Project Ikarus: Examining Solar Panel Purchasing Patterns

Kaitlin Moore, Jeff Kritzman, and Jack Ko

Fall 2008

Professor Evrard
Abstract

Should the state of Michigan offer an incentive to purchase solar panels above and beyond its new buy-back rate for solar electricity? Should this incentive be comparable to the new federal government rebate? We have attempted to answer such a question by creating an agent-based model, using the NetLogo platform, of a community of agents who interact in ways that attempt to mimic real-life social interaction. We have also used outside studies to incorporate individual environmental behavior and economic situations typical of the state of Michigan into our model. We then used our model to look at how solar panel purchase, and subsequent total solar energy generation, was affected not only by these three parameters, but also by the offer of a Michigan government rebate similar to the present 30% federal rebate. We determined that a government rebate did clearly positively affect the acquisition of solar panels and that Michigan should not, therefore, rule out the possible benefits of offering such an incentive.

Introduction

If the state of Michigan were to offer each residential homeowner an incentive, such as a rebate, to purchase a rooftop solar panel, what would be the effect? How would social networking play a role in influencing the decision to buy a solar panel? Would the costs to the state outweigh the benefits?

On September 8, 2008, the state of Michigan was one of nine states to receive a grant from the Department of Energy for the purpose of re-structuring its energy sector to be friendlier to renewable energy:

Michigan will develop statewide infrastructure to support Pay-As-You-Save (PAYS) and implement up to four PAYS pilot projects. The grant will be used to create the framework, regulatory environment, and policies to make it possible to achieve at least one gigawatt of new energy capacity either through demand-
side reductions or distributed renewable energy. This strategy will provide consumers with the option to finance cost-effective energy efficiency and renewable energy measures through a tariff on their utility bill, using a portion of energy cost savings to pay for the capital and financing cost of improvements.¹

Following this development, also in September, Michigan’s House passed Bill No. 5218 “to require certain providers of electric service to purchase electricity from eligible electric generators.”  § 4.3 of this bill provided regulations for the purchase of electricity generated by individual residents, with § 4.3.f dealing specifically with rooftop solar panels.²

In this bill, Michigan specified a buy-back rate for solar electricity that is about six times more than the average cost of electricity in Michigan.  Despite this environmentally-friendly measure, however, Michigan has consciously not taken the step to offer an upfront incentive for the purchase of a solar panel.  The federal government, on the other hand, has.  President Bush signed a tax rebate law in October 2008 offering a 30% rebate, with no cap, on any home solar panel purchased between 2009 and 2016.³

Because of these recent developments, we have chosen to model a scenario whereby the state of Michigan, like the federal government, gives each household an upfront incentive to purchase a solar panel.  We would like to analyze the effects of such an incentive, combined with the new buy-back rate, on solar panel purchase and subsequent solar energy generation.

**Background Research: Efforts at Realism**

Because our model uses social and environmental behavior, we needed to perform extensive background research, both for the accurate development of our model and to provide reasonable

---

¹ Source: http://www.energy.gov/6515.htm
² Source: www.legislature.mi.gov
³ Source: http://www.wholesalesolar.com/states/Michigansolarpanels.html
numbers for our parameters. Below is the list of studies we accumulated and used in our model:

1. **Environmental consciousness:** We did some preliminary research on green purchasing studies in the Midwest, and we hit on a study that took place in Ohio and Michigan and quantified environmental consciousness into a Gaussian distribution, which we used in our model.

2. **Failure rate of solar panels:** Based on various sources, it appears that the average failure rate of solar panels is below one percent. Thus we decided to use a failure rate of one percent in our program, as this is still a very low rate, and we thought it would be better to err on the side of predicting slightly more failures than necessary.

3. **Solar electricity buy-back rate and maximum solar panel watts:** According to House Bill No. 5218, the required buy-back rate for solar electricity will be $0.65/kWh. This rate is specifically for rooftop solar panels, and the panels can be no more than 30 kW.

4. **Michigan’s electricity statistics:** The average price of electricity for a residential consumer is $0.1080 / kWh; we obtained this figure by averaging between the two Michigan electric giants, Consumer Energy and DTE. On average a consumer uses 500 kWh a month and pays $54 a month. In addition, for the year 2008, Michigan projects a total sale of 35,299 million kWh of electricity to residential customers.

