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An Analysis of Malaysian Renewable energy target using Simulation Modelling Approach

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Abstract

Malaysia's *electricity generation depends heavily on fossil fuels. To diversify the fuel-mix the Malaysian government set a technology specific target in 2011. The dynamic complexity of generation capacity expansion decision requires for development of an assessment model to evaluate the policy target. For this purpose, System dynamics modelling and simulation approach is used in this project. The model comprises of four sub-sectors: planning and permitting; construction; renewable operational capacity vintages, and investment decision. The time varying interactions between sub-models generate the dynamic behavior of the system. The simulation reveals a failure to achieve the renewable capacity target of 985 Mega-Watts by 2015. The model adds to the renewable energy policy development literature particularly in Malaysian context.*

Keywords: Renewable capacity, system dynamics, energy policy, Malaysia, Cybernetics.

Introduction

Electricity demand in Malaysia has risen dramatically in recent years due to impressive economic growth and modern development[1]. The economic growth measured by GDP, and electricity consumption exhibit an exponential growth. This trend can be seen in figure-1. The interdependence of economic growth and electricity consumption for Malaysia has been verified by Chandran et al.[2] It is estimated that electricity demand can reach 274 trillion Watt-hour by 2030[3]. To meet electricity, Malaysia relies on fossil fuels for electricity generation: natural gas contributes 65%, coal 28%, and diesel 2% [4]. Nuclear power is not in supply chain presently, but its consideration is high on government's agenda[5]. There are 2.4 trillion cubic feet proven natural gas, 5.8 billion barrels of proven oil reserves, and 280.8 million tons of coal reserves in the country. It is estimated that oil reserves will only last for 18-20 years, and natural gas for 30-35 years[6], whereas coal for power generation is already an imported commodity[4]. Thus the inevitable fossil-fuel depletion and import dependency poses a threat to sustainable electricity generation in Malaysia.

In order to diversify the fuel mix for electricity generation, Malaysian government introduced renewable fuels for power generation in Fifth Fuel Diversification policy in 1999[7]. Subsequently, in 8th (2001-2005), 9th (2006-2010), and currently in 10th Malaysian Plan (2011-2015) it has been targeted to have more than 5% of total electricity to be generated using renewable resources. Despite abundant renewable resources[8], the share of electricity generated by such resources is less than 1%[9]. The total potential of various renewable energy (RE) technologies for power generation in Malaysia is given in table-1.

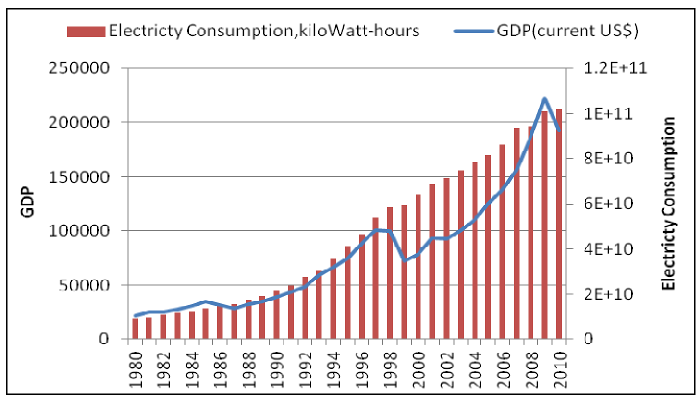

Figure-1
Malaysia economic development and electricity consumption

Table-1
Comparison of renewable energy potential in Malaysia and 10th Malaysian Plan target, Mega-Watts(MW).Source: Sovacool and Drupady[11] and 10th Malaysian Plan

RE source	Potential	Target in 10th Malaysian Plan
Biogas	1,300	100
Biomass		330
Hydropower	22,000	Not included
Mini Hydro	500	290
Municipal solid waste	400	200
Solar photovoltaic	6,500	65
Total	30,700	985

