A Classroom Simulation of a Tradable Green Certificate Market and Implications for Model Development

Asmeret Bier and Andrew Ford
School of Earth and Environmental Sciences, Washington State University
PO Box 644430, Washington State University, Pullman, WA, 99164-4430, USA
Email: asmeret@wsu.edu

Abstract

Tradable green certificate (TGC) markets are economically driven policy instruments that can be used to increase investment in renewable electricity generating capacity. This type of policy increases revenue for renewable electricity generation units, making the units more cost effective in comparison to conventional electricity generation. An educational classroom game was created to simulate a TGC market, and was played twice with university students. Outcomes of the game varied substantially between the simulations. Strategies for playing the game were discussed with participants, and students were encouraged to analyze how these strategies affected the outcomes of the game. Players' strategies were also used to extend each simulation past the number of simulation periods actually played, and to suggest ways to improve decision rules in system dynamics models of TGC markets.

KEYWORDS: classroom simulation game; market-based policy; renewable energy credits; system dynamics; tradable green certificates; tradable permits

1. Introduction

Many U.S. states have enacted policies requiring the increased use of renewable electricity. Tradable permit programs have been used in the U.S. to reduce air pollution emissions, and have been used to support renewable electricity in Belgium, Italy, Sweden, the UK (European Commission 2004) and Australia (Ford et al. 2007) (see figure 1). This paper describes an educational classroom simulation game, based on a system dynamics model of a tradable green certificate (TGC) market (Ford et al. 2007). The game allows students to act as participants in a TGC market, while learning about the electricity industry, market-based policies, and feedback dynamics. The game also acts as a test of the assumptions in the computer simulation model, to see if real decision makers generate results similar to those produced by the decision rules in the model.

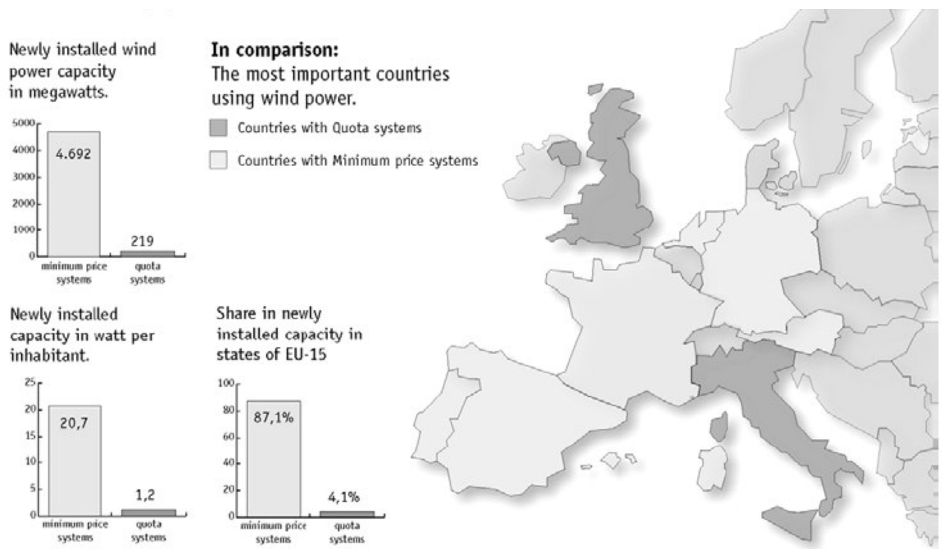


Figure 1: Renewable support policies in Europe. From Fouquet et al. (2005).

1.1. Renewable Energy

Most of the electricity generated in the U.S. today comes from fossil-fueled sources. These sources can have substantial externalities, including pollution from emissions of NO_x, SO_2, and particulate matter, as well as climate change inducing carbon dioxide emissions. Political problems can arise from fossil fuel use because reserves are unevenly distributed and extraction can cause significant environmental damage. Increasing and fluctuating fossil fuel prices are problematic because of society's strong reliance on these fuels. Both price levels and variations may be exacerbated by depleting supplies (Komor 2004). Since renewable energy includes a diverse array of sources, increasing the use of renewable energy will increase the diversity of the electricity fuel mix, leaving the industry less susceptible to risk.

Renewable electricity sources consist of those sources whose use in the present does not decrease the possibility for use in the future. Environmental and social costs exist for all sources of electricity, but the externality costs of renewable energy are much lower than those of fossil fuel generation (Komor 2004). Renewable electricity sources discussed here include wind, solar, biomass, and geothermal. Wind will likely be the biggest contributor to renewable generating capacity, with an estimated 76% of the future market for renewable electricity (Knutson and McMahan 2005).

Despite its benefits, renewable energy, not including hydropower, accounted for only 2% of electricity generation in the United States in 2004 (EIA 2005). One reason for this lack of renewable development is that the cost of renewable generation is still significantly higher than the cost of generation from conventional fossil-fueled sources. Policies such as tradable green certificate (TGC) markets are designed to lower the effective cost of renewable electricity generation to the investor, thus allowing the industry to mature.

1.2. Renewable portfolio standards

A renewable portfolio standard (RPS) is a target percentage of electricity production to be met by renewable sources. Generally, a RPS begins with a low level of required renewable generating capacity and requires incremental increases in renewable capacity over time. An RPS does not specify who is required to participate in the renewable electricity market or what incentives and disincentives will be used to increase renewable capacity. In the United States, 23 states plus the District of Columbia have state-level RPS rules (DSIRE 2006) (figure 2).

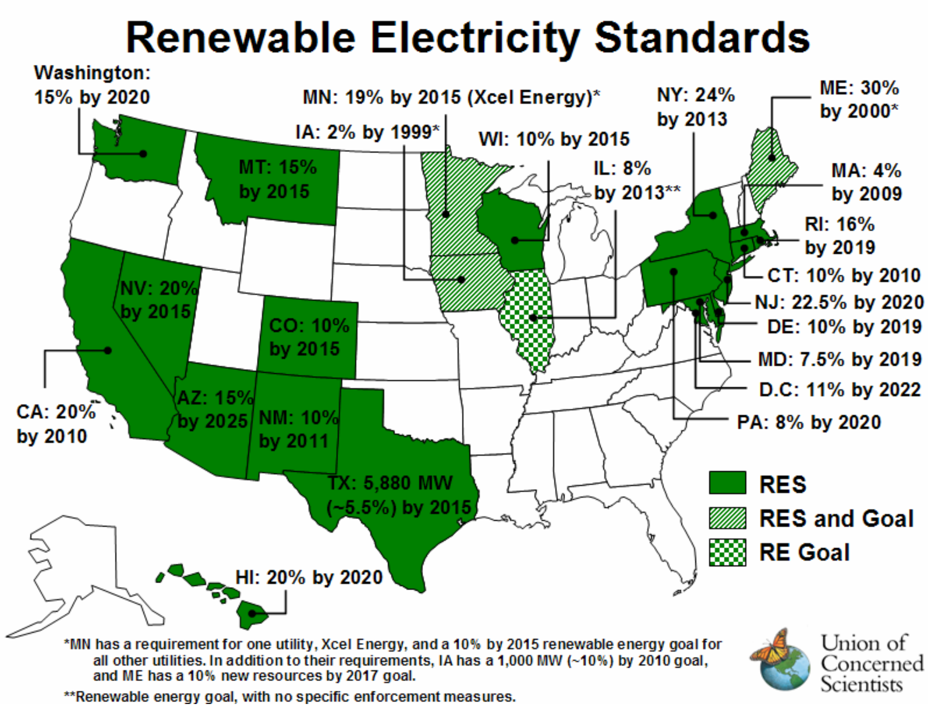


Figure 2: States with renewable portfolio standards. From the Union of Concerned Scientists (2006).

1.3. Tradable Green Certificate Markets

The intent of a tradable green certificate (TGC) market is to reduce the difference between effective costs of generation of conventional and renewable sources of electricity. The wholesale electricity market price is based on the variable cost of the market clearing units. In the western U.S. the units with the highest variable costs are most often fueled by natural gas. Their variable cost is not high enough to allow the wholesale market prices to support investment in either new fossil-fueled capacity or renewable capacity. This means that distribution companies will need to sign long-term contracts at prices above the wholesale price. We assume that these contract prices are likely to be equal to the total levelized cost of new gas-fired combined cycle units, including capital, operating and maintenance costs. This total cost might be around 15 $/mwh lower than the total cost for renewable generation (Ford et al. 2007). Thus, investors in renewable generation need policy support if they are to cover their total costs. If a TGC program increases the revenue of renewable generating companies so that the net cost of renewable generation is the same as that of the conventional alternative, it should spur investment in renewable generating capacity, and hence in the in research and development that will help to make the industry more mature and therefore more competitive.