---

Advisor of Thesis: Michele Morrone


6 Source: [www.legislature.mi.gov](http://www.legislature.mi.gov)

7 Source: [www.dleg.state.mi.us/mpsc/reports/energy/08winter](http://www.dleg.state.mi.us/mpsc/reports/energy/08winter)
5. **Calculation of solar energy needs per household:** We located a basic formula for calculating the solar power needs and costs of a household. This formula is paraphrased below:

   i. Calculate average daily usage from electric bill (kWh/day)
   
   ii. Divide by the number of full sun hours per day on a yearly average
   
   iii. Multiply by 1.15 (gives a slight over-estimate of solar power needed)
   
   iv. The average cost of a professionally installed solar panel, including hardware such as mounts, wires, etc., is $9/W

6. **Michigan income:** The average household income is $70,000, with a $40,000 standard deviation, which we have used in our program. ⁹

7. **Michigan insolation:** The average daily insolation for southeast Michigan is about 4 hours a day. ¹⁰

8. **Determining the relative strength of influences on a Michigander’s solar purchase:**

   Another appropriate green purchasing study was found. ¹¹ This study polled 1000 participants and non-participants in DTE’s solar energy purchasing program. In part of the study, these people were asked how strongly certain factors affected their solar power purchasing decision. According to the results, the following factors would “strongly” affect a Michigander’s solar power purchasing decision with the following weights.

   These factors were used to weight our overall satisfaction equation in our model:

   i. Money Satisfaction:  7.7
   
   ii. Social Satisfaction:  11.1

---

⁸ Source: Solar-electric.com

⁹ Source: http://money.cnn.com (MONEY Magazine: Best Places to Live)

¹⁰ Source: www.solar4power.com (Solar Insolation for Major U.S. Cities)
Evolution of Goals and Plans

In the early stages of the development of this project, we proposed devising a single equation that would characterize the attitude of a homeowner towards solar panels. The equation would have been in terms of various parameters, such as those mentioned above, as well as time. We intended to solve this equation in MatLab by forming a large state vector of the parameters and evolving this state vector through time.

This solution was problematic in part because the parameters were not independent of each other. Rather, they would have been intertwined, which would have made time-evolution more difficult. In addition, with the sheer number of parameters we intended to use, MatLab seemed less than ideal; we would have had to create a large, governing function to specify the relationships between all the parameters in the state vector.

We then looked into programs specifically suited to agent-based modeling. Agent-models move towards a solution by evolving “agents.” An agent owns, by itself, attributes that affect its evolution, and these attributes can change with respect to time and other parameters. This fit our goal perfectly because we could have agents representing homeowners. Instead of having to devise an equation that enveloped everything, we could have the agents interact amongst themselves.

Pursuing this avenue, we sent an e-mail to Professor Carl P. Simon from the Center for the Study of Complex Systems, but received no response. We then sent an e-mail to Professor McQuaid from the School of Information, and he responded with the following:

1 Source: Internal and external influences on pro-environmental behavior. Journal of Environmental Psychology 23 (2003) 237-246
“…I once attended a presentation on NetLogo, which is an open source multi-agent modeling tool, but I have no more knowledge the topic than any other completely novice spectator. 

http://ccl.northwestern.edu/netlogo/ …”

In this way, we were introduced to NetLogo, a language that is explained further below. After discovering NetLogo, we explored some avenues for our project that were ultimately discarded. For instance, we originally intended to model Michigan communities with geographic and population density realism; we intended to divide the problem into neighborhoods or counties, each with their own parameters. We then intended to total the results from each. Because of time constraints and considerations of simplicity, the final model did not incorporate these ideas.

The Language

NetLogo was developed in 1999 by Uri Wilensky, a computer science professor at Northwestern University. Professor Wilensky intended NetLogo as an educational tool for complex systems. It is a cross-platform environment written in Java, and it allows the user to program his/her own models. NetLogo features its own set of commands, data structures, and functions, and is by itself a unique programming language. Just as the Matlab “m-language” is a cover-up for the underlying C and Fortran codes, the NetLogo language is a transformation of the underlying Java codes.

