Engaging communities to make resilience an operational concept

Carolyn Stwertka[1], Steve Peterson[1], Emma Cutler[1], Mary Albert[1], Kathleen White[2]

[1]Thayer School of Engineering, Dartmouth, Hanover, N.H. 03755 USA
[2]Institute for Water Resources, U.S. Army Corps of Engineers, Washington, D.C., USA

Abstract

Impacts due to climate change are increasing and continue to damage communities in the United States. The private and public sectors have proposed improving the resilience of communities as a solution to minimize these damages. Although multiple definitions of community resilience exist, there is not yet consensus on how to measure or operationalize it. Through comprehensive literature synthesis, we propose that resilience is built from community engagement in work motivated by climate disturbances and from knowledge gained from project experience. We present a dynamic model to investigate the interactions between people, projects created by climate disturbances, and community capital. With this model, we simulate building community resilience to a climate disturbance such as heavy precipitation and drought. We examine resilience when there is an internal community leader, opposition within the community, and an external response to mitigate the damages. We find that internal engagement to complete projects allows the community to respond faster to additional disturbances or disturbance-created projects. We propose that this impact-to-implementation time is a key component of an operational understanding of resiliency. We further use the dynamic model to identify key policy levers that may proactively close the planning to implementation gap before climate disturbances strike.

1. Introduction

Every year, hundreds of communities in the United States suffer the casualties, damages, and disruptions inflicted by extreme events [1-4]. Recoveries may span from months to years, with some community recovery projects never completed [1]. Collectively, the annual total of local and regional losses imposes a growing significant economic, environmental, and social toll on the nation [1-4]. The private and public sectors within the United States have proposed the concept of resilient communities as the solution to minimize these damages [5-8]. The existing literature does not appear to have converged on a definition of resilience [3, 4, 9-14], including defining resilience attributes [11, 15]; consistent factors or standard metrics to evaluate community resilience [4, 16-18]; or frameworks for resilience and community engagement [1, 4, 12, 15, 17, 19-26].

The literature on defining the concept of *resilience* spans ecological [13, 27], engineering [12, 14], and social sciences [10, 15, 28]. The concept of community resilience in terms of climate change is relatively new [4]. In all definitions, resilience is generally defined in terms of a system's response to an external disturbance. For example, Cimellaro, Reinhorn [12] propose that resilience has four dimensions: rapidity, robustness, redundancy, and resourcefulness. The resilient attributes that lead to these dimensions have been proposed as: human capital, economic capital, social capital, and political capital [4, 15]. However, Lundberg and Johansson [14] argue that these concepts of resilience involve contradictory definitions. Their response is to define a model with six functions: anticipation, monitoring, response, recovery, learning, and self-monitoring, within four areas: event-based constraints, functional dependencies, adaptive capacity, and strategy [14].

A recent National Academy of Sciences study argues that the focus should be shifted away from defining resilience, and instead operationalizing the definition [4]. The proposed solution is to define measurement techniques for community resilience [4, 16, 17]. Quantitative means of assessing resilience are required to demonstrate improvements or to compare the benefits of increased resilience with the associated costs [4]. Challenges remain in developing consistent factors or standard metrics for measuring resilience [16, 17] and dealing with nonlinearity in resilience building or response.

2. Approaches to community resilience frameworks

A small, but growing number of operational guidelines for building community resilience exist and build on academic literature and field experience documented in the grey literature [1, 29-32]. They follow a similar set of principles that start by identifying an internal community leader to help define issues, and to develop, implement, and monitor a plan. Defining the assessment measures during the planning process allows planners to agree on community-specific metrics for success, and guidelines for monitoring future development.

Several high-profile community resilience-building efforts (e.g. 100 Resilient Cities [33] and HUD's Resilience competition [8]) have used community-based operational approaches [7, 26]. They have demonstrated capacity for success, although it is too early to measure long-term growth. The potential for success points to the need to understand the causal relationships that underpin community engagement, climate impacts, and community capital. The academic literature lacks consensus with regards to defining and measuring *resilience*, yet the public and private sectors are moving forward with initiatives such as the Rockefeller Foundation's 100 Resilient cities [33] and the US Department of Housing and Urban Development's Disaster Resilience competition [8].

The modeling approach presented in this research article complements existing approaches to operationalize resilience. It builds from the research developed by C. Stwertka [34], who define the critical systems elements that, when operating together, can build a resilient community and reduce the federal fiscal exposure to climate change. This modeling study aims to gain insight into the evolution of community engagement drivers and system dynamics that can build community resilience in the context of climate-induced events.

3. Tipping Points of a rEsilient Community (TPEC)

The Tipping Points of a rEsilient Community (TPEC) model presented here is a system dynamics (SD) simulation model that represents key social and climate drivers of community resilience and their interactions over time. TPEC represents the dynamic interrelationships among the critical systems identified in C. Stwertka [34]. These elements are: a community catalyst, a common community vision, an engaged government, and existing enabling resources. The model enables exploration of different community engagement and opposition scenarios in response to climate disturbances. The TPEC model was created using the STELLA Version 10.0.6 software package (ISEE Systems, Lebanon, NH). It uses a stock-and-flow structure with information feedbacks processes that support the dynamic movement of the key quantities over time. TPEC provides a modeling setting that may address some of the limitations of current resiliency frameworks and improve operational insights by investigating possible policy levers and their outcomes.

