Overcoming Inconvenience: How Society can Incentivize Individual Recycling Behavior; An Agent-Based Model.

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Abstract
Today, major obstacles to community recycling include lack of effective incentivization and opportunity cost. We attempt to ameliorate this through agent-based modeling by locating and identifying key incentives and relationships to be manipulated by policy-makers and social organizers to effectively inspire recycling behaviors. By simulating the interaction of individuals at the micro scale, we can watch as these virtual agents organize and decide either to conveniently discard the waste they generate, or to recycle at convenience's expense. Intuitively, an agent's choice is influenced by social pressure and rewards, as well as convenience. Therefore, based on the behaviors of these agents and collectives, we draw inferences as to how recycling behavior manifests itself at the communal level, and gain insight into how much convenience individuals will trade for the social credit of recycling. As anticipated, the availability of recycling bins and distribution are highly salient in determining recycling behavior.

Keywords: · Recycling · Agent-Based Modeling · Sustainability · Ideology · Environment · Peer Pressure · Collective Action · Social Pressure

1. Introduction

Widespread community recycling has progressed far since the advent of Greenpeace, Earth Day and the broader environmental movement in the nineteen-seventies. With a recycling rate of 34.6%, the United States is now more consciously engaged in recycling than in all previous decades.[1] Nevertheless, the rate of increase in recycling has sharply declined in the past decade, and comparatively little progress has been made. Thus, in an effort to understand the stagnation of the growth of recycling and determine the salient

[1] Roadrunner, smarter recycling. https://www.roadrunnerwm.com/blog/the-last-5-decades-of-recycling

factors driving recycling, our research was created to explore the critical role of individual social engagements in influencing recycling behavior at the micro level. Previous sociological and psychological literature hints at the explanatory power of theories such as the Theory of Planned Behavior, and the Theory of Basic Human Values in regards to an individual's rational choice to recycle, and, correspondingly, our Agent-Based Model builds upon such research with the goal of exploring these same decision-making processes computationally.

Our model focuses specifically on the micro, community scale, understanding the role of individual decision-making processes to be a single, though critically important building block of the components of the broader recycling processes. How do community members motivate their neighbors to recycle? How can we most efficiently place recycling bins to maximize their availability and exposure? An agent-based model, with its emphasis on the grass-roots self-organization and co-evolution of individual decision-makers and their broader effects on the environment at large provides the ideal methodology for exploring such questions. Our findings indicate that the number of bins as well as their spatial distribution in the environment are key factors in determining recycling behavior. Moreover, the results show that recycling is negatively correlated with the wealth agents possess.

Thus, our model indicates that through increased cooperation and effective monetary incentivization, broader community recycling is possible and absolutely necessary for a sustainable future. Echoing the words of economist Ernst Friedrich Schumacher, "Infinite growth of material consumption in a finite world is an impossibility."

2. Literature Review

In the past quarter-century, substantial research has been conducted on the prime motivational factors inducing recycling as well as the most effective policy and institutional levers encouraging recycling. Researchers such as Ramayah and Rahbar have applied established social-psychological theory to the study of recycling behavior, specifically Ajzen and Fishbein's Theory of Planned Behavior.[2] Their study suggests that

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[2] Ajzen, I. (1991), "*The theory of planned behavior*", *Organizational Behavior and Human Decision Processes*, Vol. 50 No. 2, pp. 179-211

a person's intent to recycle is heavily informed by their perceived social pressure to do so.[3] Moreover, alternative research conducted on other countries yield similar results. British social scientists Peter Tucker and Ducan Smith from Surrey University likewise in their study "Simulating Household Waste Management Behaviour" indicate the explanatory strength of one's neighbors as influencers in one's decision to recycle.[4] Borrowing further from socio-psychological theory, Hopper and Nielsen in their 1991 analysis *Recycling as Altruistic Behavior* apply Schwartz' Theory of Basic Human Values to illustrate that social values and expected norms often drive individuals to engage in recycling, though perhaps not truly altruistically, according to Hopper, Nielsen, and the Theory of Basic Human Values, but as a calculated action to obtain social credit or social acceptance as a payoff.[5] Hence, in line with the current literature, we have designed our model to allow the self-organization of social circles and social rewards to best emulate what the existing literature deems to be one of the most potent forces driving recycling behavior.

