Using system dynamics model to assess aluminium price volatility and propose solutions to save energy

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***Abstract* –** Aluminium production in Vietnam will increase several times over in the next few years if Dak Nong aluminium smelting project is realized. Indeed, aluminium smelting is a commodity industry with highly volatile prices. This research uses system dynamics to predict the industry to explain the part of volatility. Because of huge electricity requirement and potential to reduce electricity consumption through recycling, aluminium smelting is a special interest of environmental research. Besides the large price volatility will impact directly on production and consumption of aluminium and lead to waste or adversely affect to the environment and society. This research begins with initial model of aluminium industry. Concluding with a discussion of system dynamics and commodity production cycles, the focus is on assessing the impact of producers lag time and variable demand to price volatility. The longer the producers lag time is, the larger the price volatility is. Also with variable demand, the price will be larger fluctuated. At the end, by increasing the proportion of recycled aluminium from 25% to 40%, 8.44 Gwh of electricity power will be saved after 96 months and this will open a more sustainable direction for Vietnam aluminium industry.

Keywords*—*Aluminium, system dynamics model, volatility, demand, consumption, production, price, electricity.

I. INTRODUCTION

A. *Overview*

Aluminium is an abundant element comprising about 8% of the earth’s crust. (The oxide of aluminium is found in nearly all common rocks.). It is the third most abundant element in the earth’s crust and the most abundant metallic element. The aluminium industry is the largest non-ferrous metal industry of the world economy [4]. Aluminium is widely used as an input material in several industrial sectors. An estimate of sectoral consumption of aluminium in the principal markets shows that transportation, and building and construction took the largest share [15].

Vietnam has been dependent on imported aluminium to produce about 0.5 million metric tonnes a year worth 23,200 billion VND (1.1 billion USD) [14] with exchange rate fluctuation of 1 USD = ~ 21,000 VND. Vietnam bauxite reserves approximately 2,100 million tonnes and produces about 1.2 million metric tonnes of alumina production a year[14]. This is a point to urge and consolidate the bauxite - alumina - aluminium and complete the connection between the chain of resource industries and the other supporting industries. DakNong aluminium smelting project - the first aluminium smelter in Vietnam - can produce 0.45 million metric tonnes a year 0 and reduce dependence on foreign imports of aluminium. If ingots is 21 million VND/tonne ($1,000/tonne), annual revenues would be 9,450 billion VND/year (450 million $/year).

B. *Aluminium and Electricity*

Aluminium smelting is extremely energy intensive, and it is important to understand the close connection between aluminium production and electricity generations.

DakNong smelter with 0.45 million metric tonnes/year of capacity will consume around 6.3 Gwh/year. Aluminium can be recycled 100% and converted to metal ingots with only around 5% of the electricity required in primary production.

C. *Volatility in Aluminium Prices*

This figure 1.1 shows the price of aluminium ingots during 1993-2013.

Figure 1.1. Price of aluminium ingots in $/tonne [9]

The time series shows major swings in the price in a relatively short time interval. For example, within 2009 the price had fallen from 3,000 USD/tonne (63 million VND/tonne) to about 1,500 USD/tonne (31.5 million VND/tonne). Near the end of 1994, for example, the ingot price increased from 1,000 USD/tonne (21 million VND/tonne) to 2,000USD/tonne (42 million VND/tonne).

The large price variations pose difficult problems for the smelter operators as well as their customers. Smelters are complex facilities with a highly trained work force and massive electricity requirements. The smelter owners can't simply turn the smelter on with each upswing in the price or turn them off with each downswing.

To interpret the industry cost curve, imagine that you manage a smelter with a variable cost of 33,000 VND/kg (157 cents/kg). Now suppose the market price for ingots will be remained at 32,000 VND/kg (152 cents/kg). You could operate your smelter and earn 1,000 VND/kg.

But the Figure 1.1 shows that the price of ingots is not inclined to remain constant over time. Rather, we see major price fluctuations by plus-or-minus 100% in just a few years. If you think about your 33,000VND/kg smelter, you will immediately see major opportunities. If your smelter were operating near the end of 2008, you could sell ingots at 63,000 VND/kg (3000$/tonne), earning around 30,000 VND/kg (143 cents/kg) after covering your variable costs. But what would you do if the price goes under 33,000 VND/kg (158 cents/kg)?

