic species) behave and serves as a key component of the analysis theory.

The main root cause of subproblem B is that *Corporatis profitis* has the wrong goal of short-term maximization of profits. That's why corporations are leading the charge against solving the environmental sustainability problem, though that effort is masked by clever deception (Beder 2002, 2006; Hoggan 2009). This works due to the main root cause of successful change resistance: low political truth literacy. (As identified in Fig. 4, subproblem A, analysis substep E.) Truth literacy is the ability to tell truth from deception, i.e. to be able to "read" the truth. Political truth literacy is the ability to vote correctly, given the level of truth of political statements.

Because political truth literacy is low, corporate deception works and has become the cornerstone strategy for achieving the interests of *Corporatis profitis*. The more acceptable term for corporate deception is public relations (PR), which works like this: (Dinan and Miller 2007, pp. 11 & 12)

> Public relations was created to thwart and subvert democratic decision making. It was a means for 'taking the risk' out of democracy. The risk was to the vested interests of those who owned and controlled society before the introduction of voting rights for all adults. Modern PR was founded for this purpose and continues to be at the cutting edge of campaigns to ensure that liberal democratic societies do not respond to the will of the people and that vested interests prevail. PR functions, in other words, as a key element of propaganda managed democracy. … [PR] is overwhelmingly carried out for vested powerful interests, mainly corporations. … It characteristically involves deception and manipulation.

As numerous scholars have phrased it, "democracy is broken", e.g. (Lukensmeyer and Brigham 2002; Panagopoulos and Weinschenk 2016; Freeman 2017; Norris and Inglehart 2019). The analysis explains why. Instead of working for the common good, too many political systems are working for the uncommon good of large for-profit corporations.[2] *Corporatis profitis* is dead set against solving the environmental sustainability problem and is winning, because of its overwhelming control of the human system, superior financial power compared to mere citizens, and its obsessive goal of short-term profit maximization. This goal conflicts with the goal of *Homo sapiens*, which is the long-term optimization of quality of life for people. Because *Corporatis profitis* dominates the system its goal prevails and has become the implicit goal of the system. This causes high systemic change resistance to solving problems whose solution would

[2] As well as authoritarian leaders, a resurgent trend. For simplicity the analysis treats the populist rhetoric component of authoritarian populism as a deception strategy whose immediate root cause, in terms of subproblem A, is low political truth literacy. A more complex analysis would add a subproblem whose symptom is excessive authoritarian populism. This would be a companion subproblem for subproblem B and a further cause of subproblems A and C.

reduce short term profits. The result is the eight unsolved problems of Fig. 5 and more. The ninth unsolved problem, authoritarian populism, is a deception strategy blending authoritarian values with populist rhetoric to create a cult of fear, driving citizens into supporting only what an authoritarian leader wants, even if this requires sacrificing personal freedom (Norris and Inglehart 2019).

While it took time and some struggle, the reason the six problems on the left of Fig. 5 were solved was low change resistance. Solving these problems did not pose much of a threat to *Corporatis profitis*.

However, trying to solve the deepest root cause of the Broken Political System Problem *would* pose a threat, since *Corporatis profits* would mightily resist changing its goal. We thus propose solving subproblem A (How to overcome change resistance) first. This aligns with a prior work on the environmental sustainability problem (Harich 2010), which concluded that "systemic change resistance is the crux of the problem and must be solved first."

5.3. Testing a high leverage point with an empirical study

The SIP analysis found the main root cause of successful change resistance to solving common good problems was low political truth literacy. The high leverage point for resolving the root cause is *raise political truth literacy from low to high*.

To test how easily this might be accomplished, an online study using a Prolific panel and custom-built software was run on the effects of Truth Literacy Training. This trains voters on how to tell truth from deception, so they can make sound voting decisions. 93 US subjects (age range 22 to 51, average age 31, 49% male) were randomly assigned to three groups. Group 1 received training on a neutral topic. Group 2 received training on how to tell if a political claim (embedded in a political statement) was true or false, by spotting the pattern of fallacy or non-fallacy used. Group 3 received the same training as group 2 plus training on how to vote correctly (given the perceived level of truth of a claim) by applying two rules: Reward the Truth Teller and Penalize the Deceiver.