4. TPEC model architecture

Model basics

The TPEC model is adapted from a Bass diffusion framework. Bass diffusion models are widely used models in marketing, strategy, and management of technology [35]. The Bass diffusion model describes the adoption of new product innovations into the market [36]. In the Bass diffusion model, the adoption rate of potential adopters depends on advertising, market saturation, and word of mouth. In the TPEC model, the adoption rate translates into the state variable of the community engagement rate. In this application, the community engagement rate depends on community capital and recent successful work completed from climate disturbances (Figure 7). Building community resilience in the TPEC model thus comes from three separate components: people in the community, work generated from climate disturbances, and community capital (Figure 1). Each of these three components and their information feedbacks will be briefly discussed below.

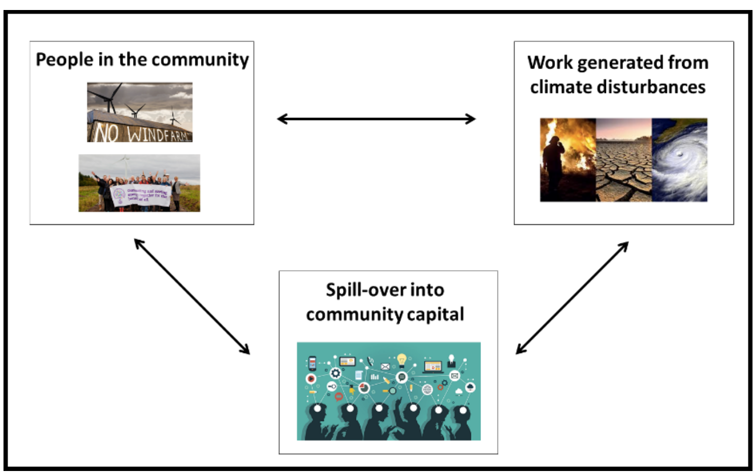

Figure 1. The model describes community resilience as the dynamic interaction between people in the community, how the community supports work generated from climate disturbances, and any spill-over into community capital (Figure 1).

People in the community

An extensive literature review found that community engagement surrounding climate issues has very complex and polarizing psychological responses [37-40]. To encompass this distribution of people discussed in the literature, the TPEC model takes a four-stock approach to represent the community, as opposed to the two-stock approach of a classic Bass diffusion model. The four stocks of people in the TPEC model are: Opposed, Indifferent, Considering, and Engaged (Figure 2). Stocks of people can change over time depending on different rates of flow. These flows are controlled by information flows and feedbacks depicted in Figure 3.

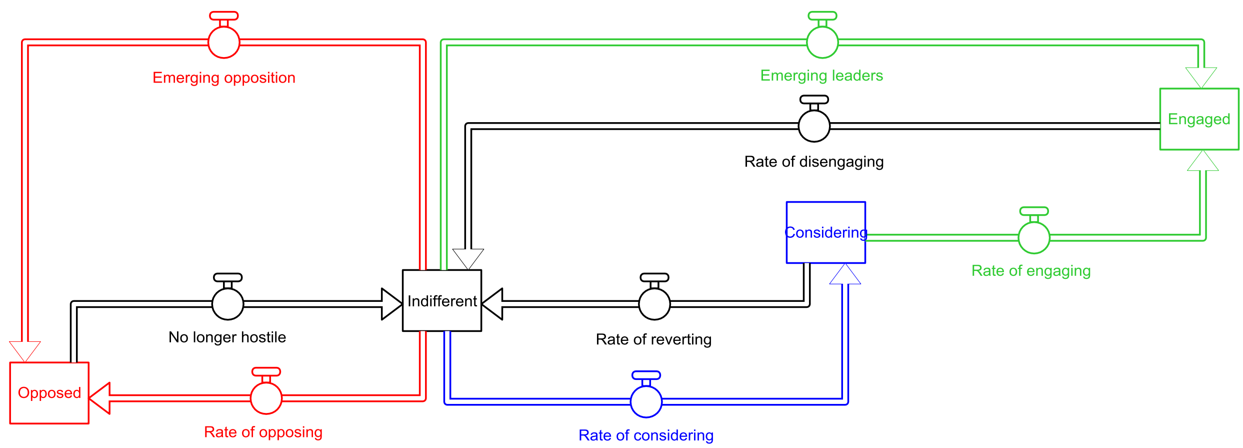

Figure 2. Community engagement chain. People in a community are distributed into four stocks: opposed, indifferent, considering, and engaged. Stocks can change over time depending on the flows between the stocks.

The community engagement pathway describes the flow in which community members can engage or dis-engage from actions (Figure 3). The drivers and barriers of the community engagement are based on the literature [15, 28, 38, 40]. They are represented in the TPEC model by information flows and feedbacks. From the perspective of resiliency, it is desirable for people to become and then stay engaged. This involves the systems components of a community catalyst and a common vision [34], but alone, these components cannot build a resilient community. Learning by hands-on work done [41, 42], which builds social capital [4, 15], is necessary, but can be limited by lack of enabling resources and an engaged government [34].