Netlogo was developed in Java, so a brief introduction to Java is in order. Java, a relatively new programming language, was developed in 1991 with the intent of being infinitely
portable. A Java code is supposed to compile once and be able to run on all machines. To this end, Java programs make use of a virtual machine: the code will run so long as the computer in use has the virtual machine installed. Java is also (almost) completely object-oriented, where all functions have to be nested inside a class. This enforces the rule that everything has to be owned somewhere by someone, and this minimizes the risk of accidentally abandoning allocated memory (memory leak). Syntactically, Java mirrors the classic C language, as intended by its creator, but it features a more complete set of built-in functions and data structures. This places Java as a higher-level language than C.

With its intended purpose in mind, it is easy to understand why NetLogo is based on Java. The portability of the code allows this educational tool to be used in any environment. Agents can be implemented as objects that own their respective parameters. Built-in data structures make sets and lists easy to implement. Memory can be dynamically allocated safely. One issue with Java, however, is that its performance is not as fast as other programs because it runs on a virtual machine. Loading the virtual machine consumes a lot of memory. Because of this, we expect to run into some memory problems if we were to use our model at larger scales.

Because NetLogo is a framework to program agent-based-models, one of the most important components of the program are the agents themselves. In NetLogo, these agents are referred to as turtles. As the observer (which is what the program user is), we can ask the turtles to do tasks, such as move to the left, change color, or change a parameter. Also, we can ask a subset of turtles to do a task by putting a qualification on what type of turtles we ask. Each turtle owns user-defined parameters, and each one keeps track of its own values for these parameters.
Another primitive in NetLogo is the patch. Patches make up the ground (or background) upon which the turtles live. Patches can own patch-specific parameters, and we, as the observer, can give commands to some or all of the patches, just as we can with turtles. Turtles can interact with other turtles or with patches, and patches can also interact with other patches. The essential difference between turtles and patches is that turtles are mobile and can have varying density, while patches have neither of these properties.

Aside from the agents (patches and turtles), NetLogo has a Graphical User Interface that allows the observer to set parameter values in the code. The main GUI is divided into buttons, sliders, and switches. Buttons execute a command in the code, either one time or continuously. Sliders assign a variable value to some parameter in the code; the position of the slider decides this value. Switches turn binary parameters in the code on or off. NetLogo also has monitors on the main screen that can plot various outputs. Examples of possible plots include histograms, the number of turtles with a particular parameter, and the value of a global parameter.

**The Interim Model**

With the above understanding of NetLogo, we developed our interim model. It developed three parameters that we felt were crucial to an overall satisfaction equation for purchasing a solar panel. We developed these parameters separately with the intention of later integrating them into the overall equation.

**Money:** Each agent was assigned an income based on a distribution from a mean income. In this interim model, a cost of living was also taken into account in order to calculate
an agent’s expendable income (this idea was later scrapped). An agent's expendable income was the difference between income and expenses.

The electric bill was also taken into account, but only insomuch as the agent was unhappy if it did not have a solar panel and thus had to pay a bill; this unhappiness affected the agent's satisfaction and propensity to purchase a panel. Also, the upfront cost to the agent of getting a solar panel affected the decision to go ahead with the purchase.

This interim model used turtles as agents and attempted to use patches to keep track of varying seasons.

**Environmental Consciousness:** Each person has some inherent tendency or affinity towards 'green' decisions – everyone is conscious to some degree of the environmental impact they have on the planet. This parameter related environmental friendliness with 'green' purchases, using the study mentioned in Background Research, above. This interim model used turtles as agents.

**Neighbor Influence:** Unlike the other isolated models, the neighbor influence model was first implemented using patches instead of turtles. This model was based on the “Rumor Mill” model in the NetLogo library, in which the agents spread and heard rumors. Although using patches simplified the definition of a neighbor, patch-use also made the assumption that homeowners were uniformly distributed. This was not realistic.

A second addition to this part of the interim model was the media, whose number and range could be set. The media was a special patch and behaved much the same like every other patch – it heard the news and spread it. However, instead of just affecting its neighbors, the media spread the news to all patches within a radius (defined by a range).
The final implementation of these parameters will be explained in greater detail below. However, in the interim model, these parameters were all developed as separate models. After verifying through the patch implementation that the neighbor influence model made sense, we moved on to transform it into a turtle implementation. Doing this allowed us to study the effect of neighbor influence in areas of varying densities (which we chose not to implement in our final model, for simplification). It also allowed us to integrate the neighbor influence model with the other two models, which, as explained above, were turtle-based.