The claims were embedded in non-hot, typical but fictional statements averaging 124 words. 13 out of 17 statements were deceptive and employed seven fallacies we found common in political appeals: cherry picking, flawed application of the Strong Evidence Rule, ad hominem attack, appeal to emotion, strawman, false dilemma, and false fact lie.

Statements were presented in random order. Each statement was followed by three questions: the *truth question* (How true to you feel that claim is?), the *probe question* (What is the main reason for your decision in the above question?), and finally the *vote question* (If the election were held today and this was all the information you had, how much impact would what the politician claimed have on your decision to vote for or against the politician?).

The main training strategy is high-speed pattern recognition, by spotting patterns of non-fallacies (truth) or fallacies (deception). This approach can nullify the deceptive power of motivated reasoning, a well-established theory explaining how political decision-making works. "In short, citizens are often partisan in their political information processing, motivated more by their desire to maintain prior beliefs and feelings than by

their desire to make 'accurate' or otherwise optimal decisions." (Lodge and Taber 2013, p. 149) When a prior belief is false (such as non-whites are inferior or climate change denial), deception has occurred and partisan reasoning will be erroneous.

The premise of motivated reasoning theory is that all reasoning is motivated to achieve either accuracy goals (slow thinking) or partisan (directional, fast thinking) goals. With enough training and experience in how to "read" the truth by pattern recognition (claim training), and how to use that knowledge to act correctly (vote training), sufficiently correct accuracy reasoning can approach the speed of partisan reasoning and replace it, thereby becoming *the reasoning default* when important new political arguments or facts are encountered, or old ones need review.

Truth Literacy Training employs the preemptive aspect of inoculation theory. Innovating by training on logic pattern recognition instead of misinformation correction (such as fact-checks and news pointing out the truth), as we have done, Cook et al. (2017) found that inoculating subjects by training on spotting false balance and fake expert strategies "neutralized" the negative influence of misinformation on perceived scientific consensus on climate change. Our approach necessarily goes one step further by introducing vote training and improves training effectiveness by adding a catalog of common fallacies and The Personal Truth Test, a short procedure for determining the truth of an argument by use of pattern recognition.[3]

Study results (Harich et al. 2020) for deceptive statements are summarized in Fig. 6. *Logical truth quotient* (LTQ) is the ability to *logically* tell if a deceptive claim is true or false, and was measured by the percent correct for the truth questions for deceptive statements. *Democratic truth quotient* (DTQ) is the ability to *vote* correctly given a deceptive statement made by a politician, and was measured by the percent correct for the vote questions for deceptive statements. DTQ measures political truth literacy, while LTQ measures only logical truth literacy.

LTQ is naturally low, at 8% for group 1. Voters not trained in truth literacy can spot a fallacy in a deceptive political statement an average of only 8% of the time. DTQ is also naturally low, at 2% for group 1.

DTQ for group 2 was 6%, a deeply counterintuitive discovery. We expected it to be low, but not that low. The 6% means that even if voters have been trained on how to tell if a deceptive claim made by a politician is true or false, they are unable to correctly translate that knowledge into how to vote correctly. Group 2, which received claim training but not vote training, averaged spotting deception 77% of the time, but could translate that knowledge into voting correctly only 6% of the time. The claim training made almost no difference on voting correctly. This is why the vote training of group 3 is required.

Because political truth literacy is naturally low, voters are easily fooled into voting for politicians who do not work for the common good, but instead work for the uncommon good of powerful special interests (mainly large for-profit corporations and their owners, the rich) or the politicians themselves. The latter includes the current rise of authoritarian

[3] For access to taking the Truth Literacy Training online so that you can examine its complex interactive design, components, and extensive wording, please contact the authors.