A TGC program usually begins with the establishment of a renewable portfolio standard. Renewable electricity generators are allocated TGCs based on their electricity production. For example, a generator may receive one TGC for each megawatt hour (MWh) of electricity it generates. The renewable generator is granted certain property rights over the TGC, including the right to sell it. When a TGC program is in effect, electricity distributing companies are required to turn in TGCs in the amount of their electricity sales, or load, multiplied by the RPS. If the RPS requires that 10% of electricity distribution be from renewable sources, then a company that distributes 50 MWh of electricity in a given period would be required to turn in 5 MWh worth of TGCs. The distribution companies (those considered here are not vertically integrated, so are not allocated TGCs) must buy these TGCs from renewable electricity generating companies in a market.

In order for a TGC policy to operate, the government must establish an agency to distribute and collect TGCs, and must establish rules governing market behavior. It must decide what constitutes renewable electricity and which distribution companies are required to participate. RPS targets must be chosen and a penalty must be established for distribution companies that do not meet their TGC obligation in a given time period. For example, the Commonwealth of Massachusetts (2006) established such a penalty which they call an alternative compliance payment (ACP). Calling this penalty an alternative form of payment rather than a penalty allows market designers to avoid giving a negative connotation to penalty payments.

Banking and borrowing of allowances may or may not be allowed. If banking is allowed, companies may save TGCs generated in one period, and turn in or sell those TGCs in later periods. If borrowing is allowed, a distribution company has the option of turning in less than the required amount of TGCs in a given year, but must agree to turn in extra TGCs in a subsequent year to compensate for the deficiency.

TGCs are traded in an entirely new market and their sale is not reliant on the purchase of renewable electricity, although allocation of TGCs to generating companies is based on generation. Thus, a distribution company may buy TGCs without buying any electricity from a renewable source. Renewable generating companies are compensated through the TGC market for the benefits they contribute compared to fossil-fueled sources, so that their total costs of generation are offset by the TGC revenues and they become more competitive within the electricity market.

2. Previous Games Simulating TGC Markets

Games can offer researchers the opportunity to look at market dynamics without any assumptions about behavior of people or firms, since real people are allowed to act as decision makers. Games can also present an opportunity to teach people about TGC markets (Peters et al. 1998). Four games simulating TGC markets are discussed here. See table 1 for a synthesized comparison of the three games that analyze market dynamics and the game discussed in this paper.

de Zoeten et al. (2001) created and tested two TGC games for the European Renewable Electricity Certificate Trading Project (RECerT). The first was a laboratory simulation experiment intended to analyze different market designs with variable penalty prices and levels of banking and borrowing. The game was played on a computer network linked to a model that simulated the behavior of the market (Energy for Sustainable Development Ltd. 2001). Four obligated buyers, two voluntary buyers who resold their purchased certificates, and six sellers participated in the game. It was assumed that there was enough renewable generation, provided by six different technologies, to fulfill demand in the beginning of the game. Renewable capacity was added throughout the game by an investor model, so decisions about construction of renewable capacity were exogenous. Players were not given information about the fundamental TGC price. The game was run 16 times to examine market dynamics with different penalty prices and banking and borrowing situations (de Zoeten et al. 2001). De Zoeten et al. found that if banking were allowed, players would tend to save a substantial amount of TGCs, causing high prices, overinvestment, and subsequent price crashes. Even in cases where banking was not allowed, the TGC price exceeded the equilibrium price through part of the simulation. They concluded that TGC markets are not always cost effective.

De Zoeten et al. (2001) also created and ran a workshop game that was used to teach players how a TGC market might work. This game was played at national TGC workshops in the European Union. In this game, each player was designated as either a buyer or a seller, and interacted with other players to trade TGCs. Prices were exogenous and predetermined and supply and demand were approximately equal, but players did not know either of these things. This game was intended to teach players how a TGC market might work, but did not analyze market dynamics.

Vogstad et al. (2003) created and ran a laboratory simulation game in which players traded TGCs with an interface connected to a model simulating the electricity market. Investment decisions were made by the model rather than players. Five participants acted as buyers and five acted as sellers of TGCs. Unlimited banking and no borrowing of certificates was allowed. The game was run twice, with both simulations resulting in a price pattern that was high in the early part of the simulation and crashed toward the end. They found that while short term price volatility was ameliorated by banking, long term price volatility became stronger when banking was allowed.

Vogstad et al. (2005) created another game simulating a Swedish-Norwegian TGC market. This game was run in Matlab over a computer network. Trading took place continuously, while capacity additions and TGC distribution and obligation requirements occurred once per year. The game assumed that generating capacity has a lifetime of only ten years and that the construction lead time for renewable capacity is two years. Participants were given roles as either producers or consumers of TGCs or investors in capacity. Seven groups of experiments were run, each with a different market design. Variations included whether or not investment was possible and changes in allowed borrowing, penalty price, and interest rate. Information given to the players included, in some simulations, a call-out of total capacity, but no information was shared about the amount of capacity that other players had under construction. Vogstad et al. found that market prices tended to be higher than equilibrium prices, and a subsequent crash in price was likely to occur. They concluded that TGC markets are not efficient.

Category	RECerT Laboratory Simulation	RECerT National Workshop Game	Vogstad et al. Laboratory Experiment	WSU TGC Game
Players	12 University students	Workshop attendees	10-20 University students	20 University students
Roles of Players	• 6 sellers • 4 buyers with obligation • 2 buyers without obligation	• 20%: buyers, low max price • 35%: buyers, high max price • 30%: sellers, low min price • 15%: sellers, high min price	• Buyers (number of players in each role varies by simulation) • Sellers • Investors in capacity	• 2 distribution company teams of 2 players • 8 wind generating company teams of 2 players
Introduction to Players	Explain and assign roles, quiz players on grasp, play a test period	Players given rules, instructions, and market information	Unspecified	Training session on TGC markets, roles, and how game works
Length of Trade Session	6 periods = 6 years	Unspecified: continuous trade throughout exercise	15 years	52 quarters = 13 years
Method of Trade	Computers on a LAN (models)	Physical interaction with other players	Computers (model)	Computers on a LAN (spreadsheets)
Renewable Technologies	Coastal, inland, and offshore wind; large and small biomass; solar	Unspecified	Hydropower, wind, and biomass	Wind
RPS Obligation	Increases linearly from 3% to 6% over 6 years	8 certificates per buyer	200 MWh/yr per buyer initially; increases by 30 MWh each year	1% for 2 years; increases linearly to 15% over the next ten years; levels off
Initial Market Share of RE	3%	Unspecified	Unspecified	1%
Allocation of budget	A budget is given to each buyer at the beginning of each period (year)	No money is allocated; Scores are based on revenues or deficits	No money is allocated; Scores are based on cumulative profits	A budget is given to each seller at the beginning of the simulation

Table 1: Comparison of games simulating TGC markets.

Category	RECerT Laboratory Simulation	RECerT National Workshop Game	Vogstad et al. Laboratory Experiment	WSU TGC Game
Allocation of TGCs	A model determines allocation to sellers each quarter, based on capacity	Each seller is giver 10 TGCs at the beginning of the game.	TGCs are allocated based on capacity owned by each generating company	TGCs are allocated based on capacity owned by each generating company
Capacity Factors	Varies by technology; varies seasonally for all but biomass	Unspecified	Unspecified; no stochasticity	Static at 33%
TGC Units	30 GWh	Unspecified	1 MWh	1 MWh
Banking Scenarios	• Unlimited • Not allowed	Unspecified: continuous trade throughout exercise	Unlimited	Unlimited
Borrowing Scenarios	• Maximum borrowing set at 50% of obligation • Not possible	Unspecified: continuous trade throughout exercise	• Maximum borrowing set at 50% of obligation • Not possible	Maximum borrowing set at 50% of obligation
Penalty Price Scenarios	• 3¢/unit (0.5 times equilibrium price) • 10¢/unit (1.5 times equilibrium price) • 25¢/unit (4 times equilibrium price)	Unspecified	250 NOK/MWh (2.5 times equilibrium price)	$30/MWh (2 times equilibrium price)
Equilibrium Price	6.8¢ per "unit"	Unspecified	100 NOK/MWh	$15/MWh
Initial TGC Price	6.8¢ per unit (equal to the equilibrium price)	Unspecified	Unspecified; different for each trade	$1/MWh
Method of Calculating Prices	Buy or sell offers for price and quantity are made; players may accept these if desired	Prices are determined through negotiations between players	Prices are bid by players; other players either accept or reject the trade	Prices determined based on supply and demand; price applies to all exchanges in that quarter.

Table 1: Comparison of games simulating TGC markets.