This paper focuses on the underlying causes of the price volatility and its potential to turn the smelting industry into a "roller coaster" industry.

II. STUDY METHODS

A. *System Dynamics Model*

System Dynamics Model use a graphical user inter face to capture dynamic behavior of the system in a causal loop diagram, also known as a stock and flow diagram. The graphical representation uses a language – a series of symbols and constructs to capture the dynamic behavior of the system.

System can be modeled by understanding the connection between:

External parameters ("smelting capacity") and the system (In this case, aluminium production system)

A system's stocks or quantities which accumulate value ("inventory at smelter and mill")

Flows between stocks or from outside the system ("monthly shipments")

Connections establishing the relationship between stocks and flows

And possibly decisions or thresholds that can cause a system to branch into new states or develop new behavior

Table 2.1. Stock – Funtion

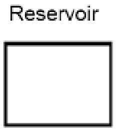
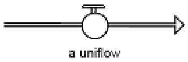
Stock	Function(s)
	Total number of entities – houses the net of what has flowed in, minus what has flowed out. Example: Water, population, cash, inventory.

Table 2.2. Flow – Characteristics

Flow Type	Characteristics
	Standard type, unidirectional indicated by the arrowhead; Uniflow pointing into a stock – fills the stock (and vice versa); If inflow calculated value is negative (flow drains the stock), value is over-ridden by a value of zero – inflows cannot operate as outflows.

B. *Initial model*

Figure 2.1 shows a diagram for an initial model without consumer reaction to ingot price. One stock is used to keep track of the aluminium will be hold at the smelter and the mill. A second stock represents the aluminium products in use in Vietnam. The model distinguishes between primary production at smelters and secondary production from the recycling of used products. Time is measured in month, and each of the flows is measured in mmt (million metric tonnes)/month.

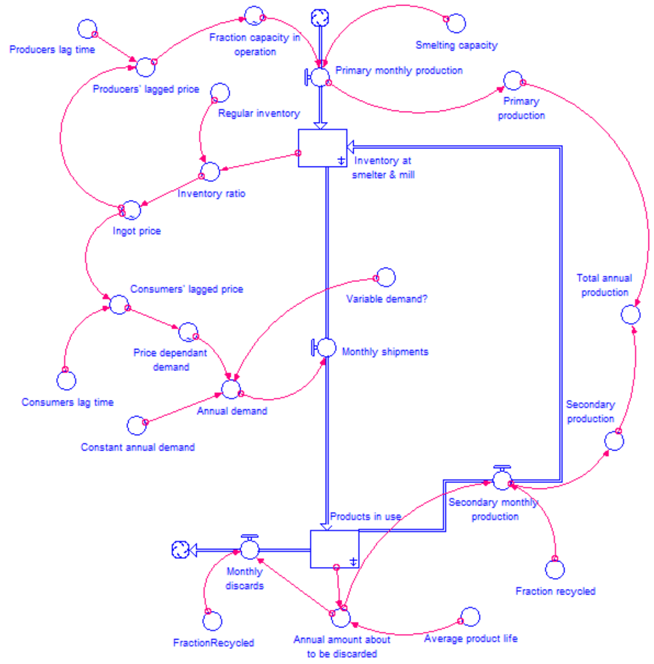


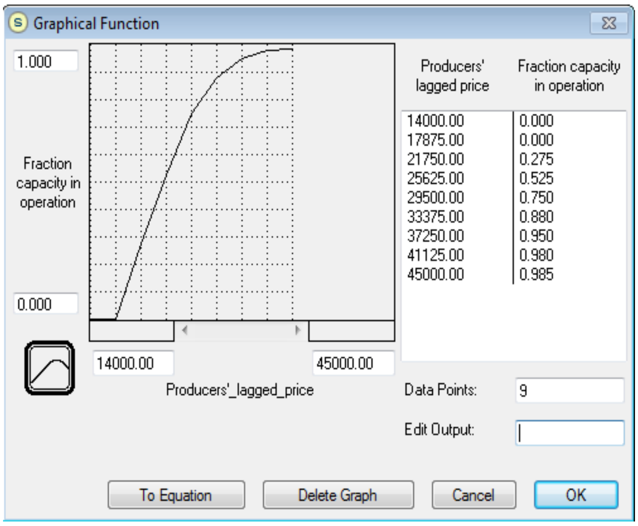
Figure 2.1.Aluminium production and demand model.