Malaysia electricity sector has been discussed by a number of researchers like Oh et al.[4], Chua et al.[6], Ong et al.[7], and Jafar et al.[10]. Some have discussed the problems facing power projects like Sovacool and Drupady[11]. From the literature review it is found that these researches are all qualitative in nature, describing renewable power generation potential, challenges and any recommendations only. The complexities, interactions of various dynamic factors within the industry are largely ignored. Therefore, the model in this research taking the policy makers' perspective tries to present a dynamic interlinked model. For this purpose, a dynamics modeling approach known as System dynamics is adopted. System dynamics incorporates non-equilibrium assumption of system delays, and bounded rationality of decision making agents being involved[12]. These conditions prevail in electricity sector in the form of changing demand, long lead times due to permitting and sitting decisions, and delays in construction of power plants, and imperfect foresight of decision makers in decision making. It is desired from the model to provide insights regarding the dynamics of generation expansion as oppose to making a point forecast.

System dynamics helps in understanding the behavior of complex systems. These systems include dynamics social-technological-economic-political systems. The focus of system dynamics is to show how structure and decision making principles within the system generates its behavior[13]. Particular attention is given to feedbacks in a system. System dynamic methodology had been used to analyse various systems such as container terminal system[14], water management system[15], health system[16] and many others. In this paper we apply the method to investigate the dynamic interaction of policy target and RE electricity generation capacity expansion.

System dynamics modelling and simulation technique has been successfully use in electric power sector around the world. It had been used to model national level power generation sector by Qudrat-Ullah and Davidsen[17], and Fuentes-Bracamontes[18]. The former looked into the effect on power generation system by a policy of supporting Independent Power Producers, whereas the latter focussed on finding the effect of market competition after deregulation of sector. Ochoa[19], and Ochoa and Ackere[20] basing their research on electricity import and export, generation capacity expansion and evolving power sector structure tried to evaluate the country's capability in meeting the future demand of electricity. Like in any other sector, investors in electricity generation are motivated by the profitability of their investment[21]. However, imperfect foresight of future results in, over and underinvestment that affects reserve-margin of power system and in turn, affects profitability[22]. Olsina et al.[22], Arango[23], Assili et al.[24], Burcu et al.[25], and Hasani-Marzooni and Hosseini[26] focussed on wind power in their respective models to evaluate the possibility of augmenting fuel mix with renewable sources. These authors however ignored other renewable sources in their studies. Thus, myriad of studies in last decade using system dynamics in electricity generation sector qualifies the methodology to be employed in this research. However, this research is unique as it applies simulation approach in analysing target achievability question. The aim of the model is to assist the policy makers in gaining knowledge through simulations on the issue of achieving the set target. The focus of the model is elucidating the role of dynamic complexity in achieving the RE capacity target. At present the Malaysian policy objective is to have 985Mega-Watt (MW) of renewable electricity generation capacity.

Methodology

Causal loop diagram: Figure-2 shows the causal loop diagram (CLD) of RE capacity target model developed in this study. The system variables are linked by arrows showing the influence whereas, polarity of each loop marked shows whether the loop is a reinforcing (positive) or a balancing (negative) one. The model behaviour is generated by the interaction of negative and positive loops[12]. The construction loop is a negative loop due to the presence of *Indicated capacity* variable. As the *Renewable capacity in operation* increases the difference between it and *Target capacity decreases,* i.e. the *indicated capacity* variable decreases with increase of *Renewable capacity in operation* value. *Indicated capacity* shows the amount of capacity that is required to be constructed in order to achieve the policy target; hence *Renewable investment rate* variable is influenced. With certain annual investment rate the renewable capacity enters planning stage. This stage indicates the regulatory requirements to be satisfied before any construction permits are endorsed. At planning stage exogenous variables p*lanning failure rate* and *planning lead time* determine the number of projects that are eligible for construction permits. The successful projects are modelled as *Renewable capacity under construction*. It should be noted that power plant construction incurs a delay, before any RE capacity can become operational. The delay in the system is shown by a double line on the link between *Renewable capacity under construction* and *Renewable capacity in operation* variables.