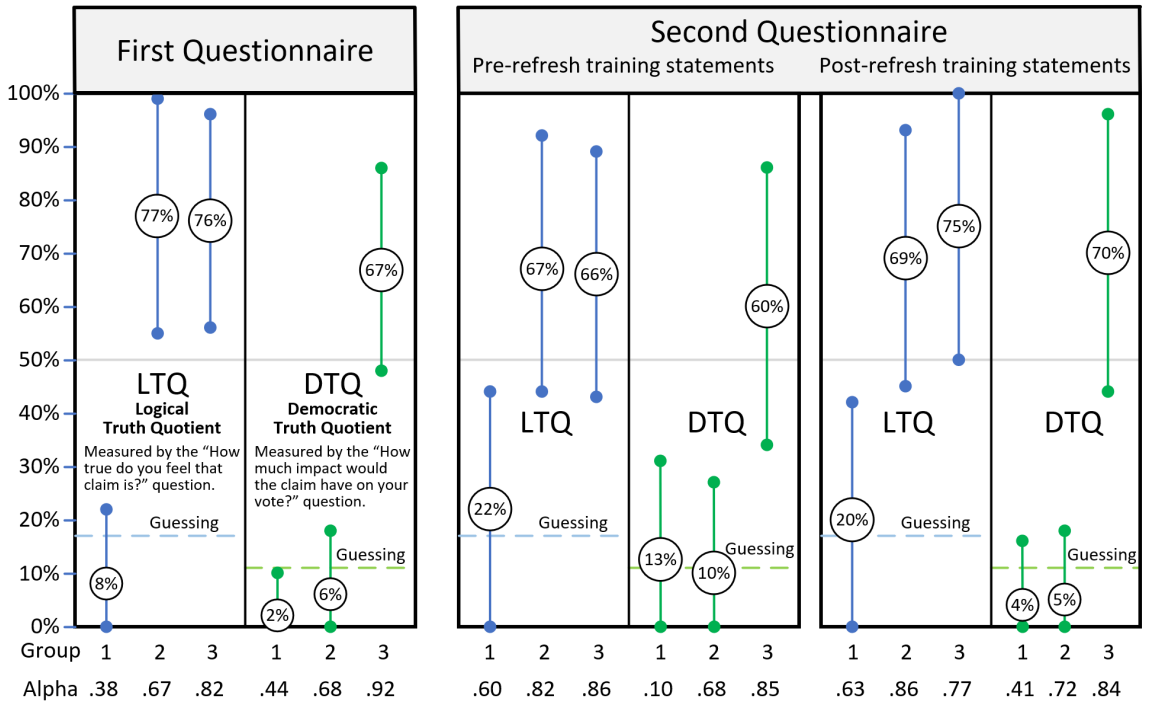

Fig. 6. Average scores and 95% confidence intervals for answers to deceptive statements. Guessing levels and Cronbach's alpha are shown. Treatment groups were:
1 – Trained on neutral topic
2 – Trained on claims
3 – Trained on claims and vote

populists, like Putin, Trump, Erdogan in Turkey, Bolsonaro in Brazil, and Modi in India, a "terrifying" trend with widespread popular support and destructive consequences for environmentalism (McCarthy 2019). Democracies worldwide are in crisis, have entered the age of post-truth politics, and are highly vulnerable to authoritarian takeover due to the deceptive power of fake news and alternative facts, the ease of falsehood transmission and targeting allowed by the internet and social media, and the decline of traditional gate-keepers of the truth (Farkas and Schou 2020). The chief mechanism is mass deception: "The transition from democracy to personality cult [authoritarianism] begins with a leader who is willing to lie all the time [using populist appeals], in order to discredit the truth as such. The transition is complete when people can no longer distinguish between truth and feeling" (Synder 2018).

The key data is DTQ for groups 1 and 3. The large increase, from 2% to 67%, a 65-point rise, suggests the solution element may be capable of resolving much of the root cause of change resistance: low political truth literacy. Group 3 training took only about one hour, indicating that Truth Literacy Training, such as in education systems and online training, will not require that much of a person's time.

A follow up study 26 days later using different statements found DTQ for group 3 had declined from 67% to 60%, a 7-point fall. After an average of 30 minutes of refresh training, DTQ for group 3 rose to 70%, indicating regular refresh training of some type will be required, or that, like reading and writing literacy, once truth literacy matures, becomes the reasoning default, and is exercised often enough, little decline occurs.