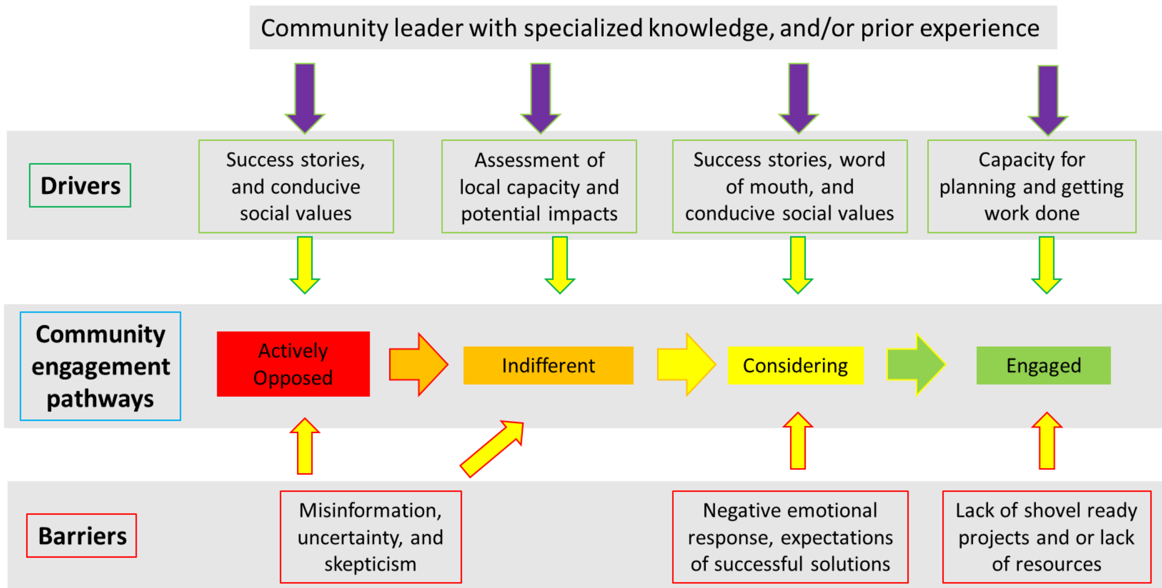

Figure 3. Community engagement adaptation pathways. People generally start out as indifferent, but can move to oppose, consider, or be engaged based on the drivers and barriers depicted here. A community leader becomes engaged based on perceived need for getting work done. This perceived need is generated by specialized knowledge and/or prior experience. Not shown are movements towards the left.

Supply chain of work from climate disturbances

Climate disturbances (such as intense precipitation that results in flooding, chronic or "sunny day" flooding due to changing sea levels, droughts, wildfire, and ecosystem degradation resulting from all of these) generate work, ideally as preparedness but more often in response (Figure 4). Work generated from climate disturbances is split into three stocks: unsupported projects, shovel-ready projects supported by the community, and recent successes. Work from climate disturbances motivates an internally-initiated response or an externally-initiated response, or both. Internal, community-initiated projects are any projects that a community member initiates, whether they are recovery activities, a community-led wind farm to diversify the economy as a drought response, or a new flood risk reduction measure. Externally-initiated projects are any projects that are initiated external to the community that concern the community, such as a developer-owned wind farm or federally driven infrastructure projects.

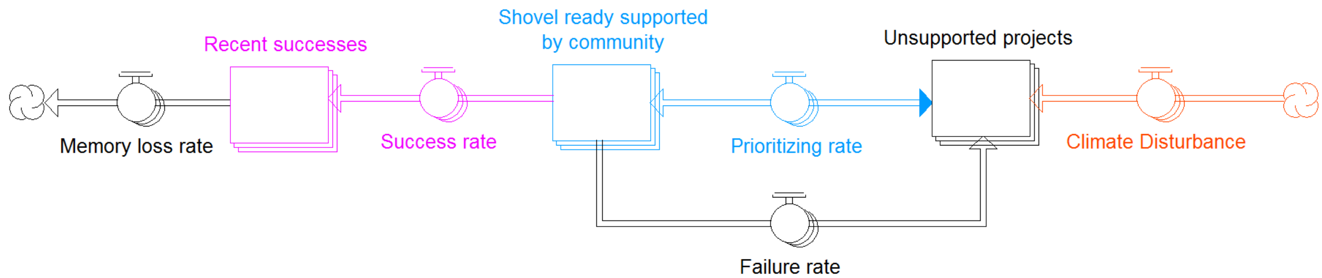

Figure 4. Supply chain of work from climate disturbances.

Shovel ready projects that are supported by the community are those projects – either internally- or externally-initiated – that the community supports, e.g., the community supported vision identified by [34]. Projects gain support through community or external leadership prioritizing of projects and by assessing and building on the community's memory stock of recent successes. This feedback loop is derived from the behavioral economics and psychology of climate communication literature [15, 38, 42, 43]. TPEC assumes that the stock of recent successes decreases over time as often seen in behavioral economic concepts [42]. The success or failure rate of these projects depends on the distribution of engaged or opposed community members, and the social capital that has been built up in the community. This feedback is derived from literature, but most clearly represented by the adoption or rejection of wind farms. The literature has highlighted that externally-driven wind farms are much more probable to fail then internally driven wind farms [44-47]. We use this work supply chain to study how community engagement can build resilience.