On the other hand, the amount of *RE capacity online* influence *market experience* variable. As it takes time to change attitude a delay is incorporated. From there on, the investors' loop follows the same path as a construction loop, through an *investment decision*, *RE capacity in planning*, *RE capacity under construction*, *RE capacity online*, and finally closing the loop at *investors' confidence*. This completes a positive loop. The use of positive and negative loops implies that over the course of time the variables in this loop will increase or decrease in their values, respectively. The use of *Market experience* variable in this model signifies the learning effect. It based on the assumption that larger the *RE capacity online* greater is the *Market experience* in RE technologies resulting in more investments. *Total lead time*, which depends on three other time factor shown in figure-2, is exogenous to system. It influences investment decision inversely.

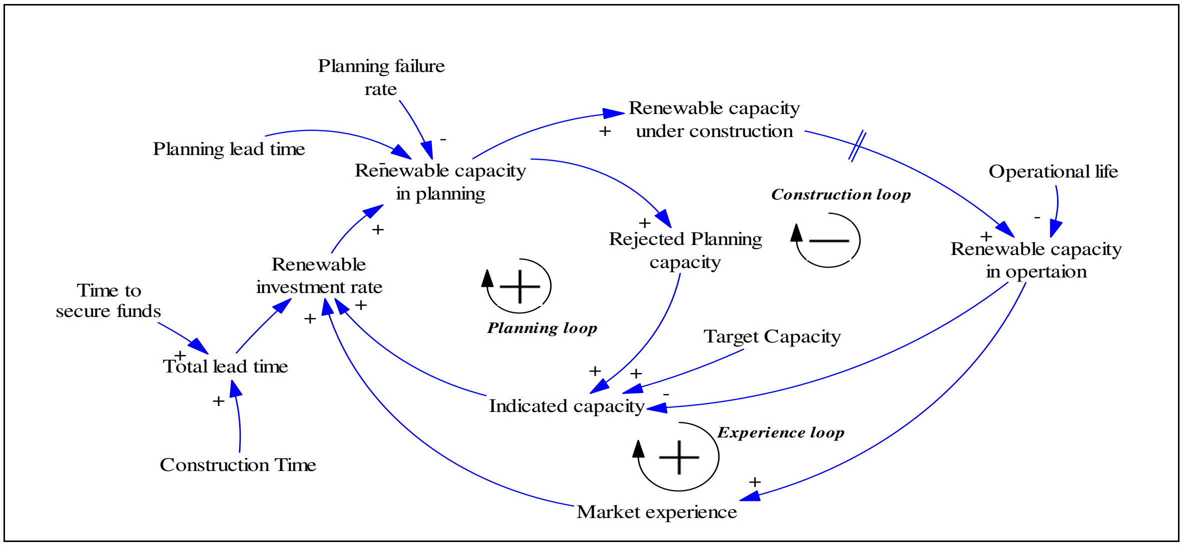

Figure-2
Causal loop diagram of RE power capacity target

Simulation model: For computer simulation the qualitative CLD is converted into a stock and flow diagram. The model consists of 4 sub-models: planning and permitting; construction; RE operational capacity vintages, and investment decision. The simulation model is shown in figure-3. The model being at an aggregate level does not differentiate between various renewable technologies available in Malaysia. Also, the model developed in this study did not take into account any land requirements for RE technologies for power generation. The reason for this was that land requirement for different technologies varies significantly and it seems inappropriate to sum that variation in a single variable. Moreover, the study focuses on RE capacity and set capacity target. The operational capacity is equally divided into three categories: new, intermediate, and old, depicting vintage stages. This division reflects reality as the capacity increments are discrete. Table-2 summarizes the equations used in the model.

To model market experience in the system, a dimensionless variable of *Market experience is used.* This approach removes any biasness by making use of *Total RE operational capacity* and *RE target capacity* ratio. This can be seen in equation 1.

Market Experience = *f* (Total RE operational capacity / RE target capacity) (1)

The value of *Market experience* varies between 0 and 1.

Model calibration: The simulation model is calibrated to the data obtained from National Energy Balance[27] and 10th Malaysia Plan. Initial generation capacity values used are: 306MW in planning, 107MW under construction, 41.2MW currently installed, and 985MW to be the target capacity. The time estimates used are: 6 months for obtaining a planning and sitting permit, 1 year for construction, and 6 months to get funds. Further, an average life 30 years of RE technology is considered in the model[28].