Category	RECerT Laboratory Simulation	RECerT National Workshop Game	Vogstad et al. Laboratory Experiment	WSU TGC Game
Players Knowledge of Prices	Players see quantity and price of each offer and transaction, and average price for each year; players are not aware of the equilibrium price	Price development information is given continuously; players are led to believe that they influence the price, but it is pre-determined	Players are given continuous information on TGC price in all transactions	Players are shown the price each quarter that applies to all exchanges occurring in that quarter; players are aware of the equilibrium price
How RE Capacity is Added	A model calculates capacity additions based on production, electricity price, and TGC price	Unspecified: continuous trade throughout exercise	Decisions to invest in capacity are made by players in the role of investor	Wind generating companies choose to add new wind capacity as desired
Lag in RE Construction	One year	Unspecified: continuous trade throughout exercise	Two years	One year
Structure of Voluntary Market	Voluntary demand is determined by model, and players are told at the start of a period the price they will receive per TGC at the end of the period.	Both buyers and sellers have the option of buying extra (not obligatory) TGCs to attempt to sell at a higher price	No voluntary market	No voluntary market
Incentive for Players	Money is paid to each participant based on the size of his or her budget at the end of the game	Reward	Money is paid to each participant based on the size of his or her budget at the end of the game	Reward
Replication	Played 16 times; not all scenarios were simulated; some replication	Played at a workshop in each participating country	Played 14 times	Played twice: once by each of two groups
Repetition of Game by Players	Those who played more than once were given different scenarios	Unspecified	Subjects played the game multiple times	None

Table 1: Comparison of games simulating TGC markets.

3. System Dynamics Model of a TGC Market

The game discussed here is based on a system dynamics model created by Ford et al. (2007). System dynamics is a modeling approach based on systems thinking that was first used by Forrester (1961) to model industrial dynamics, and has recently been explained by Ford (1999) and Sterman (2000). System dynamics models use visual software that represents the model using stocks and flows. These models use coupled sets of nonlinear differential equations, which are solved through numerical integration (Ford et al. 2007). System dynamics modeling is especially useful in analyzing the major feedback structures of a system, and determining how those underlying structures drive the dynamics of the system.

The system dynamics model simulates a TGC market with two participants: a wind generating company, which sells TGCs and invests in new wind capacity, and an electricity distribution company, which buys TGCs. Banking of credits is allowed. Distribution companies are allowed to borrow up to 50% of their obligation in any given time period. Any borrowed TGCs must be paid back within two years. This time period corresponds to twice the one year construction lead time between a decision to build new capacity and that capacity coming on line. The model assumes that players have access to lagged information on the TGC market price, and knowledge of how much capacity is installed and under construction.

Ford et al. (2007) describe the fundamental price as the TGC price required to decrease the net cost of wind generation so that it equals the net cost of conventional generation. In the model, the fundamental price is $15 per MWh of TGCs. The model assumes that wind generating companies will tend to sell certificates if the TGC price is above the fundamental price, and that distribution companies will tend to buy certificates if the TGC price is below the fundamental price. The wind generating company's desired sales are based on the TGC price, the amount of wind generating capacity, and the company's desired amount of holdings of banked TGCs. The distribution company's desires purchases are determined by the company's TGC obligation, the TGC price, and the desired holdings of banked certificates. Decisions about investment in capacity are based on the RPS requirement, as well as the TGC price in recent periods.

Some illustrative results of the system dynamics model are shown below in figure 3. The industry does not begin to build wind capacity for the first few years, causing a low TGC supply, so the price is pushed to the cap early in the simulation. This spurs investment in wind capacity, so that supply of TGCs increases and the price drops below the fundamental price. The industry stays overbuilt in comparison to the RPS, but the TGC price is just above or equal to the fundamental price for the remainder of the simulation.

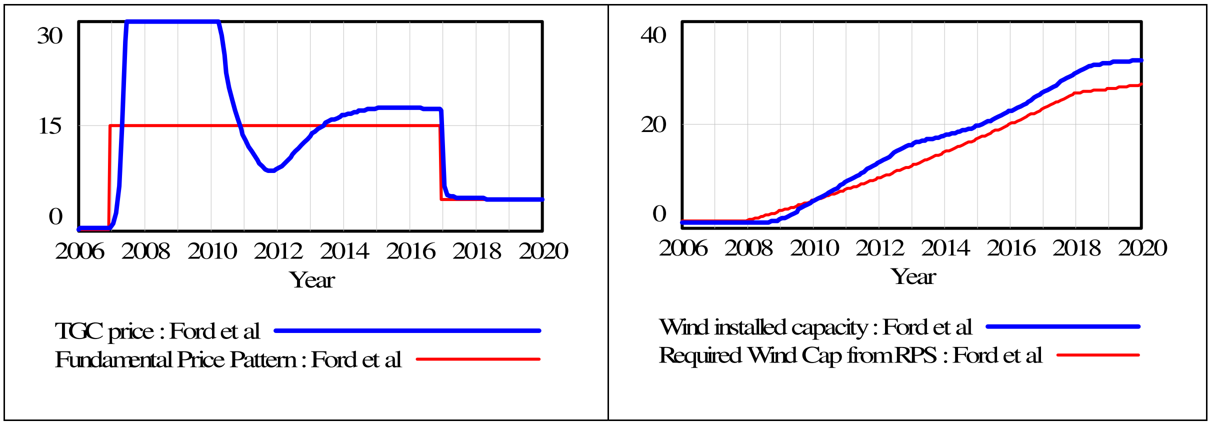


Figure 3: Base case results from the system dynamics model (Ford et al. 2007).

4. The TGC Market Simulation Game

Previous TGC simulation games did not allow the same players who made trading decisions to make decisions about investment in renewable generating capacity. This game does, thereby letting renewable capacity and TGC price mutually affect each other. This is similar to a situation that would occur in a deregulated electricity market, where capacity additions typically include renewable sources only if these sources are cost effective. This game acts as both a test of the assumptions in the system dynamics model and a learning opportunity for students participating in the game.

4.1 Players' Introduction to the Game

Before playing the game, a training session is conducted with all participants. Written information about how electricity and TGC markets operate is given to each player. An overview of the structure of the game is shown below in figure 4. Players are given a short lecture on RPS requirements and TGC markets. They are then shown how the final scores are calculated, and shown examples of a few simple strategies for playing the game. During this session, roles are distributed and players are encouraged to ask questions about the game. Players then participate in a short demonstration of the game, and are shown what information is available during the game.

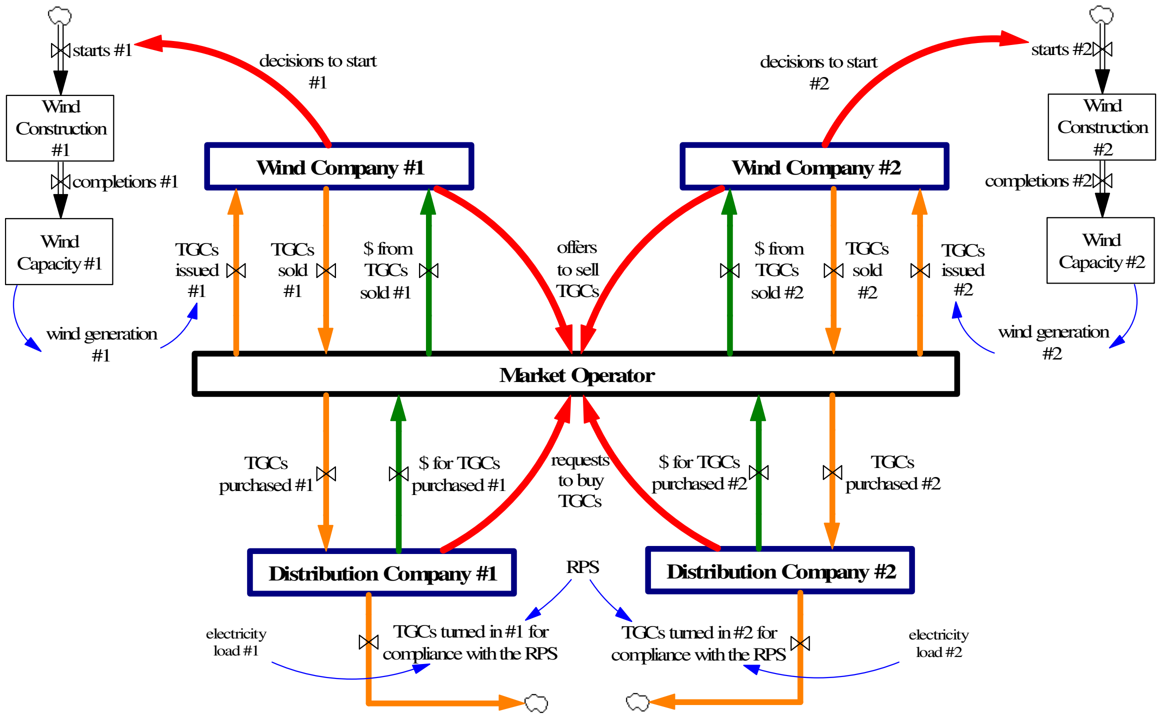
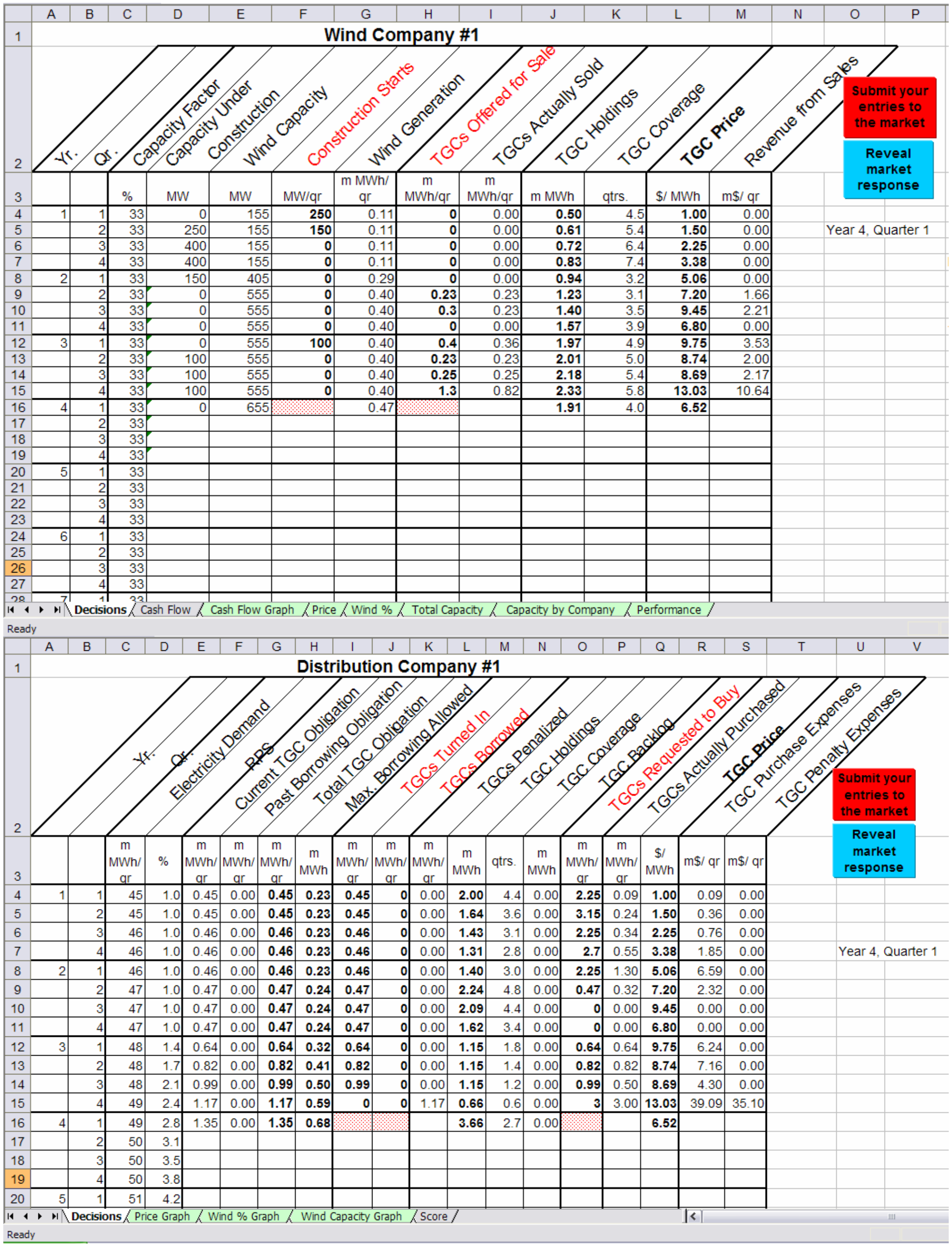