Social capital and community knowledge/learning

The stock of Community Project Experience grows by gaining experience within the community (Figure 5). Community project experience increases the community capital. The progress ratio [48, 49] determines the rate that doublings in community project experience translate into increases in community capital. The higher the progress ratio, the harder it is for the community to respond. This would be the case in a socially vulnerable community. The community capital drives the success and failure rate, and the rates of individuals opposing or considering engaging.

Learning is an integral component to any system, and is especially integral in resilient systems [14]. A review of case studies indicates that resilient communities learn from previous mistakes, thus increasing future resilience [31, 50]. In the TPEC model, the community will gain knowledge if projects involve the community regardless of whether projects fail or succeed. If all projects are completed externally, the community project experience will become obsolete.

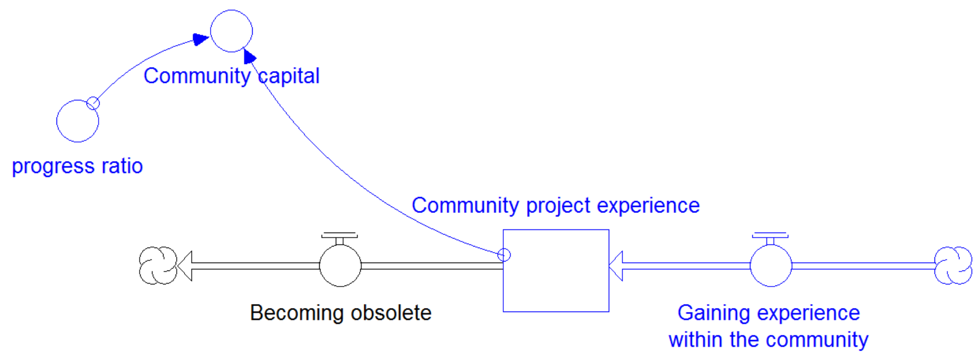

Figure 5. Concept of social capital and knowledge.

Key feedbacks and information flows

There are two opposing feedbacks built into this model. The first is the positive feedback cycle of engaging a community (Figure 6a). The second is the positive feedback of opposing work that is generated by climate disturbances (Figure 6b). The evolution of these feedbacks under different scenarios can provide insights into policy choice.

The feedback cycle of community engagement is displayed in Figure 6. Here, a community leader is engaged to generate internal community support for climate resilience projects in response to a climate disturbance. This action increases the stock of shovel-ready projects that are supported by the community. In doing so, the stock of community project experience increases, which in turn increases the knowledge and social capital within the community. Concurrently, the project completion time decreases and the failure rate decreases, which increases the stock of recent successes. More successes in recent memory increases the stock of engaged community members, which reinforces this positive feedback cycle.

The community opposition feedback cycle displayed in Figure 6 works opposite to the community engagement feedback cycle. In this case, a community member actively opposes work to improve resilience to climate disturbances, which increases the amount of time it takes to complete a project, in turn increasing the failure rate of projects, and consequentially preventing the stock of recent successes from increasing. This cycle decreases the engagement rate and the stock of engaged individuals, while at the same time increasing the stock of indifferent people. The larger the stock of indifferent people, the higher the probability they will be moved to the opposed category by stories of failure and no recent successes, reinforcing this positive feedback cycle.

Imbalances between these two opposing positive feedbacks create the potential for tipping point dynamics. Tipping points occur due to instability in the growth or decay of a system. In the current model, a tipping point generated by a stronger community engagement feedback allows all work to be completed, in absence of another external climate disturbance. A tipping point generated by a stronger community opposition feedback prevents work from being completed.

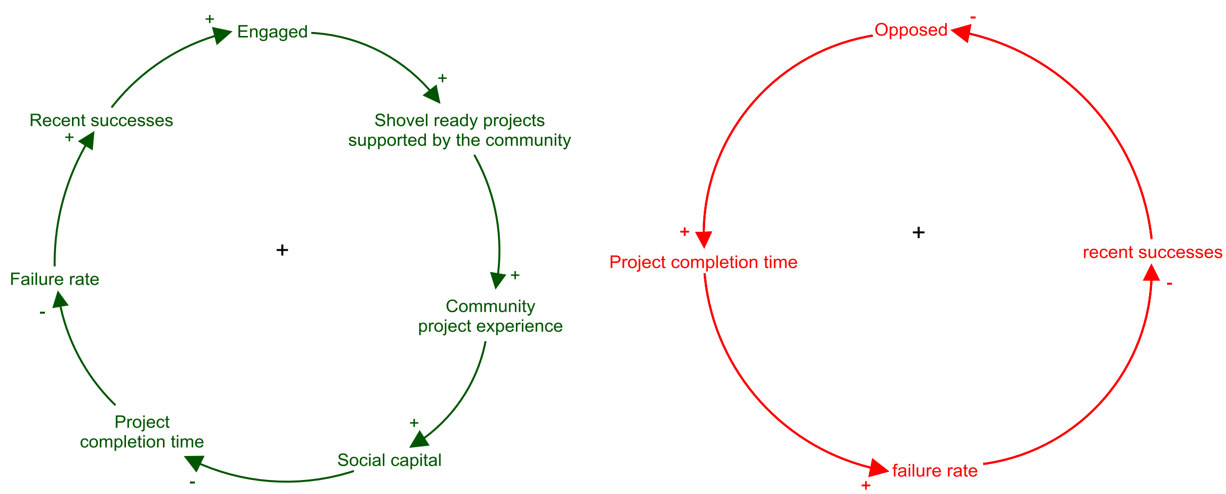

Figure 6. Key dynamic feedbacks for the TPEC model: a) left in green: positive feedback of community engagement and b) right in red: positive feedback of opposition.