Table-2
Simulation model's parameters and formulas

Item	Parameter	Formula
1	RE capacity in planning(t)	= RE capacity in planning(t-dt) + (investment rate – commence construction – project discontinued) * dt
2	RE capacity under construction(t)	= RE capacity in construction(t-dt) + (commence construction – construction completion) * dt
3	RE capacity New(t)	= RE capacity New(t - dt) + (construction completion – Interim Capacity) * dt
4	RE capacity Interim(t)	= (RE capacity New/ (Operational life of power plant/3))
5	RE capacity Old(t)	=RE capacity Old(t - dt) + (Old Capacity) * dt
6	Rejected capacity(t)	= rejected capacity(t - dt) + (project discontinued) * dt
7	Investment rate	= planned investment/avg lead time) * Market experience
8	Projects discontinued	= fraction of project discontinued * RE capacity in planning)/ Planning time
9	Commence Construction	= (RE capacity in planning * (1-fraction of project discontinued)) /Planning time
10	Construction completion	= RE capacity in construction / Construction time
11	Interim capacity	= RE capacity New/ (Operational life of power plant/3)
12	Old capacity	= RE capacity Interim / (Operational life of power plant/3)

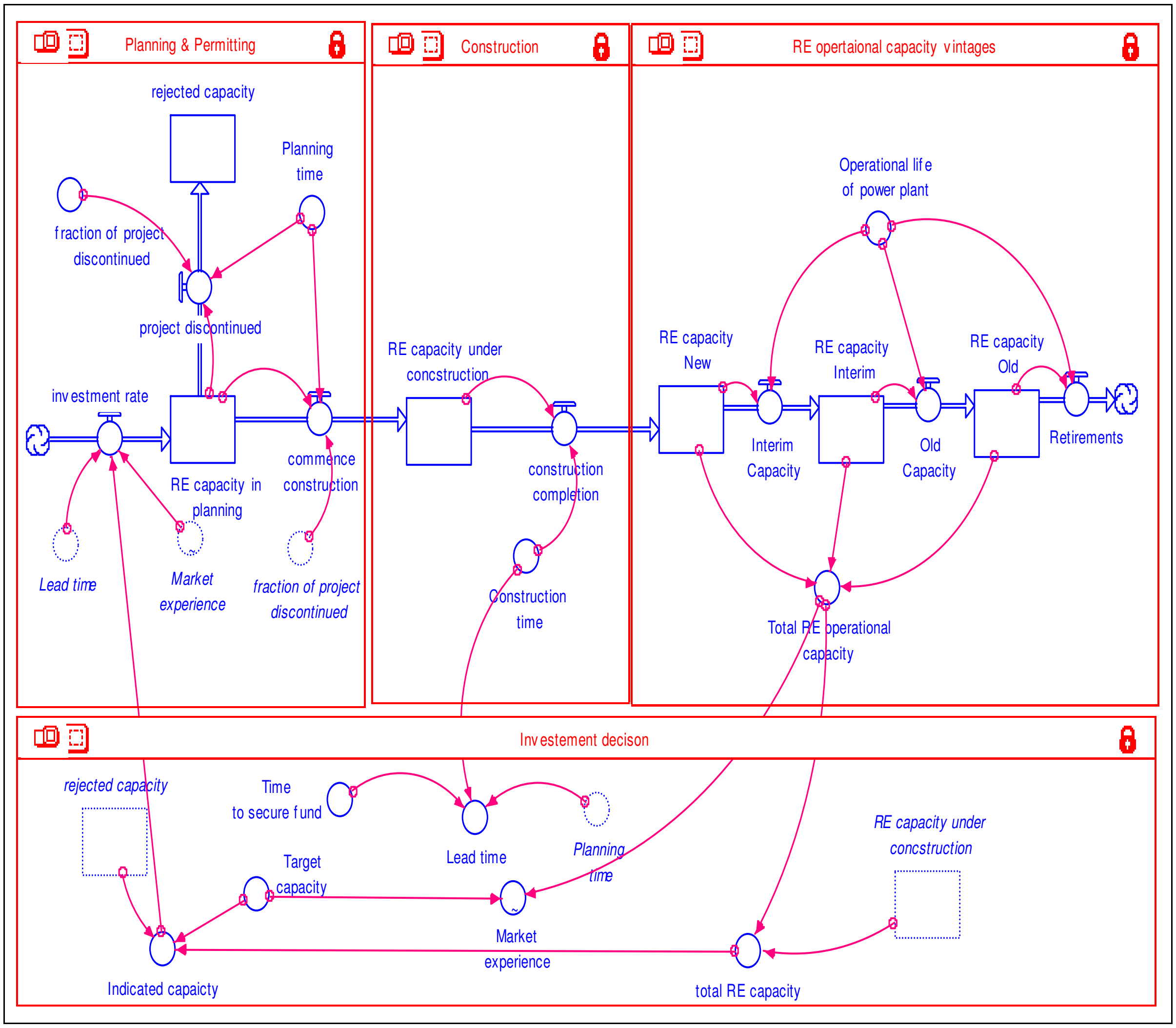

Figure-3
The system dynamics model of renewable generation capacity target

Model Validation: Following Qudrat-Ullah and Seong[29], a number of validations tests are performed on the model. These tests include: boundary accuracy, structure verification, parameter verification and extreme conditions test. Boundary accuracy and structural verification is evident from