**Final Model**

This interim model integration, eventually, led to our final model.
First, we set up our patches, which, in our program, had very little function. Then, we set up our turtles. In our final program, there were thirty-four turtle-owned variables and nine global variables. Each of these parameters had to be given an initial value during Setup. Some, like \textit{env-friend}, which represented environmental consciousness/friendliness, were given a Gaussian distribution based on realistic numbers (see above), while others, like \textit{panel} (whether or not a turtle had a solar panel) were set initially to 0. The overall satisfaction also had to be initialized, as explained below. Then, for each tick, three major procedures were carried out, also explained below:

\textbf{Satisfaction Initialization:} This part of the code ran during the Setup command. Among other things, it output the \textit{initial-money-satisfaction} parameter for each
turtle. The initial-money-satisfaction parameter is a function of how much income a turtle receives each year and how much a solar panel will initially cost the turtle (a combination of solar panel wattage and government incentive). The more money a turtle makes or the less the turtle has to pay for a solar panel, the higher the value of this parameter will be. The initial-money-satisfaction parameter acts as the money-satisfaction parameter for a turtle until the turtle buys a solar panel.

The satisfaction initialization code also set the initial-satisfaction of each turtle. If this value was above the threshold for a given turtle, it would buy a solar panel during Setup.

**Energy and Money Savings and Solar Panel Failure:** The energy-and-money-savings procedure output the variables money-satisfaction and cumulative-energy-savings for each turtle. It set up turtle variables using the numbers given in Background Research, above.

First, the parameters were initialized. The average monthly power usage (set by a slider on the interface) was used to calculate the daily power. Next, the monthly power usage was also used to calculate the usual monthly electric bill without a solar panel. The amount of kilowatts of solar power needed to cover daily power requirements was then calculated using the formula given in Background Research, above. If the turtle already owned a solar panel, then the turtle calculated the energy and subsequent monetary difference between its power requirements and the power its solar panel provided. If the difference was negative, then the turtle still needed to pay an electric bill to cover its excess power requirements. If the difference was positive, then the turtle sold its extra solar power back to the power company for the rate discussed in Background Research, above.
After initializing these parameters, if the turtle owned a solar panel, the procedure added to the global variable `cumulative-energy-savings`. Also, if the turtle owned a solar panel and the difference, above, was negative, i.e. the turtle still had to pay an electric bill each month, the money-satisfaction was set to 0.5 (half-pleased). Paying an electric bill each month, affected `cumulative-money-savings`, where the money savings per month was the difference between the monthly electric bills with and without a solar panel.

If the turtle, on the other hand, owned a solar panel that covered all of the turtle’s electric needs (i.e. the difference was positive), then the money-satisfaction was set to 0.75 (happier, but still not ideally happy). In this case, the money savings per month for `cumulative-money-savings` took into account the excess power generated each month, the sell-back-rate, and the electric bill without solar panel.

In all cases, when the `cumulative-money-saved` exceeded the initial cost (to the homeowner) of the solar panel, the money-satisfaction was set to 1 (maximally pleased).

One other procedure that affected the `money-satisfaction` parameter was the `check-fail` procedure. This used the low failure rate, discussed in Background Research, randomly distributed, to determine if a turtle’s solar panel had failed. If it had, then the turtle’s money-satisfaction went to 0.

**To Spread and Hear Rumor:** This function dictated how the agents interacted with each other and affected each other’s social satisfaction. To initialize, the turtles were divided into two groups – normal and friends. These are just names for the agent groups which allow different influence values to be set. Friends do not have to be particularly friendlier and can in fact have negative influence. Most turtles normally had a short range in which to influence their neighbors and could only affect one neighbor at one time, but some, which we dubbed “the
media”, had a larger range and could simultaneously affect all neighbors within that range. In summary, we had two groups of agent with two influence strengths, and two groups with two ranges.