Figure 4: Stock and flow structure of the TGC game, as given to students in the introductory session.

4.2 Logistics of the Game

The TGC game is played on a local area network using linked Excel spreadsheets. Participants play the game in teams of two. Each team is seated in front of a computer, where decisions are registered and information is received. Two teams take roles as distribution companies, and the rest act as wind generating companies. A market operator runs a master spreadsheet and keeps track of time limits. Players are told that the game may be interrupted to discuss how the market dynamics are unfolding.

Each team of two collaborates and submits decisions on a computer. Players' spreadsheets, shown in figure 5, are linked to a master spreadsheet, which updates all information and then makes that information available to the players. The game is simulated in quarters, so that the 13 year game interval involves 52 rounds of play. This interval is one year smaller and involves a much smaller time step than the model, which is necessary for players' attention and interest (Meadows 2001). The RPS obligation is 1% during the first two years, and then increases linearly to 15%, which it reaches at the beginning of the 13th year. The game is stopped before the end of the RPS interval to avoid players discarding large amounts of TGCs in an end-of-the-ramp problem, as explained by Ford et al. (2007).



Wind Company #1

Yr.	Qr.	Capacity Factor	Capacity Under Construction	Wind Capacity	Construction Starts	Wind Generation	TGCs Offered for Sale	TGCs Actually Sold	TGC Holdings	TGC Coverage	TGC Price	Revenue from Sales
		%	MW	MW	MW/qr	m MWh/ qr	m MWh/qr	m MWh/qr	m MWh	qtrs.	$/ MWh	m$/ qr
1	1	33	0	155	**250**	0.11	**0**	0.00	**0.50**	4.5	**1.00**	0.00
	2	33	250	155	**150**	0.11	**0**	0.00	**0.61**	5.4	**1.50**	0.00
	3	33	400	155	**0**	0.11	**0**	0.00	**0.72**	6.4	**2.25**	0.00
	4	33	400	155	**0**	0.11	**0**	0.00	**0.83**	7.4	**3.38**	0.00
2	1	33	150	405	**0**	0.29	**0**	0.00	**0.94**	3.2	**5.06**	0.00
	2	33	0	555	**0**	0.40	**0.23**	0.23	**1.23**	3.1	**7.20**	1.66
	3	33	0	555	**0**	0.40	**0.3**	0.23	**1.40**	3.5	**9.45**	2.21
	4	33	0	555	**0**	0.40	**0**	0.00	**1.57**	3.9	**6.80**	0.00
3	1	33	0	555	**100**	0.40	**0.4**	0.36	**1.97**	4.9	**9.75**	3.53
	2	33	100	555	**0**	0.40	**0.23**	0.23	**2.01**	5.0	**8.74**	2.00
	3	33	100	555	**0**	0.40	**0.25**	0.25	**2.18**	5.4	**8.69**	2.17
	4	33	100	555	**0**	0.40	**1.3**	0.82	**2.33**	5.8	**13.03**	10.64
4	1	33	0	655		0.47			**1.91**	4.0	**6.52**	
	2	33										
	3	33										
	4	33										
5	1	33										
	2	33										
	3	33										
	4	33										
6	1	33										
	2	33										
	3	33										
	4	33										
7	1	33										

Distribution Company #1

Yr.	Qr.	Electricity Demand	RPS	Current TGC Obligation	Past Borrowing Obligation	Total TGC Obligation	Max. Borrowing Allowed	TGCs Turned In	TGCs Borrowed	TGCs Penalized	TGC Holdings	TGC Coverage	TGC Backlog	TGCs Requested to Buy	TGCs Actually Purchased	TGC Price	TGC Purchase Expenses	TGC Penalty Expenses
		m MWh/ qr	%	m MWh/ qr	m MWh/ qr	m MWh/ qr	m MWh	m MWh/ qr	m MWh/ qr	m MWh/ qr	m MWh	qtrs.	m MWh	m MWh/ qr	m MWh/ qr	$/ MWh	m$/ qr	m$/ qr
1	1	45	1.0	0.45	0.00	**0.45**	**0.23**	**0.45**	**0**	0.00	**2.00**	4.4	0.00	**2.25**	0.09	**1.00**	0.09	0.00
	2	45	1.0	0.45	0.00	**0.45**	**0.23**	**0.45**	**0**	0.00	**1.64**	3.6	0.00	**3.15**	0.24	**1.50**	0.36	0.00
	3	46	1.0	0.46	0.00	**0.46**	**0.23**	**0.46**	**0**	0.00	**1.43**	3.1	0.00	**2.25**	0.34	**2.25**	0.76	0.00
	4	46	1.0	0.46	0.00	**0.46**	**0.23**	**0.46**	**0**	0.00	**1.31**	2.8	0.00	**2.7**	0.55	**3.38**	1.85	0.00
2	1	46	1.0	0.46	0.00	**0.46**	**0.23**	**0.46**	**0**	0.00	**1.40**	3.0	0.00	**2.25**	1.30	**5.06**	6.59	0.00
	2	47	1.0	0.47	0.00	**0.47**	**0.24**	**0.47**	**0**	0.00	**2.24**	4.8	0.00	**0.47**	0.32	**7.20**	2.32	0.00
	3	47	1.0	0.47	0.00	**0.47**	**0.24**	**0.47**	**0**	0.00	**2.09**	4.4	0.00	**0**	0.00	**9.45**	0.00	0.00
	4	47	1.0	0.47	0.00	**0.47**	**0.24**	**0.47**	**0**	0.00	**1.62**	3.4	0.00	**0**	0.00	**6.80**	0.00	0.00
3	1	48	1.4	0.64	0.00	**0.64**	**0.32**	**0.64**	**0**	0.00	**1.15**	1.8	0.00	**0.64**	0.64	**9.75**	6.24	0.00
	2	48	1.7	0.82	0.00	**0.82**	**0.41**	**0.82**	**0**	0.00	**1.15**	1.4	0.00	**0.82**	0.82	**8.74**	7.16	0.00
	3	48	2.1	0.99	0.00	**0.99**	**0.50**	**0.99**	**0**	0.00	**1.15**	1.2	0.00	**0.99**	0.50	**8.69**	4.30	0.00
	4	49	2.4	1.17	0.00	**1.17**	**0.59**	**0**	**0**	1.17	**0.66**	0.6	0.00	**3**	3.00	**13.03**	39.09	35.10
4	1	49	2.8	1.35	0.00	**1.35**	**0.68**				**3.66**	2.7	0.00			**6.52**		
	2	50	3.1															
	3	50	3.5															
	4	50	3.8															
5	1	51	4.2															

Figure 5: Spreadsheet interfaces for the TGC game.