model in figure-1 and figure-2, respectively. The qualitative (figure-2) and quantitative (figure-3) models comprise of variables that are related to the problem being modelled. Numerical values for parameters used in the model are from authentic government sources. Finally, for extreme condition test, a relatively large value of 100000 for *construction time* is used. The output of the model is logical as can be seen in figure-4. With a long construction time the investment rate plummets to zero with no new construction projects being initiated. Passing all validity tests assures that the system dynamics model used generates the right behaviour from the right structure.

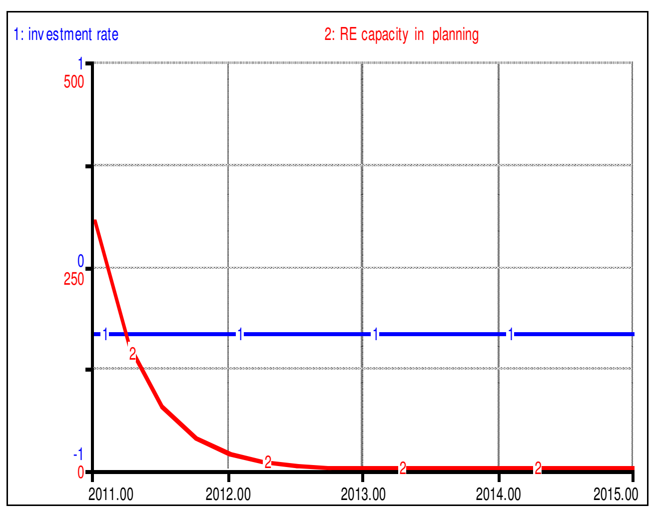

Figure-4
Model behaviour under extreme conditions

Results and Discussion

The simulations were carried out in *iThink* 9.0.3 software package. The simulation runs for 5 years from 2011 to 2015 with a time step of quarter of an year. It is found that Malaysia will not be able to meet the RE capacity target of 985MW by 2015. There is shortfall of 533 MW of capacity. It can been seen from the figure-5 that RE capacity becoming operational at a very high rate in year 2011 which is due to 412MW of capacity at planning and under construction. However increasing trend levels off beyond 2012. This change in trend is attributed to construction-loop moving the system towards equilibrium. In the time period considered market experience-loop seems less to be making any influence on the system. This is because of wait-and-see approach of investors results in a delay.