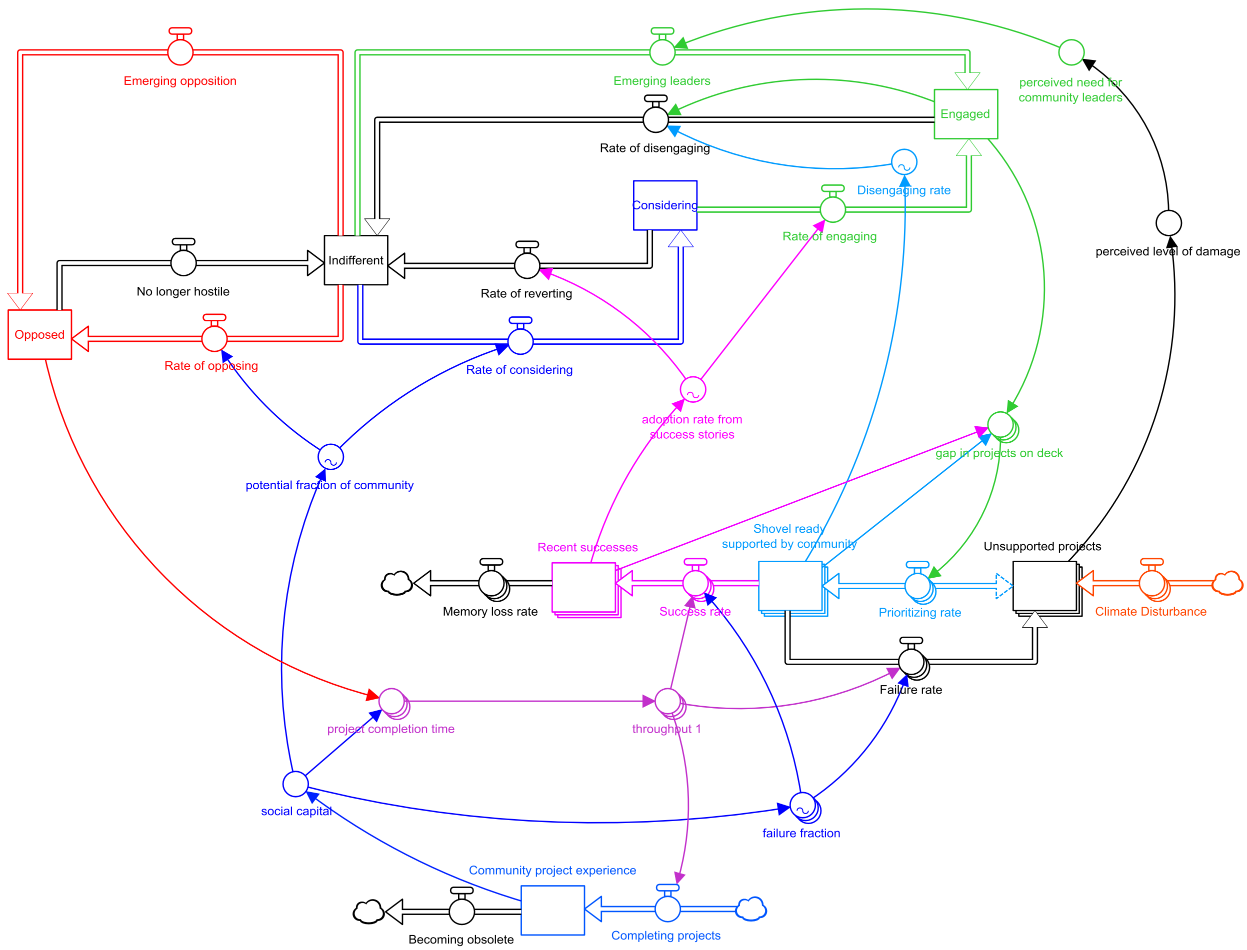

Figure 7. A very simplified visualization of the information flow and feedbacks within the model.

5. Model Scenarios

We explore two sets of experiments to broadly examine the effect of community engagement on getting work done and gaining social capital. The first set of experiments provide a concept test of building resilience to a disturbance such as intense precipitation that causes flooding (Table 1; Figure 8). These look at the evolution of community engagement initiated by a community leader as it relates to building resilience to climate disturbances. The second set of experiments adds two levels of complexity into the system: opposition within the community and an externally-initiated response to the climate disturbance (Table 2; Figure 9). Wind farms are one potential mechanism for increasing community resilience in the face of climate-related drought disturbances. Although their development is potentially divisive, wind farms can diversify the economy and thus build resilience to droughts. We test whether TPEC can capture the well-documented wind farm dynamics, e.g. [44-46], to build confidence in the model.

The concept test of building resilience to heavy precipitation that results in flooding with economic damages and decreased public safety has three scenarios (Table 1). In the first scenario, the disturbance increases the stock of unsupported projects, but there is no internal response (R1). In the second scenario, the same disturbance generates the same amount of unsupported projects, but community leadership is engaged in generating a community response (R2). The final scenario includes the second scenario and the response to a similar disturbance six years later (R3).