Still, research on the driving forces behind individual recycling behavior extends beyond social imperative, into the more tangible realm of financial incentive. Experts differ in their summations of the effectiveness of financial incentive versus social pressure in inducing recycling behavior, yet much research conducted suggests that financial incentive, when properly and economically implemented, can positively encourage people to recycle. Although some researchers such as Srun and Kurisu, (2019) have evidenced that social norms hold more sway over a person's intention to recycle, than external factors, such as facilities or government incentives.[6] Researchers such as Geller, Winett, and Everett (1982) have produced survey results suggesting financial incentive to be important to incentivizing voluntary recycling behavior, and reversely, that the cancellation of such incentive programs precedes a decline in voluntary recycling.[7] Bearing this in mind, we have elected to implement the option for economic incentive for recycling in our model. This procedure represents the model equivalent of real-world

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[3] Ramayah and Rahbar, 2013. Greening the environment through recycling: an empirical study. https://www.emerald.com/insight/content/doi/10.1108/MEQ-07-2012-0054/full/html#b68

[4] Tucker and Smith, 1999. Simulating Household Waste Management Behaviour http://jasss.soc.surrey.ac.uk/2/3/3.html

[5] Hopper and Nielsen, https://journals.sagepub.com/doi/pdf/10.1177/0013916591232004

[6] Srun and Kurisu (2019) Internal and External Influential Factors on Waste Disposal Behavior in Public Open Spaces in Phnom Penh, Cambodia

[7] E. Scott Geller, Richard A. Winett, Peter B. Everett "Preserving the Environment: New Strategies for Behavior Change."

policies such as a tax rebate or a refund value such as the CRV in the State of California and allows us to investigate the salience of financial incentive in comparison, contrast, or conjunction with social impetus.

With regards to infrastructural imperatives to recycling behavior, authors such as Raymond De Young of the University of Michigan, Ann Arbor found that the lack of opportunity to recycle intuitively plays a critical role in determining whether or not one recycles.[8] Reflective of this literature, therefore, our model is programmed with the option to test the effect of the number of generated recycling bins as well as their geographic dispersion with the goal of identifying the proper ratio and location that will enable the virtual agents to maximize their recycling actions. Our model is further inspired by studies conducted by such authors as Van Liere and Dunlap, (1980), who demonstrate that individuals tend to diverge in their willingness to recycle on an ideological basis, finding that Americans who value individual and property freedoms as well as low taxation rates are less ideologically inclined to support environmental initiatives.[9] Likewise, Samdahl and Robertson, (1988), note the trend of Americans holding a more tax-acceptant, liberal ideology to be more inclined to support environmental initiatives.[10] In this spirit, we have adopted Ideology as a crucial attribute of each virtual agent in our model, and, fitting of the literature, said Ideology plays a powerful role in each agent's decision whether or not to recycle. Ergo, our model is inspired by the existing literature's summation of the most salient drivers of recycling behavior, and seeks to simulate and replicate these real-world constructs to determine the sufficient combination of factors and levers that, when co-opted properly, can ensure a more meaningful, sustainable, and greener future.

3. Methodology

An agent-based model allows us to examine individuals as our central unit of analysis, and in so doing we can closely observe their interactions with each other and the environment. By focusing our research on individual decision-makers (agents), we can, with high granularity, identify and observe the causal factors of recycling behavior at the interpersonal and community scales. Fittingly, therefore, the importance of individual

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[8] De Young, Raymond, "Exploring the Difference Between Recyclers and Non-Recyclers: The Role of Information" (1988-1989).

[9] Van Liere, Kent D., and Dunlap, Riley E.1980. "The Social Bases of Environmental Concern: A Review of Hypotheses, Explanations and Empirical Evidence."