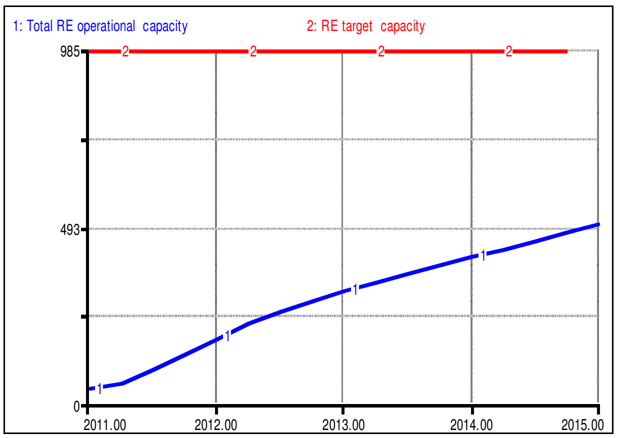

Figure-5
Base case, failing to achieve the target

Further, to evaluate the outcome of the model, sensitivity analysis of exogenous variables on model is performed. The ranges for exogenous variable used for the analysis is given in table-3 while the results of sensitivity analysis are shown in figure-6. Figure-6a shows that project construction time is the most sensitive of all exogenous variables. As the construction time increases the harder it gets to achieve the target. This situation is observable from the beginning of simulation till the end. Other variables which influence RE operational capacity are: *operational life of power plant*, and *time required for permitting and sitting clearance*. Their effects can be seen in figure-6b and figure-6c, respectively. As seen in figure-6b, initially, power plant life is less significant but towards the end of simulation we see that it does influence RE capacity online; lower capacity online for power plants that have shorter operational lives. In figure-6c, it is seen that time to get permission and sitting clearance for a power plant is influential from the start of simulation run. Finally in the sensitivity tests, *Time to secure funds* does not influence RE capacity coming online as can be seen in figure-6d. This insensitivity is valid as power generation sector requires availability of capital upfront, before any work on project can be started[30].

Table-3
Data used for sensitivity analysis

Variable	Range (years)
Construction time	1 - 5
Power plant life	1 - 30
Permitting and sitting clearance time	0.5 - 1
Time to secure funds	0.5 - 1

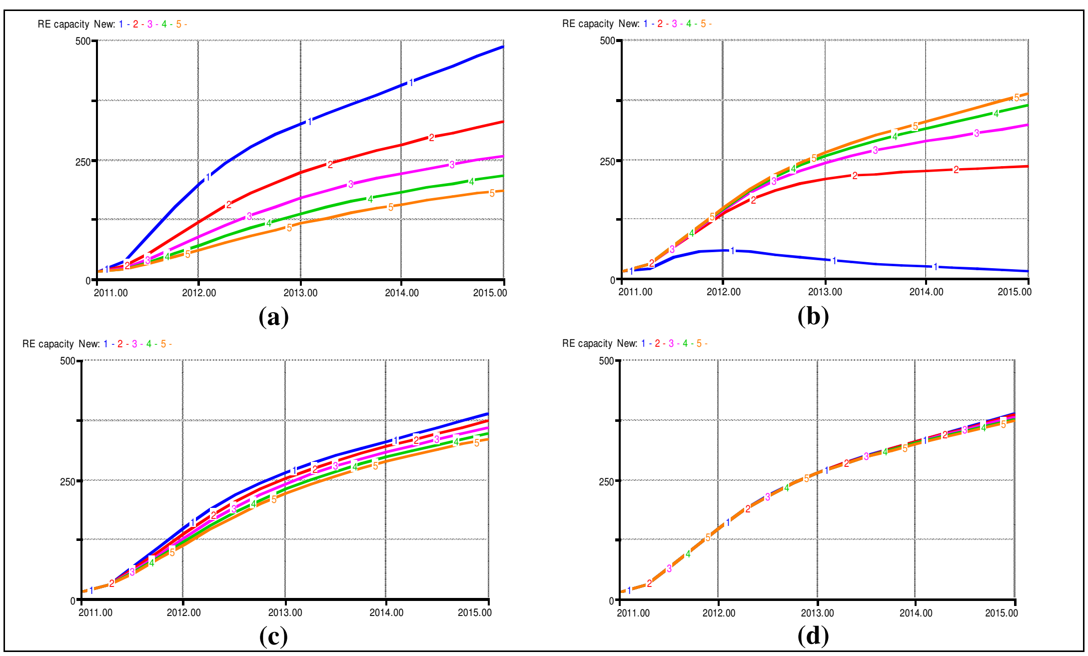

Figure-6
Sensitivity tests on exogenous variables, (a)construction time, (b)operational life, (c) time to get permission and sitting clearance, (d) time to secure funds