However, LTQ for group 1 was 22% and 20% for the pre-refresh and post-refresh training statements, versus 8% for the first questionnaire. This indicates spotting deception was substantially easier in the second questionnaire statements, and suggests there was more than the 7-point decline noted above and that the refresh training may not have worked as well as the 70% indicated. The second questionnaire statements were developed after the first questionnaire was run. Without realizing it, we structured them slightly differently and frequently omitted stating how strongly supported the premises were. This caused the second set to be substantially easier than the first set, as it made fallacies easier to spot. This problem is easily corrected, especially since probe question answers can be mined for clues on how the erroneous thinking occurred.

6. Conclusions

This paper addressed the transdisciplinary question of how the business/engineering tool of root cause analysis (RCA) can be adapted to solve difficult social problems, especially environmental sustainability. Given the method and results presented here and how well RCA has worked in industry for over a century, we offer these conclusions. All suggest opportunities for further research.

Our first and most important conclusion is that RCA can be successfully adapted to solve difficult social problems, including environmental sustainability, by thoughtful application of any RCA-based process that uses the components of essential causal structure, the equivalent of social force diagrams, problem decomposition, and a strong definition of root cause, if the process is continuously improved until process maturity becomes high enough to solve the problem to the desired level of quality. This allows social engineers to implement one of the maxims of industry: "The right process will produce the right results" (Liker 2004, pp. 85–168). SIP can serve as a seed process, as a time-saving starting point for this adaptation.[4]

Second, the SIP analysis found the Broken Political System Problem is the real problem to solve, not its side effects, one of which is environmental unsustainability.

Third, the analysis explains why popular solutions for solving the environmental sustainability problem have largely failed. All are superficial/symptomatic solutions like those listed in Fig. 4 and thus attempt, in vain, to resolve the easy to find intermediate (proximate) causes rather than the much harder to find root causes. Further efforts should be directed elsewhere, toward solutions designed to resolve specific root causes.

Fourth, the analysis found that unlike the many solutions pushing on the low leverage points, there are no large-scale solutions pushing on any of the high leverage points. This suggests that once problem solvers shift to RCA-based processes, the sustainability problem may be significantly easier and faster to solve than presently assumed, and is solvable rather than insolvable. This is especially relevant to the climate change crisis, where we are running out of time on avoidance of ecological tipping points.

[4] For full description of SIP, application results, simulation models, and sample solutions elements, please see the book "Cutting Through Complexity" at Thwink.org. This is written for a general rather than a scholarly audience.

Fifth, the Truth Literacy Training study found political truth literacy is naturally low. This crucial finding empirically explains, at the root cause level, why change resistance to solving common good problems, including environmental sustainability, is so stubbornly high and successful. As long as a democratic electorate's political truth literacy is low, that democracy is unsustainable. It is vulnerable to dangerous cults, fringe groups, conspiracy theories, and falsehoods like climate change denial, anti-environmentalism, and white supremacy, and is ripe for takeover by deceptive politicians of all kinds, including authoritarian populists.

Sixth, study results suggest a relatively straightforward way to raise a population's political truth literacy from low to high. Doing so can potentially resolve much of the main root cause of change resistance and thereby rapidly lead to solution of much of the sustainability problem, depending on how well study results generalize to real voters and elections. Further investigation can include additional solution elements for pushing on the high leverage point.

Finally, given the first conclusion and the widespread foundational role RCA has achieved in industry, we see no reason why the emerging field of sustainability science cannot do the same, and adopt RCA as one of its foundational tools.

Soon, we expect, sustainability science will have more than "a room of its own" (Clark 2007). It will have a seat at the table with the other engineering sciences.

History is about to repeat itself. Switching to RCA-based processes will precipitate a long overdue paradigm shift in social problem-solving methods, solution strategies, and curriculums, and will repeat the same fundamental change industry underwent generations ago when, beginning in post WWII Japan, the RCA-based quality revolution swept the business world. Gabor (1990, p. 286) [5] describes that transformation and ends his story with this prophetic passage: "…as Deming's principles [of quality management] are embraced by pioneers in government and education in the 1990s, they could give the United States [and anyone who adopted 'a new belief system that executives and workers of all industries could share'] powerful new tools for tackling the country's *most pressing social problems*."

Acknowledgments

The authors thank Fariborz Zelli and Randy Stanczyk for reviewing manuscript drafts. (Additional thanks to be added after acceptance.)