[10] Samdahl, Diane M., and Robertson, Robert A. 1988. "Social Determinants of Environmental Concern: Specification and Test of the Model."

decision processes coupled with the lack of availability of real-world data renders our research question uniquely suited to agent-based modeling and bottom-up simulative prediction, ideal for revealing unexpected emergent behaviors otherwise unobservable with formal, top-down statistical modeling.

In this model, we simulate an environment wherein agents generate recyclable material and then must choose to dispose of it in one of the available bins initialized on the environment, either into recycling bins, or into landfill bins. Agents are constantly moving, generating waste every tick and searching for the bins in which to dispose their waste. The modeler can determine the number of trash bins and recycling bins that will be available in the environment as well as their spatial distribution. Agents' attributes include wealth, which is normally distributed by wealth's mean and standard deviation sliders. For the sake of modeling simplicity, any real-world currency is substituted for "psuedo-wealth," measured in "units" in our simulation. Additionally, each agent is beset with a unique ideological value, (I_l), normally distributed with a mean value of 0 which defines the agent's proclivity to recycle on a scale from -1.0 (unlikely) to 1.0 (likely). Additionally, agents maintain a contamination level, which represents the accumulation of the trash the agent does not recycle, and finally, a vision level, representing the availability of information for every agent. In this respect, vision is a cogent variable that determines not only with whom an agent can interact with, but also the number of peers who can influence her Ideologically.

Every tick, equivalent to a day in our model, agents move randomly at the cost of wealth proportional to the number of patches moved and then generate waste. Thereafter, the agent must discard the waste. The choice to recycle or waste is informed by the agent's own Ideology in conjunction with that of her neighbors, as well as the proximity of the bins. If the sum of the agent's Ideology (I_l) and the weighted mean Ideology (I * (n * T) of her neighbors within her vision is larger than the given ideological threshold, (defined as 0.5), she will look for the nearest recycling bin to dispose of the generated waste even if the agent has to look outside her vision. This transaction is actualized within the code with equation 1 as follows;

$$I_i = I_l + [\bar{I} * (n * T)] \quad \text{If } I_i > .05\text{, the agent will recycle.} \qquad \textbf{(1)}$$

However, if this condition is not met, the agent will simply choose the closest bin within her vision, without regard to the bin's type. Thus, at this point, the agent's choice to recycle or contaminate is determined by convenience. Nevertheless, in either case, if the agent does choose to recycle, the agent's waste and contamination will decrease by one, and half of the distance from the agent's position to the bin will be deducted from her wealth. Contrarily, if the agent does not recycle, and the material is disposed of into a trash bin, the agent's contamination attribute increases by one, but waste and wealth are summarily affected as before. In both cases, the agent's Ideology will be altered by the Ideology of her neighbors bringing her own Ideology closer to -1.0 in the case of less-recycling prone neighbors, or closer to 1.0 in the case of environmentally-friendly neighbors. Alternatively, the observer can opt to introduce an "economic incentive" that would add to the agents' wealth every time she recycles. This incentive can be "turned ON" at any point in time for a desired period.

Figure 1 below provides a high-level architecture of the model. As mentioned earlier, each agent is initialized with a given starting Ideology and wealth at the model initialization stage. Every time an agent moves, she loses wealth and generates waste. As she generates waste, it must be disposed of. Her Ideology is as aforementioned updated based on her neighbors, and following that, said newly updated Ideology determines her decision whether to recycle or maximize her convenience. If the second is true, she finds the nearest bin regardless of its type and disposes the material. Every time an agent recycles, she decreases her own contamination level and her wealth decreases based on the distance traveled. The process is sequential and iterative, as diagrammed in the flow-chart below.