All agents start with a social-satisfaction value of 0, social-satisfaction being a component of total satisfaction. With all the turtles respectively grouped, we ask them, once for each tick, to spread and hear a rumor (the turtles “spread” their overall satisfaction levels and “hear” their neighbor’s overall satisfaction level). When a turtle attempts to hear the rumor, we first look to see if it is a media agent. If it is, then it hears the rumor from all turtles within its influence range and takes the average satisfaction value. It then sets its media satisfaction (not to be confused with overall satisfaction) to be this average. After hearing the rumor, the media will spread it by changing the social satisfaction of all turtles within its range to be media influence times the media satisfaction.
If, on the other hand, the turtle is not media, then it only hears the rumor from one of its neighbors. This neighbor is chosen at random. The neighbor’s *social-satisfaction* (again, not to be confused with its overall satisfaction, of which *social-satisfaction* is a component) then becomes the value of friend influence or normal influence times the overall satisfaction of the turtle who is spreading the rumor, depending on whether the two turtles are friends.

**Overall Satisfaction Equation and Determination of Threshold:** The overall satisfaction equation was governed by the *env-friend, social-satisfaction*, and *money-satisfaction* parameters. These were put together using the weights discussed in Background Research into the following equation:

\[
Satisfaction = 0.22 \times env\text{-}friend + 0.111 \times social\text{-}satisfaction + 0.077 \times money\text{-}satisfaction
\]

To determine whether or not a turtle had enough satisfaction to purchase a solar panel, a threshold condition was created. This threshold is a coefficient (set by the user) times the maximum satisfaction value, \(0.22 + 0.111 + 0.077\). Once a turtle’s satisfaction rose above this threshold, it would purchase a solar panel. The “normal” coefficient was taken to be 0.8, because this, coupled with other “normal” parameter values, as explained below, resulted in a reasonable total kilo-wattage of initial solar panel installation in the absence of both a government incentive and the new solar electricity buy-back rate; in other words, the total kilo-
wattage initially installed by the turtles was, with this coefficient, on the order of the total solar panel kilo-wattage currently present in Michigan.\textsuperscript{12}

To give a better summary, below is the pseudo-code for our final model:

Setup
\begin{itemize}
  \item initialize patches
  \item initialize turtles
    \begin{itemize}
      \item random environmental friendliness
      \item 0 everything else
    \end{itemize}
  \item get initial satisfaction
    \begin{itemize}
      \item assign money satisfaction based on income
      \item satisfaction = 0.22 * environmental friendliness + 0.0777 * money satisfaction
    \end{itemize}
\end{itemize}

For each tick
\begin{itemize}
  \item spread and hear rumor
    \begin{itemize}
      \item increase/decrease a random neighbor's satisfaction
      \item user-set range and influence
      \item proportional to satisfaction * influence
      \item if media
        \begin{itemize}
          \item takes mean of an area of surrounding satisfaction
          \item affects an area
        \end{itemize}
    \end{itemize}
  \item check energy and money savings
    \begin{itemize}
      \item get normal daily consumption
      \item see how much is saved and spent due to the panels
      \item if saved more than spent
        \begin{itemize}
          \item set a higher money satisfaction
          \item if savings accumulated > cost of buying panel
            \begin{itemize}
              \item set an even higher money satisfaction
            \end{itemize}
          \item if spent > saved
            \begin{itemize}
              \item same as above but set lower satisfaction
            \end{itemize}
        \end{itemize}
      \item check failure of panel
        \begin{itemize}
          \item generate random number from 0 to 480000
          \item if smaller than 10 (failure rate of 1/48000, or 1% in 10 years)
            \begin{itemize}
              \item trash the panel
              \item set money satisfaction to be 0
            \end{itemize}
        \end{itemize}
    \end{itemize}
  \item check satisfaction
    \begin{itemize}
      \item if satisfaction > threshold buy a panel
    \end{itemize}
\end{itemize}

\textsuperscript{12} Source: http://www.michigan.gov/documents/CIS_EO_Solar_Chart_140010_7.pdf
Final Results

The output of our program can be analyzed in many ways. We can learn about the model itself. We can also try to apply our model to real world scenarios, allowing, of course, for lapses in realism.

**How satisfaction spreads with time:** First, we look at how satisfaction spreads with time. Satisfaction is represented in our program interface by a histogram in the bottom right corner of the screen.