Table 2.3. Input data

Regular inventory and inventory at smelter & mill	= 0.09mmt
Products in use	= 5mmt
Fraction recycled	= 0.25
Average product life	= 10 years
Constant annual demand	= 0.5mmt/year
Producers lag time	= 6 months
Consumers lag time	= 24 months
Variable demand?	= 0
Primary monthly production	= Fraction capacity in operation * Smelting capacity /12
Primary production	= Primary monthly production *12
Annual demand	= IF (variable demand?=1) then price dependant demand else constant annual demand
Inventory ratio	= Inventory at smelter and mill/ Regular inventory
Monthly shipments	= Annual demand/12
Total annual production	= Primary production + secondary production
Monthly discards	= (Annual amount about to be discarded - (Annual amount about to be discarded *FractionRecycled))/12
Secondary monthly production	= Annual amount about to be discarded *Fraction recycled /12

"Smelting capacity" is the default refining capacity of DakNong aluminium smelter. "Regular inventory" and "Inventory at smelter & mill" are assumed at 0.09mmt. "Constant annual demand" is the amount of imported aluminium into Vietnam a year.The "?" in "Variable demand?" is a binary variable. Define "0" mean that the price of aluminium does not change demand.

The fraction of smelting capacity that would operate at 70 cents/pound is found by a nonlinear graph shaped to match the industry cost curve in Figure 1.1.



Producers' lagged price	Fraction capacity in operation
14000.00	0.000
17875.00	0.000
21750.00	0.275
25625.00	0.525
29500.00	0.750
33375.00	0.880
37250.00	0.950
41125.00	0.980
45000.00	0.985

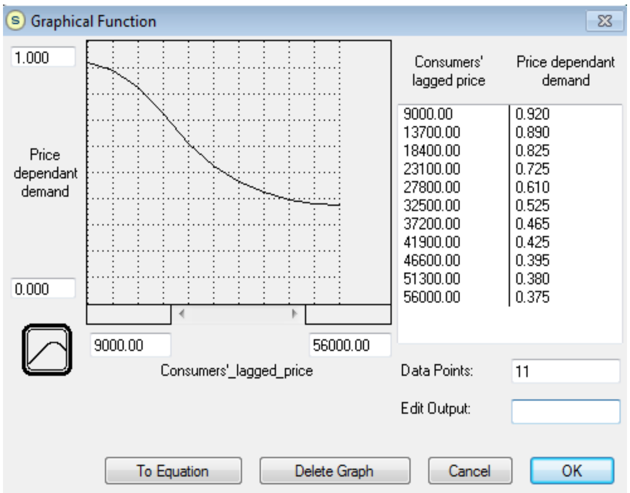
Data Points: 9

Edit Output:

Figure 2.2.Illustrates the relationship between Producers' lagged price and fraction capacity in operation.

The monthly shipments move the aluminium from the mill to the ultimate consumer. The model combines the many uses of aluminium (i.e., automobiles, airplanes housing, beverages,etc.) into a single category with an average product life of 10 years. The total stock of aluminium "products in use" is initialized at 5 mmt. With a ten year product life, approximate 0.5 mmt/year would be ready for discard in the first year. The user specifies the fraction of the potential discards that will be collected and shipped to secondary producers. The "fraction recycled" is set at 25% as defaults to collect scrap rate in Asia based on secondary products (excluding China and Japan)[2]. The recycled products are delivered to secondary producers who extract the aluminium and sell the metal to the mill operators.