	Disturbance, no internal response (R1)	**Disturbance, internal response (R2)**	**Additional disturbance, internal response (R3)**
Storm (Week 20)	Yes	Yes	Yes
Leadership response	No	Yes	Yes
Storm (Week 320)	No	No	Yes
Opposition	No	No	No

Table 1. Concept test for building resilience to a climate disturbance such as a coastal storm.

The concept test of building drought resilience by diversifying the economy with wind farms has four scenarios (Table 2). These experiments added multiple layers of complexity into the system. The first set of scenarios looks at externally-initiated wind farms and the second set of scenarios looks at internally-initiated wind farms. In the externally-initiated set, the first scenario describes an external investor who wants to build a wind farm in a given community. The community responds with both opposition and support. The second scenario looks at the response to another external investor who tries again six-years later to build a wind farm in the same community. The internally-initiated set of experiments looks at the same scenarios but with the wind farm idea generated from within the community. Here, community capital is economic capital.

	Project, externally driven (Pe1)	**Additional project, externally driven (Pe2)**	**Project, internally driven (Pi1)**	**Additional project, internally driven (Pi2)**
Project introduction (Week 20)	Yes	Yes	Yes	Yes
Internal/external project division	10% / <u>90%</u>	10% / <u>90%</u>	<u>90%</u> / 10%	<u>90%</u> / 10%
Leadership response	Yes	Yes	Yes	Yes
Opposition response	Yes	Yes	Yes	Yes
Addition project (Week 320)	No	Yes	No	Yes

Table 2. Concept test for wind farm development to diversify the economy in response to climate-related drought disturbances.

6. Results

The TPEC model generates results that provide insights into the drivers and dynamic interactions of community resilience and are not intended to be predictions. The quantities and variations in the model output are provided to facilitate comparisons between our experiments and scenarios and contribute to an operational understanding of resiliency.

Building resilience to a flood-related climate disturbance

The results of the concept test for building resilience to a climate disturbance such as a storm that causes flood damages are presented in Figure 8. These results reflect changes resulting from internal leadership. Scenario R1 represents a not-resilient community in which the community members consider engaging, but lack the capacity to engage. In response, nothing happens and the climate related disturbances continue to build within the community. This type of behavior can be seen in response to infrequent coastal climate disturbances [51, 52] and/or in communities that lack resources [53]. C. Stwertka [34] attribute this behavior to a lack of a common community vision, lack of engaged government, and lack of enabling resources.

In Scenario R2, internal leadership engages the community in responding to projects that build resilience to similar climate disturbances. In absence of any other complexities, it takes one community leader around four years to trigger a tipping point in community engagement. During the intervening time period, the engaged community members slowly build community capital and recent success stories. These grow until a critical point generates a tipping point. The rapid addition of engaged community members allows for quick completion of the majority of remaining projects. Once the majority of projects are completed, community members slowly move back towards being indifferent or considering. In absence of another external impact, the success stories in recent memory decreases and the project experience becomes obsolete. This type of behavior can be seen in response to some level of a common vision, enabling resources, or an engaged government [34, 51, 54, 55].

In Scenario R3, another climate disturbance hits six years after the first. This time frame is short enough that there are still engaged community members, recent memory of successes, and increased community capital from recent project experience. Now, the engaged community members can rapidly boost engagement around projects, moving them through the project supply chain in half the time. Of note is that with social capital, more community members can be engaged in project support and completion. This type of behavior can be seen in response to continuous floodplain management [55, 56] that contains the critical elements of a community catalyst, a common vision of floodplain management, enabling resources, and an engaged government.

In these experiments, community engagement builds knowledge and community experience. These drive the resilient response of the community. Sustained community resilience depends on continuous supply of, and response to, projects from climate disturbances, engaging community members, and maintaining recent successes and community capital. In these cases, without an internal response from the community, the community remains in its altered non-resilient state. The TPEC model indicates resilient behavior over time is a tipping point dynamic. It does not take the entire community to respond to all of the damages, but the positive feedback loop in Figure 6a creates a tipping point under critical conditions.