Each team begins the game with TGC holdings sufficient to cover their obligation for one year. Unlimited banking of TGCs is allowed by both distribution companies and renewable generation companies, so teams are not required to offer TGCs for sale. Distribution companies are allowed to borrow up to 50% of their current obligation in any given year. Borrowed TGCs become due one simulation year after the quarter in which they are borrowed.

Each quarter, each distribution company must make three decisions: how many TGCs to turn in to the regulating agency, how many TGCs to borrow, and how many TGCs to request to buy. Wind generating companies must decide how many TGCs to offer for sale and how many MW of capacity to begin to construct. Construction comes on line four quarters after the decision to build is made.

Players are given various graphs and other information to assist them in making their decisions. All players are given graphs of the TGC price over time, the amount of wind generation as a percentage of electricity load, and wind capacity both online and under construction. Each team is also shown a graph of their score, which is based on financial earnings. Wind generating companies are given a table and graph of their company's cash flow to keep track of whether their construction decisions have been profitable, as well as a graph showing capacity on line and under construction for each company. All information about capacity under construction has a one quarter information lag, so that construction that begins in one quarter will not be visible until two quarters later.

Players are told that the fundamental price of TGCs is $15 per MWh. The TGC price at the beginning of the game is $1 per MWh. There is a price cap of $30 per MWh, twice the fundamental price, and a price floor of $1 per MWh. A 33% capacity factor for wind generating capacity is assumed, and there is no stochasticity in renewable generation; as soon as wind capacity comes on line, it generates electricity steadily at 33% of its nameplate capacity. If distribution companies are unable to turn in obligated TGCs in a given quarter, a penalty equal to the price cap is charged for each obligated TGC not turned in or borrowed.

After the game is completed, a winning wind generating company and a winning distribution company are identified. The winning distribution company is the company with the lowest total cost of compliance. The winning wind generating company is the company with the highest net profits. A small award is given to all players on winning teams.

5. Results from the TGC Market Simulation Game

The TGC market simulation game was run twice. Players were recruited from classes at Washington State University, and participated in a training session as described above before playing the game. The games were stopped after a few simulation years to answer questions and discuss strategies, and a debriefing session followed a few days after each game was played.

5.1 Results from the First Simulation

The first TGC game was played with eight undergraduate environmental science students, all of whom were taking a class in system dynamics modeling of environmental systems. The group was split into teams of two, with two teams acting as electricity distribution companies and two teams acting as wind generating companies. The game was run for 10 simulation years, before the allotted time for playing the game ran out. Results of the first simulation of the TGC game are shown below in figures 6 and 7.

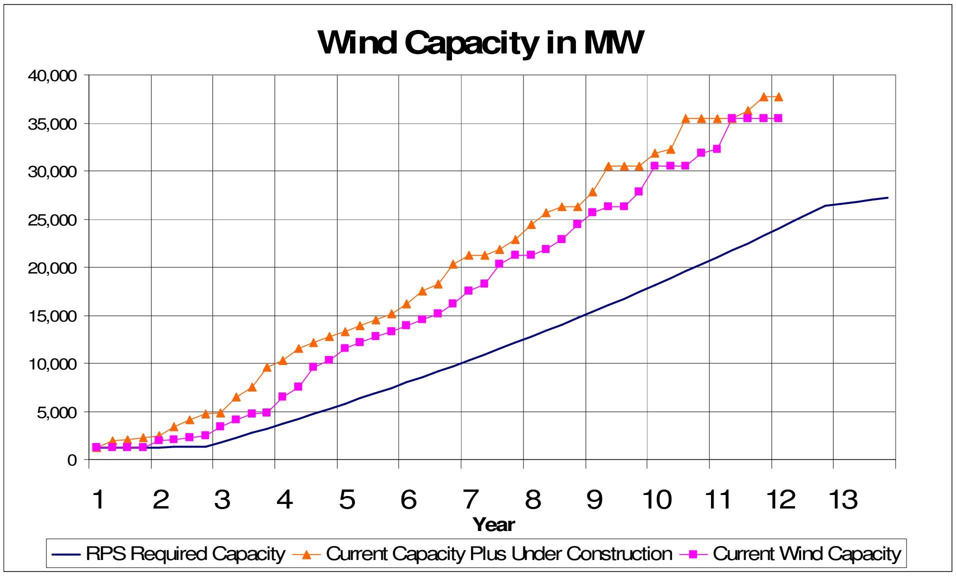


Figure 6: Wind capacity in MW from first game simulation.

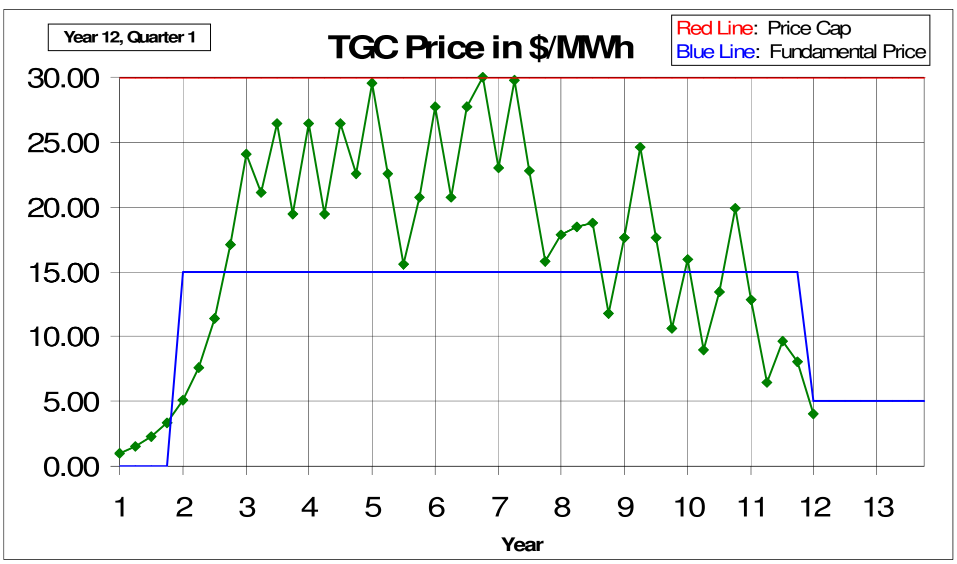


Figure 7: TGC price from second game simulation.

The teams acting as wind generating companies built enough wind capacity to cause wind generation to exceed the RPS throughout the simulation (figure 6). However, the TGC price was above the fundamental price for the majority of the simulation (figure 7). Since supply exceeded demand, the high TGC price was questioned by some of the players.

In the first few quarters of the simulation, the distribution companies requested very large amounts of TGCs (figure 8), that could not be met by the supply. This behavior was eliminated in the second simulation by putting restrictions on the amount of TGCs that a distribution company could request.

The wind companies offered less than the amount of electricity generated in many of the simulation periods (figure 8). They were taking advantage of the banking provisions, and understood that a lower supply would keep the price elevated. The distribution companies, on the other hand, displayed an erratic behavior in their requests to buy TGCs. The distribution companies found that because of the wind companies' strategies, there simply were not enough TGCs on the market to allow them to build TGC holdings as they desired; sometimes the distribution companies were therefore forced to pay penalties. Since the penalty price was set to be equal to the price cap, the distribution companies often requested very low amounts of TGCs when the price was at the cap, causing the price to fall, then requested exorbitant amounts of TGCs whenever the price was not at the cap. The wind generating companies held much of the control over the TGC price, but distribution companies' behavior caused the price to fluctuate from the wind companies' desired pattern.