![Image](image.png)

*Figure 4: Examining satisfaction on the interface*

We see here a screenshot taken after one time step. Notice that the satisfaction values are clustered at the low end of the range of possible values. This is because satisfaction has not yet risen due to people purchasing solar panels and commencing to save energy and money.
Figure 5: Examining satisfaction on the interface

Here we see a screenshot taken of the same scenario used above, but now after a year instead of a week. The satisfaction histogram is much more spread out now. Some turtles still have low satisfactions, but many have higher satisfactions. Some turtles will always have low satisfactions, due to environmental unfriendliness, poverty, or social exclusion. A neighborhood's overall satisfaction rises when turtles buy panels and save money and then tell their neighbors. Both the turtles who saved money and those who heard about it have higher satisfactions afterwards.

**How income affects results:** Also, it is interesting to note how changing the income level of the neighborhood affects the results.
In Fig. 6, we see a neighborhood with a mean income of $20,000. Out of 669 turtles in the neighborhood, only 264 turtles buy a solar panel after one year. The buying rate decreases quickly after a year.

In Fig. 7, we see a much more affluent neighborhood represented. The mean income here is $150,000. After one year, 575 out of 669 turtles have purchased a solar panel. This is
much higher than the low-income neighborhood, as expected. We also see from Figs. 6 & 7 that the majority of those turtles who did not buy a panel live in clusters. This makes sense; if neighbors are not spreading how great solar panels are, a turtle’s satisfaction will never increase, and the turtle will never cross the threshold to buy a solar panel.

**Varying influence of friends:** Next, we want to investigate the contribution of varying friends’ influence. With higher social influence from one’s friends, more satisfaction will be propagated, and the number of people satisfied will increase at an even faster rate. As the spreading is also dependent on the number of people satisfied, we expect the change in propagation speed to be exponential.

*Figure 8: Examining friends-influence on interface*
Figs. 8 & 9 verify our observation. When friends’ influence is just the same as normal people, it takes 24 ticks to reach 500 solar panels. When friends’ influence is very high, it takes only 11 ticks.

Figure 10: Examining negative friend influence
To make things interesting, we have included the option to set friends’ influence to be negative (an evil friend). This represents people that are distrusted and decrease their neighbors’ satisfaction. Acting as a force pulling people away from the buying decision, a negative friend influence makes the satisfaction spread at a much slower pace. In the settings for Figs. 10 & 11, it takes 369 ticks to converge to a stable solar panel number, and this number is noticeably smaller than when the influence is positive. Fig. 11 plots the satisfaction as a function of color shade, where white denotes extremely satisfied and black not at all satisfied. Comparing the two graphs, we realize that some people are no longer satisfied with the panel even if they have bought it. However, the turtles cannot get rid of their solar panels, so they can only waited for the panels to malfunction. It is also interesting that there is always a network of agents who are always satisfied with the panels. These are agents that have reached a local equilibrium satisfaction by supporting each other.

<table>
<thead>
<tr>
<th>Time for 500</th>
<th>Friends-infl</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>0.9</td>
</tr>
<tr>
<td>13</td>
<td>0.8</td>
</tr>
<tr>
<td>15</td>
<td>0.7</td>
</tr>
<tr>
<td>16</td>
<td>0.6</td>
</tr>
<tr>
<td>18</td>
<td>0.5</td>
</tr>
<tr>
<td>21</td>
<td>0.4</td>
</tr>
<tr>
<td>24</td>
<td>0.3</td>
</tr>
<tr>
<td>30</td>
<td>0.2</td>
</tr>
</tbody>
</table>
In Fig. 12, we did a logarithmic plot of friends influence against the length of time it takes to reach a total of 500 solar panels. The logarithmic plot shows a concave-up curve; hence friends’ influence is related exponentially to time or as a function of even higher order.
Figure 12: Friends’ influence on the length of time to obtain 500 solar panels (log plot)
**Influence of media:** The influence of the media is also an interesting parameter. In Figs. 13 & 14, we plot the number of panels with and without the media. Without the media, Fig. 14 shows just the usual S-shaped curve, where it takes a while before the initial jump, at around tick 17. However, with the media (Fig. 13), the jump occurs much earlier, at tick 6.