References

Abson DJ, Fischer J, Leventon J, et al (2017) Leverage points for sustainability transformation. Ambio 46:30–39. https://doi.org/10.1007/s13280-016-0800-y

Andersen B, Fagerhaug T (2006) Root Cause Analysis: Simplified Tools and

[5] Nowhere in the book (or most of the quality literature) will you find "root cause" or "root cause analysis." The concept is so basic it's taken as a given. The term "cause" is used instead. For example, see p47 where common and special causes are discussed in the context of control charts, graphs for monitoring the effects over time of what we call root causes. In a "stable process" the root causes ("common causes") are under control, which we call resolved.

Techniques, Second Edition. ASQ Quality Press
Beder S (2006) Suiting Themselves: How Corporations Drive the Global Agenda. Earthscan
Beder S (2002) Global Spin: The Corporate Assault on Environmentalism, Revised Edition. Chelsea Green
Biermann F, Kanie N, Kim RE (2017) Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. Curr Opin Environ Sustain 26–27:26–31. https://doi.org/10.1016/j.cosust.2017.01.010
Burch S, Gupta A, Inoue CYAA, et al (2019) New directions in earth system governance research. Earth Syst Gov 1:100006. https://doi.org/10.1016/j.esg.2019.100006
Carson R (1962) Silent Spring. Houghton Mifflin Company
Clark WC (2007) Sustainability science: A room of its own. Proc Natl Acad Sci U S A 104:1737–1738. https://doi.org/10.1073/pnas.0611291104
Cook J, Lewandowsky S, Ecker UKH (2017) Neutralizing misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence. PLoS One 12:1–21. https://doi.org/10.1371/journal.pone.0175799
Costanza R, Cumberland J, Daly H, et al (1997) An Introduction to Ecological Economics. St. Lucie Press
Costanza R, Leemans R, Boumans R, Gaddis E (2007) Integrated Global Models. In: Sustainability or Collapse: An Integrated History and future Of People on Earth. p 417
Daly H, Farley J (1997) Ecological Economics, Second. Island Press
Dew J (2003) The Seven Deadly Sins of Quality Management. Qual Prog 36:59–65. https://doi.org/10.1309/lmn5ej2caruo0unt
Dinan W, Miller D (2007) Thinker, Faker, Spinner, Spy: Corporate PR and the Assault on Democracy. Pluto Press
Farkas J, Schou J (2020) Post-Truth, Fake News, and Democracy. Taylor & Francis
Folke C, Carpenter SR, Walker B, et al (2010) Resilience thinking: Integrating resilience, adaptability and transformability. Ecol Soc 15:. https://doi.org/10.5751/ES-03610-150420
Forrester JW (1969) Urban Dynamics. The M.I.T. Press
Forrester JW (1971) World Dynamics. Wright-Allen Press
Freeman B (2017) Democracy Rising: Politics and Participation in Canada. Dundurn Press
Gabor A (1990) The Man Who Invented Quality: How W. Edwards Deming Brought the Quality Revolution to America. Penguin Books
George M, Rowlands D, Price M, Maxey J (2005) The Lean Six Sigma Pocket Toolbook. McGraw Hill
Gooyert V, Rouwette E, Kranenburt H, et al (2016) Sustainability transition dynamics; Towards overcoming policy resistance. Technol Forecast Soc Change 111:
Hardin G (1968) The Tragedy of the Commons. Science (80-) 162:1243–1248
Harich J (2010) Change resistance as the crux of the environmental sustainability problem. Syst Dyn Rev 26:35–72. https://doi.org/10.1002/sdr
Harich J, Rosas MK, Hoefer M (2020) Truth Literacy Training: Analyzed data. http://dx.doi.org/10.17632/nfbp7fnjwh.2
Hoggan J (2009) Climate Cover-Up: The Crusade to Deny Global Warming. Greystone Books
Hornborg A, Crumley C (2006) The World System and the Earth System: global socioenvironmental change and sustainability since the Neolithic. Left Coast Press, Walnut Creek
Howes M, Wortley L, Potts R, et al (2017) Environmental sustainability: A case of