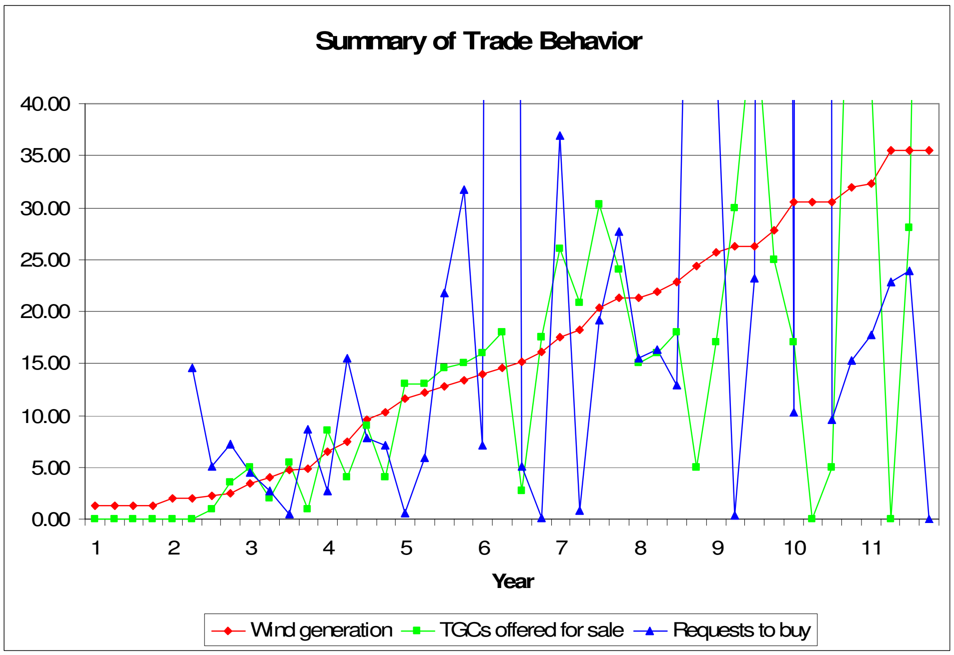


Figure 8: Summary of trade behavior from first simulation.

5.1.2 Extended Results from the First Simulation

By the end of the first simulation of the TGC game, wind generating companies had built substantially larger amounts of wind capacity than was required by the RPS. The price of TGCs had also begun to fall. This led us to wonder how the wind generating companies would have fared if the game had been run for a longer period of time.

To analyze the affects of the overbuilding patterns seen in the game simulation, we extended the game results through year 20. Decisions were figured automatically. From conversations with players, it was clear that they did not intend to build further wind capacity, so no capacity was added. Wind companies offered TGCs for sale in the amount of their generation each quarter, and distribution companies requested the amount of their obligation. The results of the extended simulation game are shown in figures 9 and 10 below.

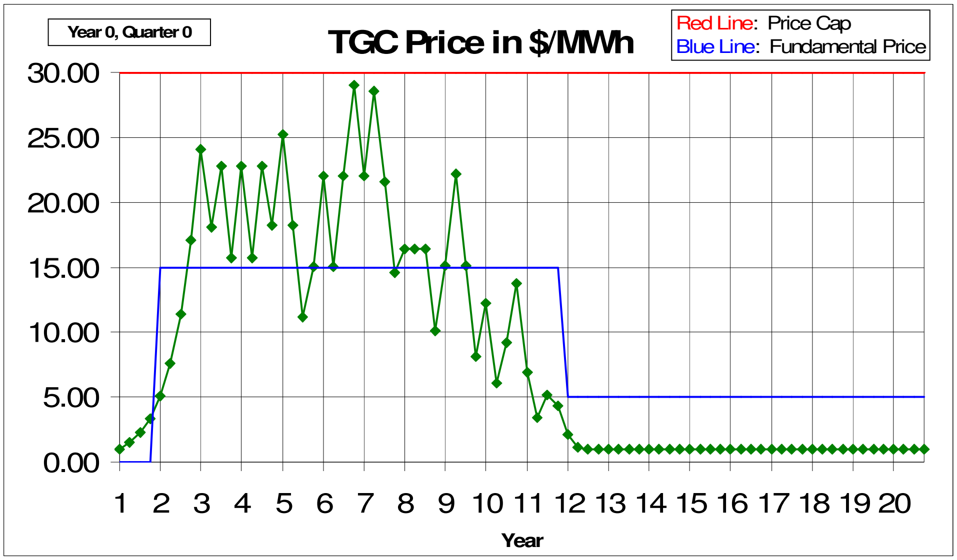


Figure 9: TGC price from the extended simulation of the first game.

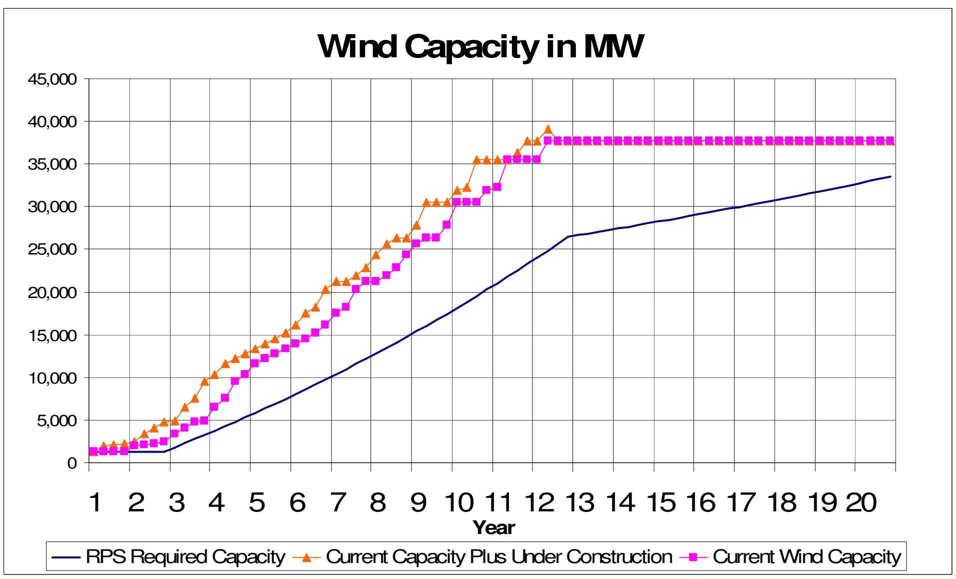


Figure 10: Wind capacity from the extended simulation of the first game.

Because of the drop in price, both wind companies would have gone bankrupt within one year after the simulation ended. One of the wind companies, in fact, had a negative account balance beginning in the quarter in which the original simulation ended. The overbuilt system therefore doomed both wind companies to bankruptcy in the long run.

5.1.3 Game Debriefing for the First Simulation

After playing the game, participants took part in a debriefing session. During this session, the players were shown the system dynamics model, and encouraged to look for the feedback loops in the system. For example, the players' decisions determined how much wind capacity was added, which affected decisions about purchases and sales, which affected the TGC price, which affected decisions about how much wind capacity to add. Players were encouraged to discuss their strategies, and to analyze how these strategies affected the dynamics of the simulated TGC market.

One of the things that students noticed was that the dynamics of the TGC price did not match their expectations prior to playing the game. Some students expected the price to equilibrate near the fundamental price. However, banking caused a low supply early in the simulation, leading to a spike in TGC price within the first few years. Students who acted as distribution companies initially accused the wind company teams of trying to manipulate the market price to the detriment of the distribution companies, but later realized that the teams' desire to bank certificates was not necessarily intended to keep the TGC price artificially high.

When the players saw the price hit the cap early in the simulation, they assumed that it would be possible to keep the price near the cap for the remainder of the simulation. Although wind companies knew that the fundamental price was all that was needed to make a profit, their expectation of a high price from the early part of the simulation led them to believe that they should offer to sell fewer TGCs when the price was below the cap, thus leading to the high prices seen throughout the simulation. The distribution companies were not able to purchase enough TGCs to create sufficient holdings (in their opinions), so they requested TGCs even when the price was substantially higher than the fundamental price.

Both wind companies had similar amounts of capacity near the end of the simulation. However, one of the wind companies built earlier than the other. Since the capacity built by this company had more time to generate TGCs, the team that built earlier had the most revenue, and was therefore the winning wind company. The early building strategy therefore paid off in the short run, but as seen in the extended version of the game, the team was nevertheless doomed to bankruptcy.

5.2 Results from the Second Simulation

The second time that the TGC game was played, participants were recruited from the electrical engineering department at Washington State University. Ten teams played the game, with two teams acting as electricity distribution companies and 8 teams playing the parts of wind generating companies. The game was stopped after 10 simulation years because of time restrictions.

Players acting as wind companies built capacity in excess of the RPS requirement early in the game (figure 11), causing a surplus of TGCs for the first half of the simulation. The TGC price (figure 12) stayed below the fundamental price during this time. In years five through seven, wind capacity dropped below the RPS requirement. Starting in year seven, the TGC price began fluctuating above and below the fundamental price. Players then began constructing more wind capacity, raising it significantly higher than the RPS requirement for the remainder of the game.