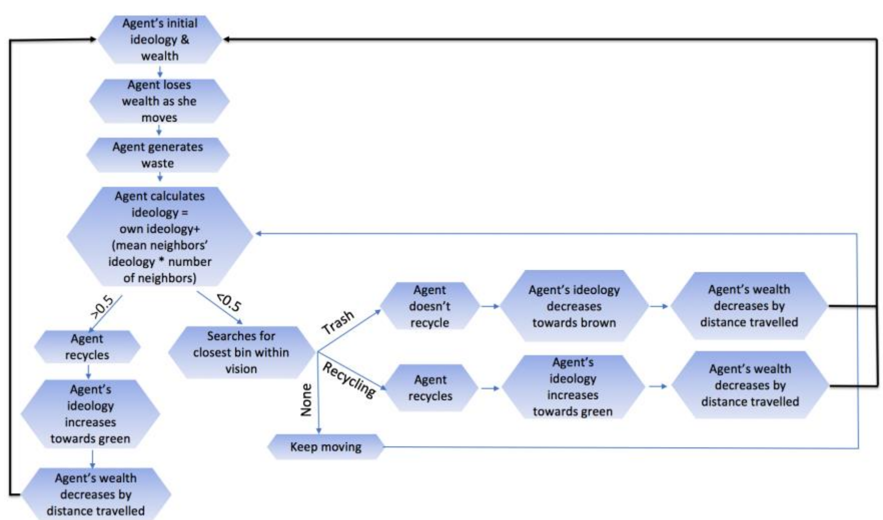

Figure 1. Model Architecture

3.1 Model Implementation

To initialize our model Baseline, we establish a small community comprised of 50 agents. To service the waste needs of these agents we beset them with 4 recycling bins and 4 disposal bins equally distributed across the environmental space, 8 in total, all equidistant from each other. This is to ensure that each bin is easily accessible to each agent, and their emergent recycling trends and behaviors will not be weighted by the mishap placement of bins. Thereafter, we allot each of these agents an initial sum of wealth randomly and normally distributed with a mean of 10 units with a standard deviation of 1 unit.
Every agent has a vision of 1, the smallest unit in the vision continuum, establishing a relatively small sphere of susceptibility from within which the agent can be affected by peer pressure. Additionally, we leave the economic incentive switched off to emulate a real-world scenario where economic incentive to recycle is negligible. Finally, the Baseline model is run for 3000 in-model ticks, allowing the modeler ample time to observe the model's emergent behaviors.

3.1.1 Baseline and Initial Conditions

Under our Baseline conditions, we observe agents alternating in their decision to recycle or dispose of their waste into the trash bin. Figure 2 demonstrates the number of agents by recycling behavior. The green line shows the number of agents that preferred recycling, whereas brown illustrates the number of people who preferred disposing waste into trash bins. As observed, both figures evenly increase in the beginning of the run, followed by more cyclical behavior in the later period. The figure exhibits the behavior given by the balanced set of initial conditions. Figure 3 shows the average normalized Ideology of agents in a histogram, where the x axis displays the value of Ideology, bounded between 0 and 1.

After 3000 model ticks, the Baseline results show normally distributed values of Ideology clustered approximately around the mean of 0.5, suggesting that the balanced set of initial conditions produces a similar recycling behavior for all agents on average. Finally, contamination levels, portrayed in Figure 4, remain low and steady.

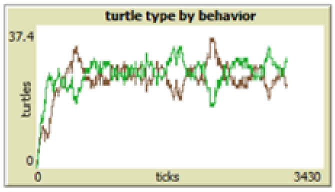

Figure 2

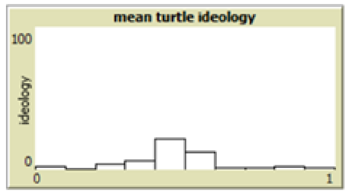

Figure 3

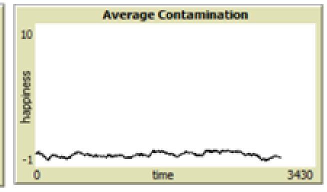

Figure 4

3.1.2 Scenario 1. Increasing the number of recycling bins

Having now observed the Baseline conditions, we would like to further explore the model for potential salient factors. We begin with altering the number of recycling bins.
We increase the number of recycling bins to 7 and leave the rest of the settings unchanged (4 trash bins). Intuitively, increasing the number of available recycling bins increases the number of agents that recycle their waste, exhibited in Figure 5. Likewise, there is a positive effect on the average ideology of turtles given the prevalence of recycling bins. This is clearly shown in Figure 6, where the histogram distribution is skewed towards 1. Finally, the average contamination consistently decreases over time, which follows the general logic.