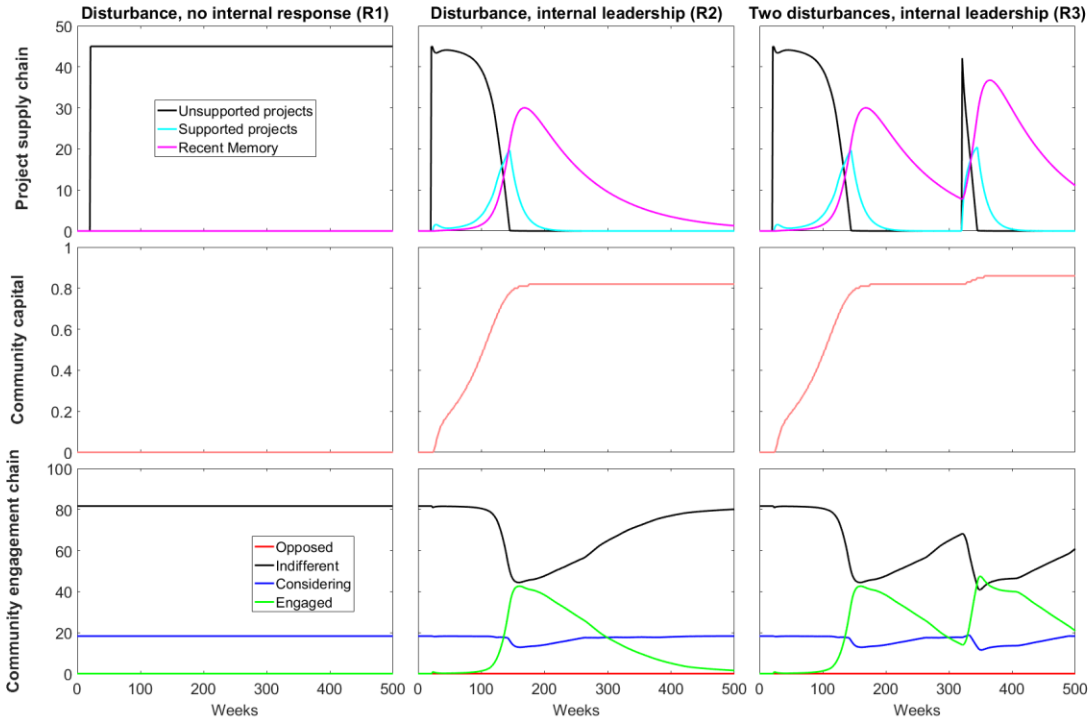

Figure 8. Results from the concept test of building resilience to a climate disturbance. The three scenarios are the vertical columns. The horizontal rows look at each component of the model.

Community engagement around diversifying the economy due to drought disturbances

The results from the scenarios (Table 2) around community support for a wind farm are presented in Figure 9. Droughts cause climate disturbances and a need to diversify the economy which leads the introduction of wind farms. The dynamic behaviors reflect changes in community capital between internally-initiated projects and externally driven projects.

In Pe1, the externally-initiated wind farm generates a bifurcation in the community. Community members are extremely opposed to the wind farm and delay action such that these external projects do not get completed over the ten-year case study period. However, the community is still able to gain minimal community capital based on the throughput of project failures. Any projects completed externally do not contribute to the community's collective knowledge. This scenario and response have been documented in the literature [44-47].

In Pe2, a second externally-initiated wind farm or other project is attempted within the community. Although the community has gained some project experience, it is not enough to engage with the external agent to promote a more community-friendly wind farm option. The opposition continues to bifurcate the community, increase the project completion time, and stall progress despite a small number of engaged community members. No tipping point in project completion can occur. This type of behavior can be seen in response to externally-initiated wind farms, but also in external government infrastructure projects [44, 45, 47, 54, 57].

In Pi1, the opposition initially bifurcates the community. However, projects supported and completed internally generate success stories and community project experience within the community. The community engagement feedback becomes stronger than the opposition feedback, and tips the community towards an engaged community that can overwhelmingly support the wind farm project. Once the project is completed, the community returns to a slightly diminished bifurcated state, but with a higher level of community capital then before [44, 46, 58].

In Pi2, another internally-initiated wind farm or other project is generated within the community. Now the community can respond faster and more efficiently with a larger number of max engaged community members. This brings more knowledge and community capital into the community, reduces the project completion time, and generates a tipping point to complete the projects in both supply chains. The second project has a much more rapid project completion time indicating it is a more resilient community. This is plausible behavior based on many of the examples of resilient communities in the literature on wind farms [44, 46, 58].

In this set of experiments, the dynamics of the opposing feedbacks represented in Figure 6 become much clearer and more plausible. With an external wind farm and additional project, the developer cannot create a tipping point dynamic to get the work done. The opposition feedback is stronger than the engagement feedback. However, when the project is initiated internal to the community, the engagement feedback is stronger than the opposition feedback and a tipping point dynamic is observed.

The value added by this reinforcing system is demonstrated in the project supply chain response curves. The project completion time is greatly reduced in the secondary set of projects, in both sets of experiments scenarios with internally-initiated projects. There is still enough recent memory to drive community engagement to build a common vision, identify enabling resources, and complete the projects. Community engagement occurs faster and the shape of the projects supply chain demonstrates an almost immediate response.