Figs. 13 & 14 show that the media can very quickly spread the “rumor”. Nevertheless, media influence is less important than expected, as far as the total time needed to influence the whole area. As seen in the graphs, both Figs. 13 & 14 take around 30 ticks to converge to a total solar panel number of 580. Looking more closely at Fig. 13, we notice that there are in
fact two jumps in the “Number of Panels” graph. The first represents those influenced by the media, when they got persuaded enough by the media to buy a panel; this jump is short and rapid, and falls flat soon after, as the agents remaining are all out of range. The second jump presents those really influenced by their neighbors. Hence, in the end, social satisfaction, and subsequent panel purchase, still depend largely on neighbor influence. The media can spread the “rumor” fast – but not far.

Analysis and Recommendation: Government Incentive and Solar Panel Wattage

Our original goal was an analysis of the effect of a government incentive, such as a rebate, on overall solar energy generation. In order to accomplish this, we needed to define a “normal” region in which we could vary only \texttt{gov-incentive} and \texttt{solart-panel-wattage}, while all other variables remained constant. Our goal was to have the “normal” region be as realistic as possible.

We defined the “normal” region to be the following variables:

\begin{itemize}
  \item \texttt{Friends} = 500 (Half the total number of turtles are friendly)
  \item \texttt{Media} = 2 (Two media sources)
  \item \texttt{Normal-inf} = 0.10 (Normal people had a 1/10 strength of influence)
  \item \texttt{Friends-inf} = 0.50 (Friends had a 5/10 strength of influence)
  \item \texttt{Media-inf} = 0.25 (Media had a strength of influence less than friends but more than normal people)
  \item \texttt{Neighbour-range} = 8 (Neighbours could be in the eight surrounding patches)
  \item \texttt{Media-range} = 50 (Media affected 50 surrounding patches)
\end{itemize}
In this way, **gov-incentive** and **solar-panel-wattage** were the only two parameters to vary.

Presently, Michigan offers zero government incentive, while the federal government offers 30% of the total solar panel cost. These two possibilities were tested three times each (for an average) in solar panel increments of 5 kW. The results are given in Table 2 below.

<table>
<thead>
<tr>
<th>Government Incentive</th>
<th>Solar Panel Wattage</th>
<th>Consumer Cost ($)</th>
<th>Initial S.P.</th>
<th>Final S.P.</th>
<th>Total Energy (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>5 kW</td>
<td>45 000</td>
<td>71</td>
<td>936</td>
<td>5.801</td>
</tr>
<tr>
<td></td>
<td>10 kW</td>
<td>90 000</td>
<td>37</td>
<td>885</td>
<td>10.511</td>
</tr>
<tr>
<td></td>
<td>15 kW</td>
<td>135 000</td>
<td>11</td>
<td>808</td>
<td>13.873</td>
</tr>
<tr>
<td></td>
<td>20 kW</td>
<td>180 000</td>
<td>3</td>
<td>733</td>
<td>16.537</td>
</tr>
<tr>
<td></td>
<td>25 kW</td>
<td>225 000</td>
<td>1</td>
<td>629</td>
<td>16.066</td>
</tr>
<tr>
<td></td>
<td>30 kW</td>
<td>270 000</td>
<td>1</td>
<td>508</td>
<td>16.723</td>
</tr>
<tr>
<td>30%</td>
<td>5 kW</td>
<td>31 000</td>
<td>78</td>
<td>929</td>
<td>5.758</td>
</tr>
<tr>
<td></td>
<td>10 kW</td>
<td>63 000</td>
<td>54</td>
<td>910</td>
<td>11.066</td>
</tr>
<tr>
<td></td>
<td>15 kW</td>
<td>94 000</td>
<td>29</td>
<td>873</td>
<td>15.545</td>
</tr>
<tr>
<td></td>
<td>20 kW</td>
<td>126 000</td>
<td>16</td>
<td>838</td>
<td>19.508</td>
</tr>
<tr>
<td></td>
<td>25 kW</td>
<td>157 000</td>
<td>5</td>
<td>787</td>
<td>22.136</td>
</tr>
<tr>
<td></td>
<td>30 kW</td>
<td>189 000</td>
<td>1</td>
<td>712</td>
<td>24.005</td>
</tr>
</tbody>
</table>

In all cases, the purchase rate leveled out by the end of the time period indicated, so that the estimates could be taken to be representative of the total number that would have been purchased for all time. The first thing to notice from Table 2 is that, while the exact numbers may not be realistic, the overall behavior of our model works as expected; in other words, the
larger and more expensive the solar panel, the less people who can afford to buy it both initially and over time. This trend occurs both with and without a government incentive.