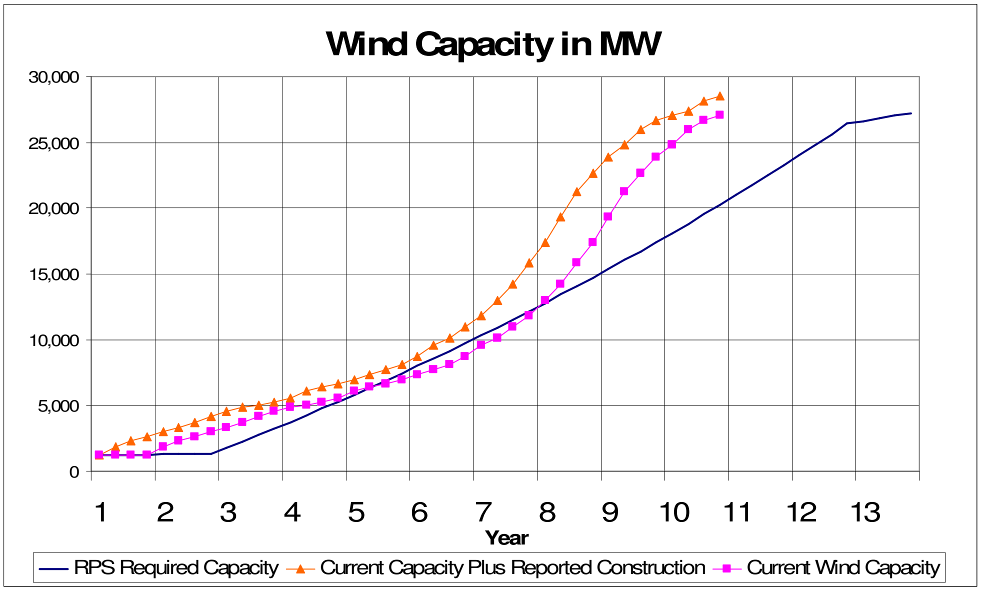


Figure 11: Wind capacity in MW from second game simulation.

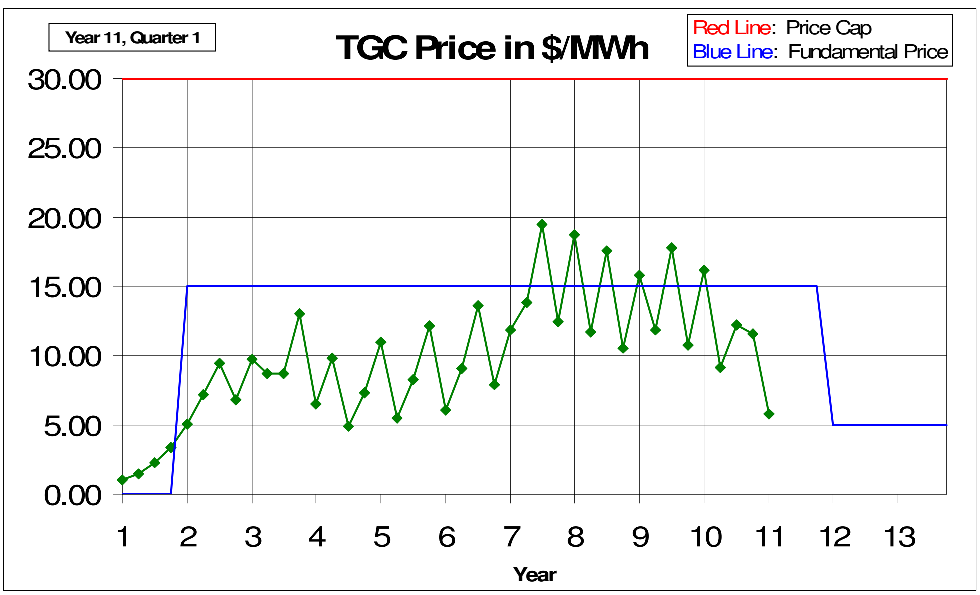


Figure 12: TGC price from second game simulation.

Beginning in year two and continuing throughout the simulation, the TGC price exhibits a fluctuating pattern that can be attributed to the cobweb theorem, and is similar to a hog cycle (Ezekiel 1938, Harlow 1960, Stein 1992). The supply and demand in one quarter determines the price for the next quarter, which creates the fluctuating pattern. At the end of year two, the price dropped due to shifts in supply and demand. Demand in that quarter exceeded supply, causing the price to rise in the next quarter. Players viewed this pattern and supply exceeded demand in the following quarter, and so on, as shown in figure 13.

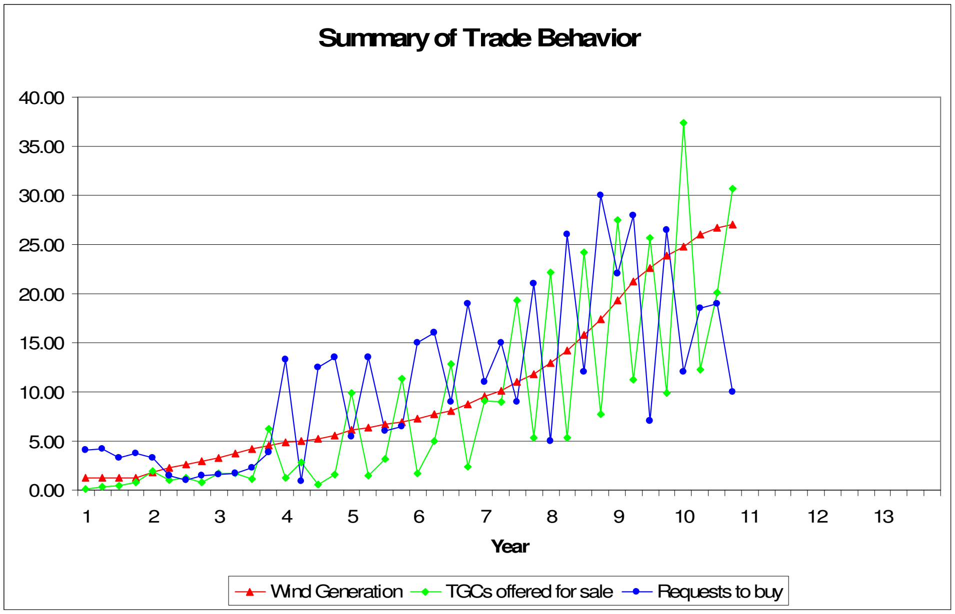


Figure 13: Summary of trade behavior from game simulation.

The winning wind generating company team had the second highest amount of capacity by the end of the game (the second place team held the largest amount of capacity), as shown in figure 14. Scores determining the winners of the game were based on the sum of the teams' account balances and cumulative payments to stockholders. While the account balances of the heavily building wind company teams were low by the end of the game, each of these two teams had paid significant amounts to their stockholders, thus increasing their net score (figure 15).

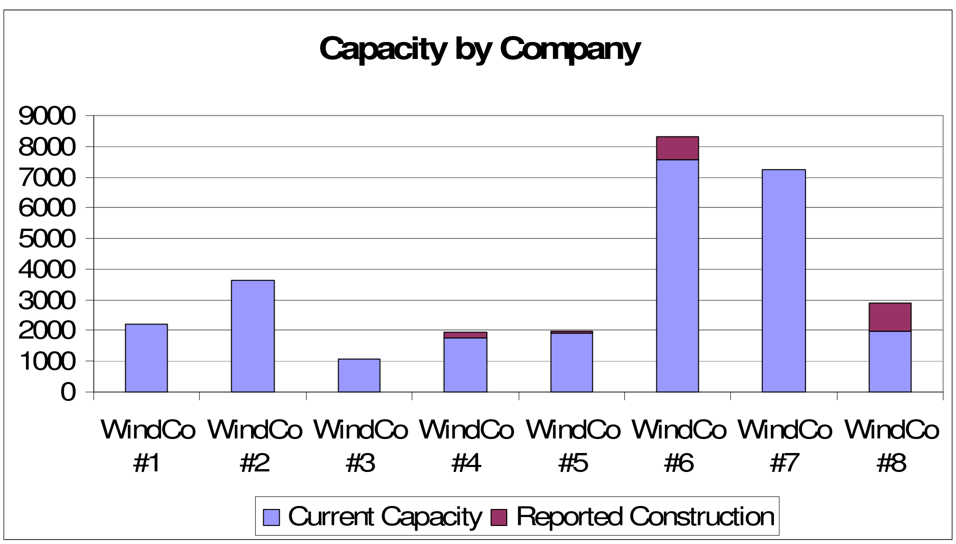


Figure 14: Installed capacity for each wind generating company team at the end of the game simulation. Companies 6 and 7 were the winners.