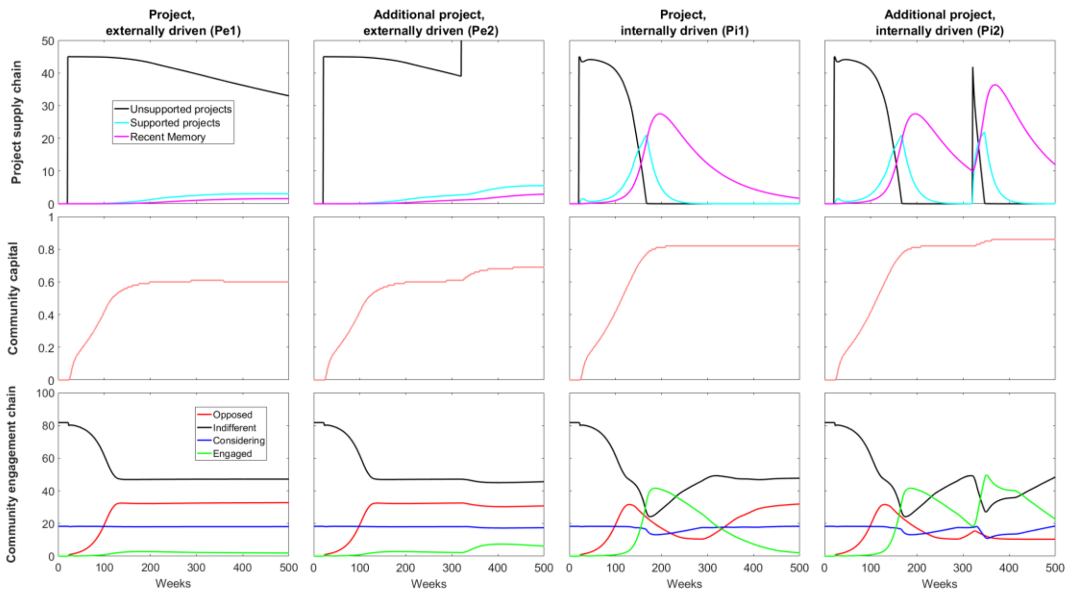

Figure 9. Results from the concept test of community engagement surrounding projects that are internally or externally driven.

7. Discussion

Results from the TPEC model demonstrate the role of community engagement in supporting projects (internal or external), learning and resilience. A community leader responds to climate disturbances and gains engagement in the community by creating and learning from successes and failures. This learning process allows the community to recover and rebound faster while being flexible to adapt to new conditions. This behavior demonstrates that the engaged community can self-monitor, prepare, and anticipate changes. These concepts are all cited in the literature as integral and opposing concepts of community resilience [11, 12, 14, 15, 50].

The behavior over time of a resilient community is demonstrated by the tipping point dynamics of the first set of projects, in which the community 'learns' and the second set of projects when the community has the community capital and experience to respond much faster (e.g. R3 and

Pi2). Instead of focusing the discussion on an exact definition of resilience, resilience is generated through the dynamic relationship between the critical components of a community.

The value added can be demonstrated by the reduced time to move projects through the supply chain to completion. This impact-to-action time can be considered a metric for a resilient community. A more resilient community will have a smaller impact-to-action time, which demonstrates the ability for a community to pre-emptively prepare for climate impacts before they occur.

The TPEC model provides insight into how to operationalize community engagement and resilience. One path forward is to strengthen the feedback cycle in Figure 6a, and weaken the feedback cycle in Figure 6b. This begins by finding and supporting a community leader, but this is not sufficient. The community also needs to gain a sufficient amount of community capital to generate a tipping point in community engagement. We argue that community capital is built through community project experience, which requires the critical components of a community catalyst to engage community members, a common vision, enabling resources, and an engaged government.

Strengthening engaged community members and community project experience within the engagement feedback will decrease the failure rate, decrease the project completion time, and increase recent successes. It will weaken the strength of the opposition feedback. Additional ways to decrease the project completion time and failure rate can include identifying pre-existing resources. To further explore these leverage points, the concept of resources would need to be built into the model.

These are preliminary results and are not predictions but rather indicate situations where tipping points, bifurcations, and feedback controls may arise. The main utility of TPEC is to develop insights into the interplay of factors that contribute to community resilience and community engagement. This is why we examine the dynamics of scenarios, instead of a specific detailed uncertainty analysis around any given scenario.

The concept of community capital is difficult to operationalize and not well defined. One response could be to disaggregate it into multiple categories as is done is Abramson et al, 2015

[19]. These categories are human capital, economic capital, social capital, and political capital. This would provide another level of sensitivity and leverage points.

Finally, the concept of disaggregating climate disturbance projects into internal or external projects has its limitations. It forces projects into categories and does not allow for flow between the projects, e.g. an external agency taking on a project that was originally initiated by community members. In the TPEC model, we diffused this by providing the role of the community leader to generate “support” for a project. Although community support is a critical component for project completion – either external or internal projects – it still leaves room for further development. One way to build on this, is to add resources into the model. Adding resources to the model would generate a whole new level of interesting dynamics because they feedback into multiple components.

8. Conclusion

In conclusion, the TPEC model has been developed to be a tool for studying community resilience by engaging a community in projects created by climate disturbances. The TPEC model is built from three components: people, work generated from climate disturbances, and community capital gained through project experience. The model is based on a Bass diffusion framework, a disease model, and a learning model. It has two dominating feedbacks that generate tipping points under certain conditions. Two illustrative experiments were done to validate and verify the TPEC model could produce plausible results. The model also produced plausible dynamics of community engagement resulting from internal versus external projects. The case studies demonstrated that resilience is a function of an engaged community, recent successfully completed projects, and internal knowledge gained and maintained within the community. It can be operationalized as the concept of action-to-implementation time. The value added of this new reference frame is a metric to follow over time to see how effectively a community responds to climate impacts. If instead of climate impacts driving the model, we consider planning actions that need to be done, a reduction in the planning-to-implementation time would demonstrate that a community is prepared for climate impacts before they occur. The results provide a springboard for discussions about current and future climate policies. The discussion focused on strengthening the engagement feedback cycle by finding and supporting community leaders and designing support tools to engage in hands-on project experience by connecting them with enabling resources. Both are critical, but neither is sufficient to guarantee success. Future research will be designing these decision support tools to connect hands-on experience with enabling resources.

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