Situation beyond 2015: One of the convincing reason of using simulations is one can look farther into the future without changing any conditions. In this study the time horizon for the target is extended to 2020 from 2015. It is found that the target is achieved by 2020, as can be seen from figure-7. After 2015 there is sharp increase in RE capacity becoming operational. Analysis reveals that this situation occurs due to delay in the buildup of *market experience*. The market experience loop (for reference see figure-2) is inhibited by the initial strong influence of target oriented construction loop. Moreover, in figure 8 we can see that system fails to achieve target due to late thrust given to system by *investment rate.* The peak of the variable comes around 2015 which is the ending year for achieving the target. At this instant the *market experience* is showing a strong trend as compared to *investment rate* but structure of system in its dynamical context, favors target oriented construction loop. Hence, target capacity goal is missed.

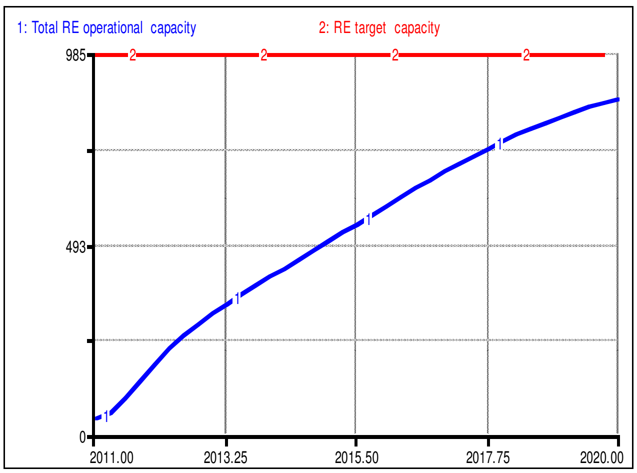

Figure-7
Total RE capacity online by year 2020

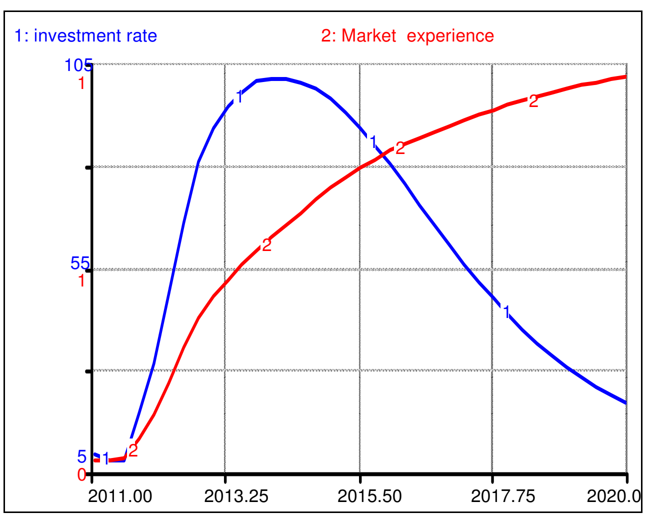

Figure-8
Investment rate and market experience

Conclusion

In this study System Dynamics approach in evaluating a policy target has proved to be a valuable tool. Modelling investors' bounded rationality, regulatory requirements, and construction delays in a feedback setting is a realistic approach. Study reveals that dynamics involved in system are not visible to policy and decision makers which could result in failing to achieve a certain target. This situation accounts to fact that every system has a limit to growth that can only be extended when system structure or policies governing it are changed. Based on our analysis we recommend the following leverage points in the system to policy makers: i. Priority be given to power plant technologies with shorter lead times; this will bring RE capacity online swiftly. ii. Priority be given to technologies that have longer production life; this will increase power plants' length of stay within the system which will influence investors' confidence in investing in renewable power generation. iii. Simplify permitting and sitting requirements; this will increase the number of projects moving from planning phase to actual construction. By reducing this time, the risk of projects not making to construction phase will be reduced also.

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