The model includes three nonlinear relationships represented by graph functions. For example, figure 2.2 illustrates the relationship between "Producers' lagged price" and "fraction capacity in operation". The next nonlinear relationship controls the demand for ingots:



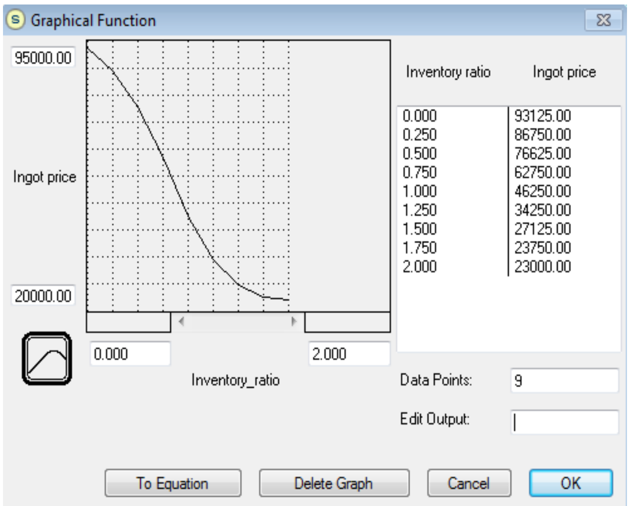
Consumers' lagged price	Price dependant demand
9000.00	0.920
13700.00	0.890
18400.00	0.825
23100.00	0.725
27800.00	0.610
32500.00	0.525
37200.00	0.465
41900.00	0.425
46600.00	0.395
51300.00	0.380
56000.00	0.375

Data Points: 11

Figure 2.3.Relationship between Consumers' lagged price and Price dependant demand.

The demand for aluminium may change with changes in the consumer's view of price. If the price were to increase from 32,500 to 37,200 VND/kg, for example, this graph would lower the demand from 0.525down to 0.465mmt/year. The third graph represents changes in the "ingot price" with changes in the inventory ratio:

A ratio of 1.0 means that the industry has approximately the inventory needed to allow efficient operations of the smelter and the mill. The model assumes that the ingot prices would be at 33,000VND/kg under these "regular" conditions. Lower values of the inventory ratio are assumed to push the price higher. If the ratio falls to 75%, for example, ingot prices are assumed to increase to 62,750 VND/kg. If inventory fall to 50% of the regular levels, ingot price is assumed to climb even higher to 76,625 VND/kg.



Inventory ratio	Ingot price
0.000	93125.00
0.250	86750.00
0.500	76625.00
0.750	62750.00
1.000	46250.00
1.250	34250.00
1.500	27125.00
1.750	23750.00
2.000	23000.00

Data Points: 9

Figure 2.4.Relationship between Inventory ratio and Ingot price.

The model uses two lagged relationships. The first involves the producer's reaction to a change in prices. Assuming that smelter operators watch price changes over a time interval before committing to opening or closing a smelter. Closing costs could be several million dollars, so we should assume that operators will not react to each and every fluctuation in the ingot price. It makes more sense to assume that they react to a time averaged price which can be represented by a third order smooth function. The length of the lag is uncertain, but let's begins with a value of 6 months.

Producers'_lagged_price = SMTH3(Ingot_price,Producers_lag_time,33000)

Producers_lag_time=6

Consumers are not likely to react instantaneously to price changes either. The initial model assumes that the delay in the consumers' reactions may be described by a third order smoothing delay with a two year lag time:

Consumers'_lagged_price = SMTH3 (Ingot_price, consumers_lag_time,33000)

Consumers_lag_time = 24

The third entry in the SMTH3 function is 33,000 for both the producers and the consumers. This means that the simulation begins with both producers and consumers using 33,000 VND/kg as the appropriate price for decision making. The SMTH3 function performs a third-order exponential smooth of input, using an exponential averaging time of averaging time, and an optional initial value initial for the smooth. SMTH3 does this by setting up a cascade of three first-order exponential smooths, each with an averaging time of averaging time/3. SMTH3 returns the value of the final smooth in the cascade.

III. RESULTS

A. *Simulating a production cycle*

Figure 3.1 shows the simulation results. The "annual demand" for aluminium is held constant at 0.5 mmt/year allows us to concentrate on a situation in which only the producers react to changes in prices. The simulation runs for 96 months to allow sufficient time to see if there are volatile swings in prices. This simulation reveals a production cycle which may be attributed entirely to the operating decisions of the primary producers. "Total demand" and "secondary production" are both constant throughout the simulation. "Primary production" is simulated to decline in the first few months of the simulation because of low ingot prices. The decline in "primary production" causes total production to fall below demand during the first few months. This allows the inventory to decline to more regular levels, and prices are simulated to swing upward. Producers react to the upswing after a delay, and more capacity comes into operation.