policy implementation failure? Sustain 9:1–17. https://doi.org/10.3390/su9020165
Ishikawa K (1986) Guide to Quality Control, 2nd revised edition, edited for clarity. Asian Productivity Organization
Jerneck A, Olsson L, Ness B, et al (2011) Structuring sustainability science. Sustain Sci 6:69–82. https://doi.org/10.1007/s11625-010-0117-x
Kates RW, Clark WC, Corell R, et al (2001) Sustainabilty Science. Science 292:641–642. https://doi.org/10.1126/science.1059386
Korten D (2015) When Corporations Rule the World - Third Edition. Berrett-Koehler Publishers
Liker J (2004) The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw Hill
Lodge M, Taber C (2013) The Rationalizing Voter. Cambridge University Press
Lukensmeyer C, Brigham S (2002) Taking Democracy to Scale:Creating a Town Hall Meetingfor the Twenty-First Century. Natl Civ Rev 91:
Markard J, Raven R, Truffer B (2012) Sustainability transitions: An emerging field of research and its prospects. Res Policy 41:955–967. https://doi.org/10.1016/j.respol.2012.02.013
Marx M (2007) Six Sigma Saves a Fortune. Six Sigma Mag. 3
McCarthy J (2019) Authoritarianism, Populism, and the Environment: Comparative Experiences, Insights, and Perspectives. Ann Am Assoc Geogr 109:301–313. https://doi.org/10.1080/24694452.2018.1554393
Meadows D (1999) Leverage Points: Places to Intervene in a System. In: Sustain. Inst. http://www.donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/. Accessed 10 Feb 2016
Meadows D (2008) Thinking in Systems: A Primer. Chelsea Green
Meadows D, Meadows D, Randers J, Behrens W (1972) The Limits to Growth. Universe Books
Miller TR, Wiek A, Sarewitz D, et al (2014) The future of sustainability science: A solutions-oriented research agenda. Sustain Sci 9:239–246. https://doi.org/10.1007/s11625-013-0224-6
NASA Safety Center (2013) NASA Root Cause Analysis Tool. http://nsc.nasa.gov/RCAT/. Accessed 16 Feb 2016
Newman J, Head BW (2017) Wicked tendencies in policy problems: Rethinking the distinction between social and technical problems. Policy Soc 36:414–429. https://doi.org/10.1080/14494035.2017.1361635
Ng I, Tseng L-M (2008) Learning to be Sociable: The Evolution of Homo Economicus. Am J Econ Sociol
Norris P, Inglehart R (2019) Cultural Backlash: Trump, Brexit, and the Rise of Authoritarian Populism. Cambridge University Press
Ohno T (1988) Toyota Production System: Beyond Large-Scale Production. Productivity Press
Okes D (2019) Root Cause Analysis: The Corre of Problem Solving and Corrective Action. ASQ Quality Press
Panagopoulos C, Weinschenk A (2016) A Citizen's Guide to U. S. Election: Empowering Democracy in America. Taylor & Francis
Pyzdek T (2003) The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels. McGraw Hill
Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4:155–169. https://doi.org/10.1007/BF01405730
Sterman J (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw Hill, Boston
Synder T (2018) The Cowardly Face of Authoritarianism. New York Times

Tague N (2005) The Quality Toolbox. Quality Press
Takeuchi K, Komiyama H (2006) Sustainability science: building a new discipline. Sustain Sci 1:1–6. https://doi.org/10.1007/s11625-006-0007-4
Tummala VMR, Tang CL (1996) Strategic quality management, Malcolm Baldrige and European quality awards and ISO 9000 certification: Core concepts and comparative analysis. Int J Qual Reliab Manag 13:8–38. https://doi.org/10.1108/02656719610114371
van Vuuren DP, Kok MTJ, Girod B, et al (2012) Scenarios in Global Environmental Assessments: Key characteristics and lessons for future use. Glob Environ Chang 22:884–895. https://doi.org/10.1016/j.gloenvcha.2012.06.001
Womack J, Jones D, Roos D (1990) The Machine that Changed the World: The Story of Lean Production. Harper Perennial
World-Commission (1987) Our Common Future (The Brundtland Report). Oxford University Press