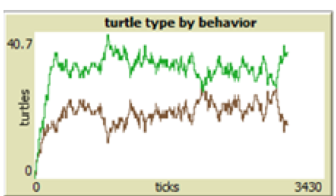

Figure 5

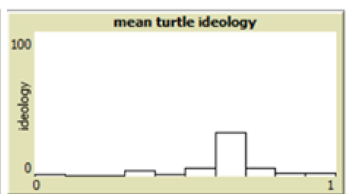

Figure 6

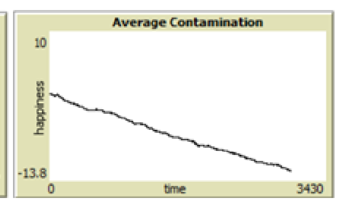

Figure 7

3.1.3 Scenario 2. Clustering recycling bins

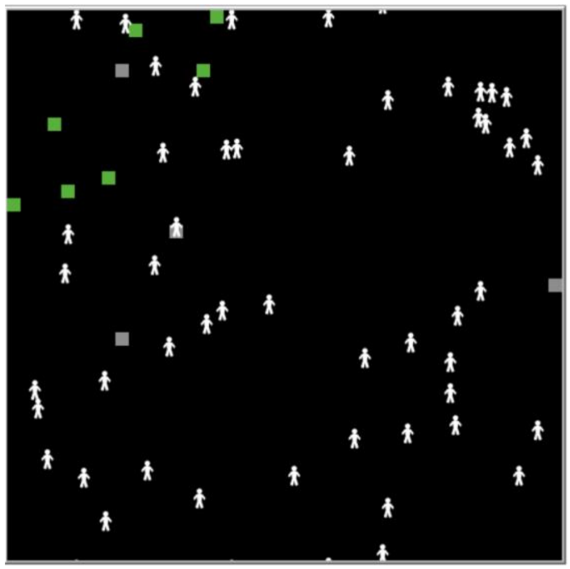

Figure 8. Clustered Bins

Maintaining the same parameters as in scenario 1, the recycling bins are this time initialized solely within the upper-left quadrant of the environment to simulate an asymmetric dispersion of recycling bins. In this scenario, the agents are free to roam across the wide expanse of the environment, yet all recycling bins are clustered in a single location, as shown above in Figure 8. This scenario allows us to test and simulate agent behavior in an environment wherein they have limited knowledge and recycling opportunity. In this scenario, similar to scenario 1, the number of recycling bins is positively correlated with an agent's decision to recycle as evidenced in Figure 9. A dampening effect is noticeable, nonetheless, when one compares the behavior plot from scenario 1 (Figure 2), and the behavior plot in scenario 2 (Figure 9). This indicates that in addition to the number of recycling bins inducing recycling behavior, likewise the geographical dispersion and availability thereof are explanatory factors in determining recycling behavior. Mean Ideology, however, is not displaced towards 1 as represented in Figure 10. Figure 11 shows as well that contamination is reduced given the number of agents who choose to recycle.

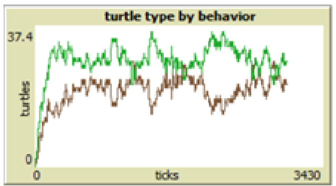

Figure 9

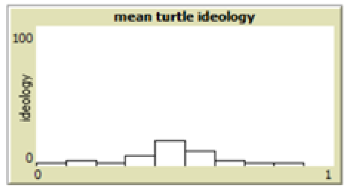

Figure 10

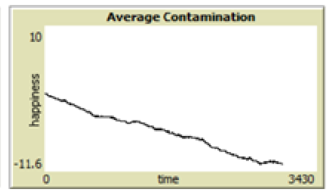

Figure 11

3.2 Internal Validation

We begin model verification through conducting a global sensitivity analysis by way of a regression analysis in R, fed with our data generated in Netlogo. All the input data is normally distributed given the set of initial conditions that produced model outputs in 1000 runs. We deploy Pooled Ordinary Least Squares Analysis (OLS) to analyze the direction and significance of relationships between the variables. The model results are summarized in Figure 8 below.