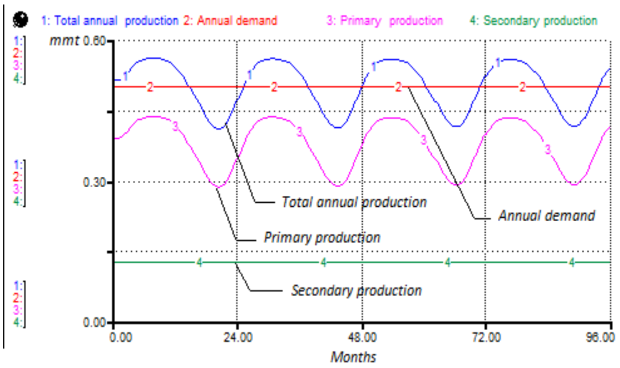


Figure 3.1.Initial simulation of aluminium production and demand.

Figure 3.2 shows that almost all of the smelting capacity would be in operation shortly after the peak in ingot prices. This high production causes inventories to build past the regular levels causing the drop in prices seen around the third year of the simulation. Smelters are gradually taken out of operation during this time period, and the excess inventories are reduced.

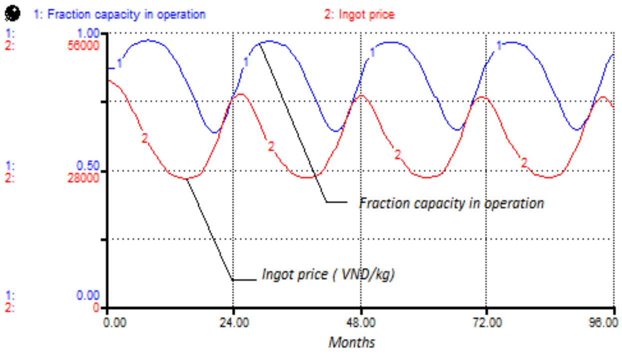


Figure 3.2.Initial simulation of ingot prices and capacity operation.

The simulation reveals that the action of primary aluminium producers could be a major contributor to be volatility in the industry. The simulation shows price swings from a low of around 28,000 VND/kg to the highest of over 56,000 VND/kg. These large swings are quite surprising when you consider that there are no further disturbances after starting out the simulation with extra inventory. Moreover, the price swings occur even though there are no variations in the demand for aluminium, in the amount of secondary production, or in the total smelting capacity.

Figure 3.3 shows the negative feedback loop involving the reaction of primary producers to changes in aluminium price. Primary production adds to the inventory at smelter and mill. This builds the inventory ratio and lowers the ingot price. After a delay to watch and evaluate the price changes, the primary producers reduce the fraction of capacity in operation. This lowers monthly production and allows monthly shipments to lower inventory levels to regular levels. The // on the link from the ingot price to the fraction of capacity operation draws our attention to the key in the loop.

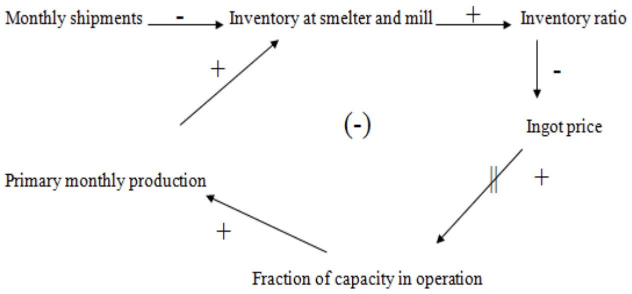


Figure 3.3.Negative feedback responsible for the simulated production cycle.

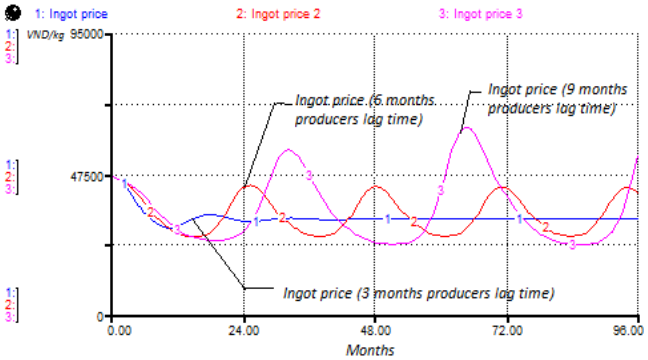


Figure 3.4.Simulated production cycle with three values of the lag in producers' reaction to ingot prices.