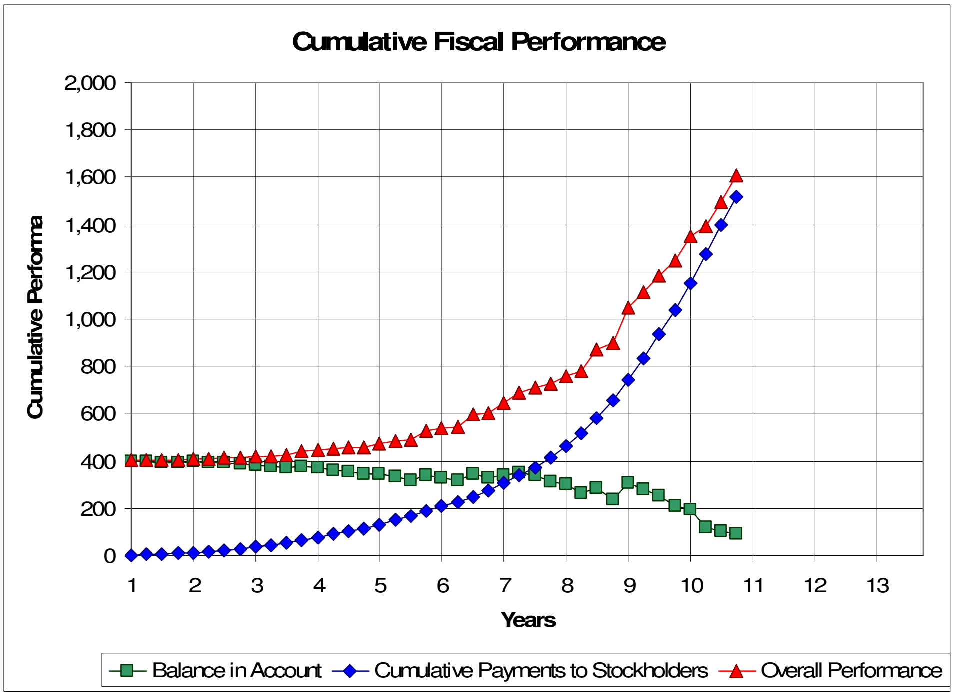


Figure 15: Cumulative fiscal performance at the end of the game for one of the winning wind companies.

5.2.1. Extended Results from the Second Simulation

Results from the second simulation of the TGC game were also expanded, using the same decision rules as in the expansion of the first simulation. The results are shown below in figures 16 and 17. The extended TGC game resulted in all wind companies going bankrupt. All but one of these companies had negative account balances by the 14th year, and the last went bankrupt in the 18th year. Although the capacity was on target by year 16 and below the target after that, the TGC price did not exceed the fundamental price for the duration of the extended simulation. The excess production of TGCs earlier in the simulation allowed all companies to build their TGC holdings. The price stayed low, and overbuilding in the early portion of the game doomed each wind company to bankruptcy in later years of the simulation. Short term benefits thus led to long term problems.

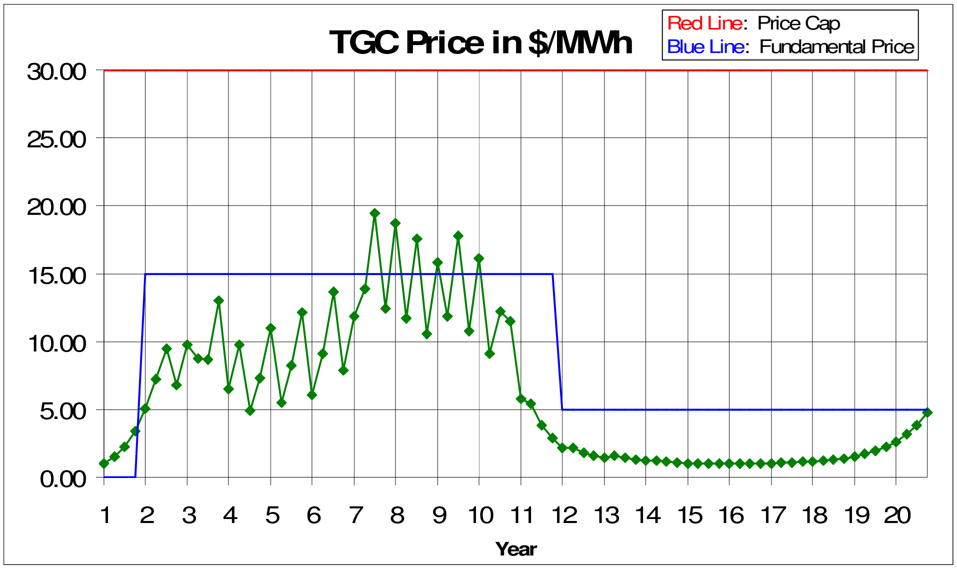


Figure 16: TGC price from the extended game simulation.

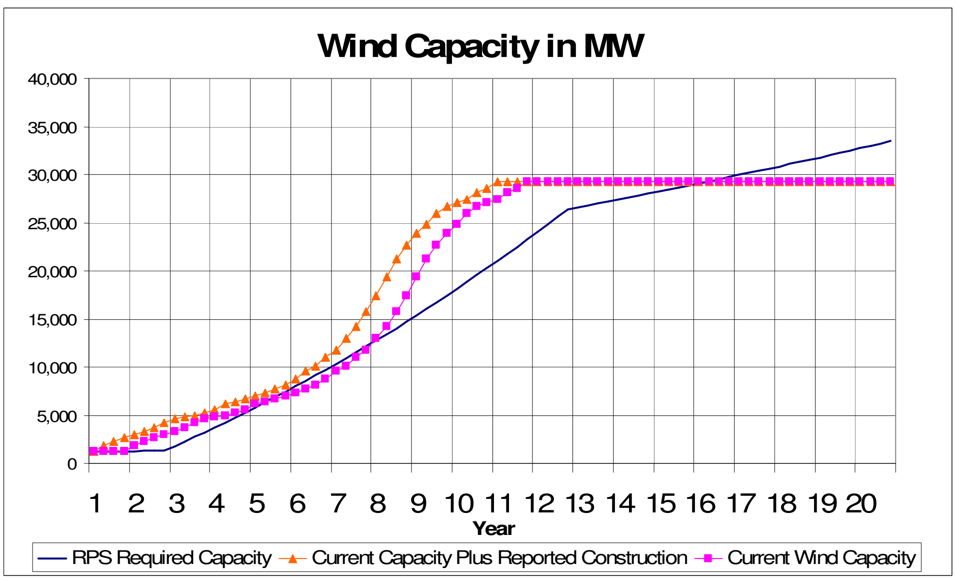


Figure 17: Wind capacity from the extended game simulation.

Contrary to the results of the system dynamics model, the TGC price never reached the cap during the second simulation. This can be explained by the aggressive building strategies applied in the early years of the game by some wind companies. TGC holdings, as described above, were allowed to build during these early years. Therefore, the TGC price was not above the fundamental price for more than one consecutive quarter, even though the wind capacity was below the RPS requirement at some points during the simulation.

5.2.2 Game Debriefing for the Second Simulation

The two highest scoring wind companies built more wind capacity than the other six generating companies combined (figure 14). By the end of the game, constructed wind capacity exceeded the RPS requirement, and had achieved 16% of total electricity load. Players were shown the results of the extended game, and told that each of the companies would have gone bankrupt in the long term. The winning wind company teams explained that they were optimistic about the TGC price rising and they felt competitive with one another.

Nearly all players had recognized the fluctuations in the TGC price. The distribution companies explained that once they had recognized this pattern they assumed that they should not have to buy TGCs for more than the fundamental price. As soon as this pattern was recognized, its continuance was ensured. Players were also aware that the game would be stopped at the end of the RPS interval, so ignored some of the long term consequences of their actions.

The two wind company teams who built large amounts of capacity mentioned market domination as a goal in choosing their strategies. Both teams believed that more capacity would give them more power to manipulate TGC prices. These two teams caused a substantial amount of the overbuilding in the simulation. Other wind company teams noticed this overbuilding and limited their capacity additions. This reinforced the market power held by the teams with larger amounts of capacity.

8. Implications for Model Development

The decision making strategies used by players during the TGC game suggests some possible ways to improve decision rules in the system dynamics TGC market model (Ford et al. 2007). While players did consider the information that the model's decision rules are based on, they also took other information into account when making decisions.

Price patterns early in the simulation played a large role in players' expectations of future price. In the first simulation, the early price pattern seemed to have a larger role in expectations than did the fundamental price. If fluctuations appear in the TGC price, decision makers will likely try to take advantage of the situation, possibly resulting in further price fluctuations.

Players who built large amounts of capacity early in the simulation tended to earn more money through the TGC market, and many of the players anticipated this result. It should also be kept in mind that decision makers might build large amounts of wind capacity in efforts to gain market power.

6. Conclusions

Through playing this game, students were able to learn about TGC markets in an interactive environment. Topics including renewable electricity, policy design, market-based policies, and accounting were all incorporated into the game. Discussions encouraged players to incorporate systems thinking concepts into the experience. Students learned about how price fluctuations can occur, and the implications of such fluctuations in tradable green certificate markets.

Both of the simulations allowed insight into actual decision making processes, and therefore suggest ways to improve the system dynamics model. These suggested changes would alter the decision rules of actors in the model, including decisions to buy and sell tradable green certificates and decisions to build wind capacity. While serving as a learning tool for participating students, the TGC game thus also represented a valuable tool for modelers looking for information on which to base decision rules.

Large fluctuations in the TGC price were seen in both the system dynamics model and both game simulations. While it might be expected that the system would equilibrate with the TGC price near the fundamental price, this has not been the observed pattern. This result shows that optimal outcomes cannot be relied upon, and that the fundamental price is not necessarily a fair estimate of price in a TGC market. If such a pattern is undesirable to policy designers, other policies might be considered that do not require a market to find its own equilibrium. Fixed feed in tariffs and production tax credits are two policy options that could eliminate this problem by creating exogenously defined benefits for generators of renewable electricity.

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