VARIABLES	(1) Recycling Agents	(2) Agent Ideology
wealth	-14.43***	-0.545***
	(0.224)	(0.0122)
vision	4.944***	0.0576
	(0.789)	(0.0507)
recyclingbins	1.067***	0.0672***
	(0.230)	(0.0118)
Constant	-12.47***	-0.643***
	(1.137)	(0.0560)
Observations	1,000	1,000
R-squared	0.924	0.860

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 12 Regression Output

Column 1 of the regression summary table shows the regression results for recycling agents, those who preferred to recycle. We likewise observe the corresponding values of wealth, vision and recycling bins. Interestingly, there is a negative and statistically significant correlation between wealth and recycling agents, which seems intuitive, since, in the model, the distance traveled to recycling bins is often greater, and thus more costly, decreasing the wealth possessed. Vision, moreover, is quite salient at the magnitude 4.9, suggesting that the awareness of one's surroundings and opportunity to recycle corresponds with an increase in recycling behavior. Rather intuitively as well, the magnitude of recycling bins is significant and positively correlated with the recycling behavior of agents.

In like manner, Column 2 looks at agent Ideology, which we expected to demonstrate a similar behavior to that of column 1. Nevertheless, in the regression, wealth appears to be negatively correlated with individual Ideology, albeit at a lower magnitude. Surprisingly, vision has no observed significant relationship with our second variable, Ideology. It is possible, therefore, that an agent's vision has a direct and significant impact on one's recycling behavior as demonstrated in Column 1, yet only an indirect impact on one's Ideology. Future testing and verification may yet clarify this observation. Finally, the number of recycling bins is positively correlated with Ideology and significant at the 1% significance level. We thus interpret this to be a natural relationship, as the larger the number of recycling bins would intuitively correlate with a greater proclivity to recycle.

In summary, the regression results as displayed in Figure 8 fall in line with our expectations of the model and support the main findings outlined previously in the Baseline and Scenarios sections.

4. Policy Implications and Conclusion

Understanding the fundamental incentives, interactions and social linkages that inspire successful recycling initiatives at the grass-roots level is an essential part of creating a greener, more sustainable world. Often the solution to a complex problem is not merely a top-down mandate, but rather a strategic partnership at the micro, meso, and macro levels. Our model provides insight into the social and ideological processes that inform an individual's choice to recycle. In scenario 1, our results demonstrated a positive correlation between the number of recycling bins available and total recycling behavior. The implications of such are simple and straight-forward, yet effective. The populace is unable to recycle if there are no such opportunities to do so. Similarly, our results from scenario 2 indicate that in addition to the number of recycling bins, the spatial distribution of them is important in order to maximize an agent's exposure to recycling. Additionally, policy-makers can take a more proactive approach to encouraging recycling behavior by bearing in mine the inherent opportunity costs that come with recycling. Our regression output indicates a monetary cost to recycling and responsible policy ought to attempt to remedy this cost, perhaps through a tax rebate or a refund value added for recycled goods. As it stands today, research on recycling motivation is a relatively data-poor field.

4.1 Future Research

For the purpose of verification and validation, more exploratory research and modeling of real-world scenarios is key to generating the data necessary to finely validate our model. Likewise, a more long-term model scenario observing how recycling agents interact over the span of multiple years could be a boon to further research on how recycling policies introduced wax or wane over time providing greater insight into how we may craft more sustainable policy solutions. Additionally, further research that is more general, less case-specific and thus more broadly applicable to given environmental problems would enrich our toolset for solving such real-world recycling hurdles. Lastly, given the underestimated complexity of waste management and processing, we would welcome future studies analyzing the role of available recycling information and education in driving individuals' recycling behavior.

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