Figure 3.4 shows that the longer lag time causes more volatile cycles. It demonstrates that the length of the producers' lag time is an important determinant of the overall stability of the aluminium industry.

B. *Adding the Consumer's Reaction*

Change Variable_demand? = 1

Figure 3.5 expands the causal diagram to show the reaction of consumers to changes in ingot prices. An increase in price will cause a reduction in consumption and a corresponding reduction in monthly shipments. When less aluminium is shipped, the inventory tends to build more rapidly causing a reduction the price.

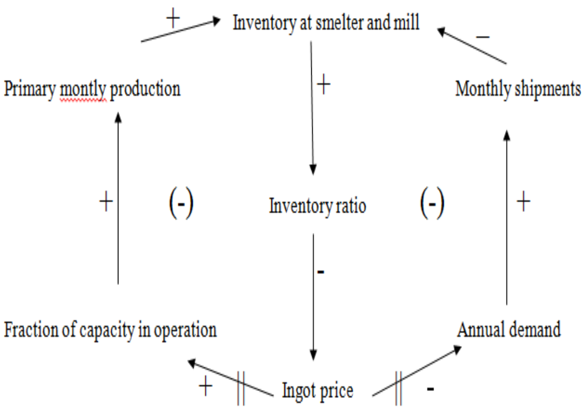


Figure 3.5. Coupled negative feedback loops controlling the supply and demand for aluminium.

Figure 3.6 shows the simulated changes in production and consumption when the consumers' price response is added to the model. The "annual demand" is no longer at the constant 0.5 mmt/year. Instead, we see modest fluctuations in demand as consumers react to the changes in ingot prices. "Total annual production" varies in a cyclical fashion, due to cycles in "primary production".

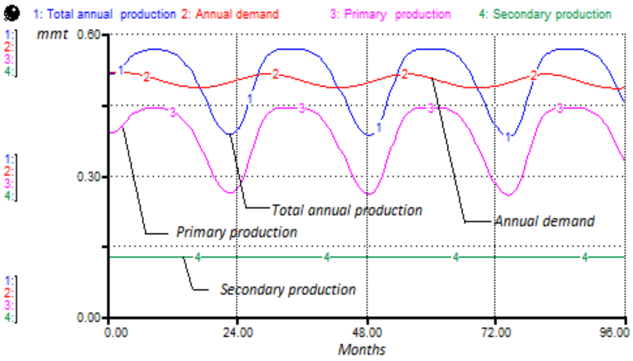


Figure 3.6. Production and demand in a simulation with both producers and consumers reacting to ingot prices.

Figure 3.7 compares the simulated changes in ingot prices in the two simulations. The comparison shows that the introduction response to prices introduces somewhat more volatility to the system. With "variable demand", the cycles show somewhat higher peaks and a somewhat longer period.

The simulation with "variable demand" is the more realistic of the two simulations. It shows cyclical behavior in ingot prices with the cycles taking on the characteristic look of a limit cycle.

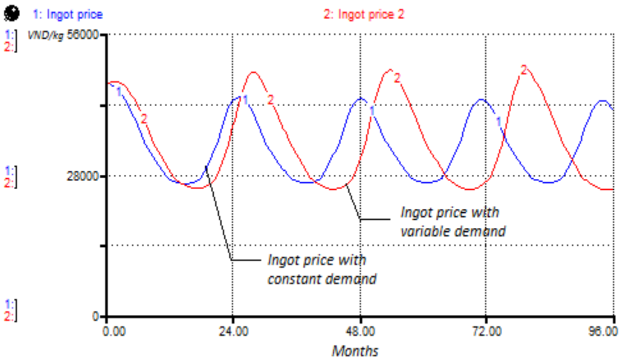


Figure 3.7. Comparison of ingot prices in previous two simulations.