Second, as expected, especially for more expensive solar panels (solar panels > 5 kW), the 30% government incentive results in both higher initial solar panel purchases and a higher number of purchases after 52 weeks, than zero government incentive.

However, the question is, how much total money must the government spend, and how much residential solar energy will be generated in return?

It is interesting to see, in Table 2, the trade-off in energy that occurs between fewer purchases of expensive solar panels and the higher power generation capacity of these panels. “Total energy” refers to the total solar power generated by all the solar panels over time. From Table 2, we see that this number seems to somewhat plateau with zero government incentive, but total energy continues to rise with 30% government incentive. The three highest amounts of total solar power generated are achieved through offering a government incentive.

To achieve the highest amount of solar power generated, 24.005 GWh, the government must spend over $57 million in rebates. To achieve the next highest, 22.136 GWh, the government must spend about $53.5 million. As discussed in Background Research, above, for the year 2008, Michigan projects a total sale of 35,299 GWh of electricity to residential customers. Our projections in Table 2 are for a comparable time period: 52 weeks. With our optimal scenario, Michigan might consider offering a solar rebate similar to the federal government’s solar rebate. If this occurred for the maximum allowable rooftop solar panel, 30 kW, Michigan might generate 0.06 % of its residential electricity demand from rooftop solar panels.
So, is this a viable trade-off? Should Michigan spend almost $60 million to obtain a 0.06% reduction of residential fossil fuel-based electricity generation?

Our recommendation: In the current economic climate, Michigan does not have enough funds for such expenditure. However, our results, although relatively small, are on the order of GWh, which is close to the order of the total residential electrical requirement per year. Therefore, while it may not be worthwhile to implement the government incentive program as is, it may be worthwhile for Michigan to use its Department of Energy grant (a few hundred thousand) to implement a pilot project whereby it investigates the effects of offering a smaller rebate percentage to a smaller number of people.

Future problems

In order to improve the realism of our model and to better model the response of Michigan residents to solar panel rebates, we have identified a few areas of the model that require further exploration.

**Varying population density:** For now, our model simply randomly plants agents. It would be interesting if we could generate agents that cluster together into neighborhoods. If we could also set it so that similar people live next to each other – like in real life where we have the rich sharing one neighborhood and the poor living in another – we should be able to see some interesting interaction along the border of the neighborhoods. Doing such generation, however, is difficult because we have to write our own weighted random generator. This is, nevertheless, an interesting problem to tackle further.

**Varying patches:** Right now our patches are all the same and contribute nothing to the model. However, we could modify patches so that they represent geographical areas with
differing characteristics. For instance, we could have areas that allow the solar panel to produce more kilowatts, representing sunny areas in real life. We could also have areas with increased social influence, representing cities.

**More agent types:** For our current model, we have only 3 types of agents – normal, friends, and media. Potentially we could add more, differently behaving agents. Possibilities include agents that have varying income, agents whose environmental friendliness increase with satisfaction, agents who may die, agents who will get rid of solar panels, and so on.

**Conclusion**

Should the state of Michigan offer an incentive to purchase solar panels above and beyond its newly required buy-back rate for solar electricity? Should this incentive be comparable to the current federal government rebate? We have attempted to answer such a question by creating an agent-based model, using the NetLogo platform, of a community of agents representative of Michigan homeowners. We identified three crucial parameters as influences of solar panel purchase: environmental consciousness, money satisfaction, and social satisfaction. Over about three months, we successfully incorporated these parameters into our model to obtain an overall satisfaction equation. When an agent accumulates overall satisfaction above some threshold, it buys a solar panel and begins generating solar energy with it. We analyzed various permutations of the model parameters, and we determined a “normal” region, in which to study how solar panel purchase, and total solar power generation, was affected by the offer of a government rebate. We determined that a government rebate did clearly, positively affect the acquisition of solar panels. We decided that Michigan should, therefore, indeed study this option further. However, in the current economic climate,
Michigan should probably begin with a smaller-scale pilot project, utilizing some of the funds it received in September from the Department of Energy. More specifically, Michigan should use these funds to hire Project Ikarus to further study this scenario.