Figure 3.8 displays the same simulation shown in Figure 3.6, but this diagram shows the ingot price versus the "fraction of capacity in operation" from each month of the simulation. The start point is 87% operation and 46,250 VND/kg. The first few months show an increase in the fraction of capacity in operation. By the time the fraction reaches 98%, the ingot price is falling, so dots in figure 3.8 "change course" from a northerly to anwesterly direction. The dots then circle down toward 58% and come back around. By the time they have completed one cycle, the system is further removed from the starting point. This outward growing spiral is characteristic of an unstable system.

Unstable systems cannot grow forever; they will eventually encounter limits. In this example, the limits are reached after only one or two cycles. The most visible limit is on the top of figure 3.8. The fraction of capacity in operation cannot exceed 100%. Figure 3.8 also reveals a nonlinear limit on the left side of the diagram. The limitation is somewhat arbitrary. It corresponds to the assumption that aluminium prices are not likely to fall below 20,000 VND/kg even if inventories build to very high levels.

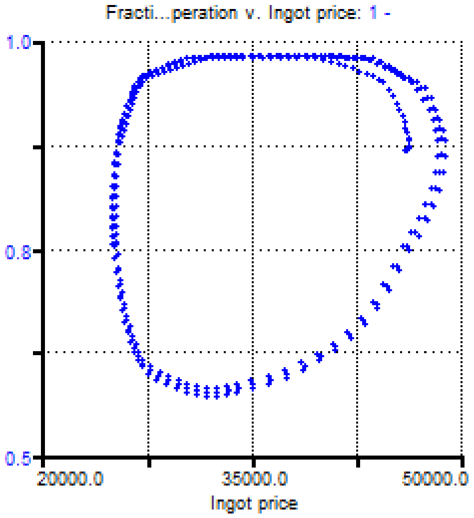


Figure 3.8. Scatter graph depicting the limit cycle in the simulated aluminium industry.

C. *Expand model with electricity demand*

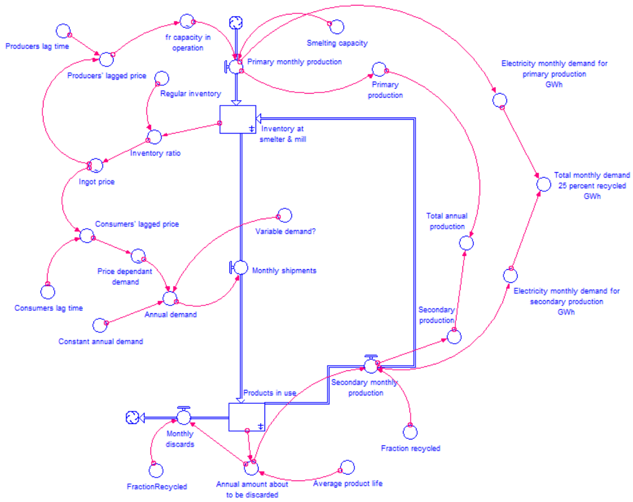


Figure 3.9. Expanded model

This expanded model with power demand in order to calculate the energy savings while increasing Fraction recycled to 40%. Secondary production needs only 5% of electricity required in primary production.

To produce 0.45 mmt aluminium need 6.3 Gwh , which is equivalent to 14 Gwh/mmt0. Electricity_demand_for_primary_production_Gwh = Primary_production*14

Electricity_demand_for_secondary_production_Gwh = Secondary_production*14*0.05

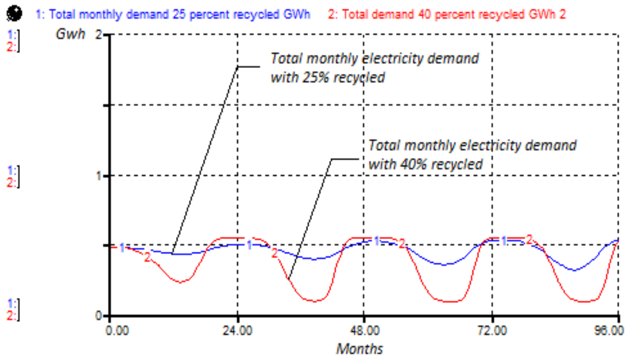


Figure 3.10. Comparison between electricity demand with 25% fraction recycled and 40% fraction recycled.

Table 3.1. Table value of electricity demand with different fraction recycled.

Months	Electricity demand with 25% recycled	Electricity demand with 40% recycled	Months	Electricity demand with 25% recycled	Electricity demand with 40% recycled	Months	Electricity demand with 25% recycled	Electricity demand with 40% recycled	Months	Electricity demand with 25% recycled	Electricity demand with 40% recycled	Months	Electricity demand with 25% recycled	Electricity demand with 40% recycled
0	0.47	0.47	21	0.48	0.54	42	0.42	0.23	63	0.35	0.08	84	0.37	0.29
1	0.47	0.47	22	0.49	0.54	43	0.44	0.37	64	0.35	0.08	85	0.35	0.21
2	0.47	0.47	23	0.49	0.54	44	0.46	0.49	65	0.36	0.08	86	0.33	0.15
3	0.47	0.47	24	0.49	0.54	45	0.48	0.53	66	0.38	0.09	87	0.31	0.11
4	0.47	0.46	25	0.5	0.54	46	0.49	0.54	67	0.41	0.12	88	0.31	0.09
5	0.46	0.44	26	0.49	0.54	47	0.5	0.54	68	0.44	0.22	89	0.32	0.08
6	0.46	0.42	27	0.49	0.54	48	0.51	0.54	69	0.48	0.36	90	0.35	0.08
7	0.45	0.4	28	0.49	0.53	49	0.52	0.54	70	0.49	0.48	91	0.37	0.09
8	0.45	0.37	29	0.48	0.51	50	0.52	0.54	71	0.51	0.53	92	0.41	0.11
9	0.44	0.34	30	0.48	0.49	51	0.52	0.54	72	0.52	0.54	93	0.47	0.17
10	0.43	0.3	31	0.47	0.44	52	0.51	0.54	73	0.52	0.54	94	0.49	0.3
11	0.43	0.26	32	0.45	0.37	53	0.5	0.54	74	0.52	0.54	95	0.51	0.43
12	0.43	0.23	33	0.44	0.29	54	0.49	0.53	75	0.52	0.54	96	0.52	0.51
13	0.43	0.22	34	0.42	0.21	55	0.48	0.5	76	0.52	0.54			
14	0.43	0.23	35	0.41	0.15	56	0.47	0.46	77	0.52	0.54			
15	0.43	0.26	36	0.4	0.11	57	0.44	0.38	78	0.51	0.54			
16	0.43	0.31	37	0.39	0.1	58	0.42	0.31	79	0.5	0.53			
17	0.44	0.38	38	0.39	0.09	59	0.4	0.22	80	0.48	0.52			
18	0.45	0.46	39	0.39	0.09	60	0.38	0.16	81	0.47	0.49			
19	0.46	0.5	40	0.39	0.1	61	0.36	0.11	82	0.43	0.44			
20	0.47	0.53	41	0.4	0.14	62	0.35	0.09	83	0.4	0.37			

Figure 3.10 shows the difference in the monthly electricity demand when we change fraction recycled from 25% to 40%.With that change, producers can save around 8.44 Gwh of electricity power after 96 months. If electricity price = ~1,052 VND/kwh (5 cents/kwh)[11], producers can save around 8,900 billion VND (423 million USD) after 96 months, equivalent to over 1,112 billion VND/year (53 million USD / year).

IV. CONCLUSION

Based on scenarios that this system dynamics launched, this research has assessed the role of the lag time of producers and consumers to aluminium market. Since then giving the feedback loops to understand the rules in this industry and limitations of the system.

In next few years, Vietnam's aluminium production will increase from 0 to 0.45 mmt/year if current plans materialize. We need to be prepared for market fluctuations may occur. This research illustrates the use of system dynamics to look "inside a system" for an explanation of highly volatile behavior to predict the future for Vietnam aluminium market. This might help producers understand the system of aluminium production and consumption to make alternative operations suitable for both energy savings and achieve higher economic efficiency. High price fluctuations will affect many aspects of our lives, especially our environment. By increasing rate of secondary aluminium from scrap can help save billions of VND each year from energy use, waste disposal and mining. Thereby, we can see other more sustainable direction in the future instead of the continuous exploitation.

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