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Is the Land Rehabilitation Project in Australia Using Coal-fired By-products Sustainable and Profitable?

– A Feasibility Analysis with System Dynamics*–

Kaoru Yamaguchi † Yoshitaka Nitta ‡
Takahisa Yokoyama § Takayoshi Kato ¶

Abstract

The encroachment of sodicity, salinity and acidity on Australian land is of national concern. The land rehabilitation project dubbed COALA (COal industry by-product Applied to LAnd rehabilitation) aims to assess the feasibility of enhancing greenhouse gas reduction by sodic / acidic land reclamation in Australian condition using coal-fired power plant by-products such as Flue Gas Desulphurisation (FGD) gypsum or coal-ash delivered fertilizer. The technical feasibility of the project has been carried out though the field trial for sodic soils and laboratory pot trail for acidic soils successfully. In this paper the sustainability and economic feasibility of the COALA Project are discussed using system dynamics business modeling method. The major finding is the COALA project is profitable under sustainable forest management.

1 Introduction

Two of the authors, Nitta and Yokoyama, have been working on the land rehabilitation project in Australia dubbed COALA (COal industry by-product Applied to LAnd rehabilitation). As the project proceeds favorably, they needed

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†Professor, Ph.D., Doshisha Business School, Kyoto, Japan

‡Central Research Institute of Electric Power Industry, Japan (currently Professor, Ph.D., Yokkaichi University, Japan)

§Senior Research Scientist, Dr., Environmental Science Research Laboratory, Central Research Institute of Electric Power Industry, Japan

¶Graduate Student of Global Environmental Studies, Kyoto Univ., Japan (currently, researcher, M.S., Mitsubishi UFJ Research and Consulting Co. Ltd.)

Electric Power Company (EPC)	KWh/Year
Hokkaido EPC	1.449e+10
Tohoku EPC	2.3187e+10
Tokyo EPC	5.832e+9
Chubu EPC	2.9206e+10
Hokuriku EPC	1.5644e+10
Kansai EPC	4.09e+8
Chugoku EPC	1.9635e+10
Shikoku EPC	7.377e+9
Kyushu EPC	1.1677e+10
Okinawa EPC	4.468 e+9
Electric Power Development Co.	5.1133e+10

Table 1: Power Generation by Coal: Data in 2004

to evaluate its economic feasibility to see if it could be really implemented as a sustainable business model in Australia jointly with Japan. Upon their request, the other author, Yamaguchi, was invited to build its system dynamics business model with the modeling assistance by Kato, who was a graduate student of global environmental studies.

The modeling task gets started in this way as a year-long joint research in the spring of 2005. Toward the end of the research we had a chance to present our model to the Environmental Protection Agency, Queensland Government of Australia in March 2006. Though the model was written only in Japanese at that time, out aural presentation turned out to be good enough to attract their attention. Later on we are asked to write the model in English for the further examination of the project, which turns out to be the model attached to the current paper.

2 The Issue: Coal-fired Power Plant By-products

There are 10 electric power companies (EPC) which are exclusively located in 10 regions in Japan such as Hokkaido EPC, Tohoku EPC, Tokyo EPC, Chubu EPC, Hokuriku EPC, Kansai EPC, Chugoku EPC, Shikoku EPC, Kyushu EPC and Okinawa EPC, and several whole sale electric companies such as Electric Power Development Company (JPOWER). Table 1 shows their annual electricity generated only by coal in 2004, which constitutes 24% of total electricity generated in Japan. The coal-fired power generation depends on imported coals, mainly from Australia, China and Indonesia. For instance, in the year 2004, 63.3% of coals were imported from Australia and 18.7% and 11.6% were from China and Indonesia, respectively.

Figure 1 illustrates a typical structure of electric generation activities, say, in the Hokkaido Electric Power Company, which simultaneously produces by-products such as carbon dioxide (CO_2), FGD gypsum and coal ash[1].

Figure 2 shows a sub-model for calculating a whole domestic power generation by coals and its by-products as a sum of the above-mentioned 10 electric power companies (excluding Okinawa EPC) in Japan, though the information arrows of inflows and outflows from such 10 companies are hidden from the model to avoid a drawing complexity.

In order to estimate the demand for electricity generated by coal in Japan over the coming half a century from 2006 through 2060, a very conservative assumption is made in our research such that it increases linearly by 20% in 2030 (or roughly 0.8% annually) and by 30% in 2060 (or about 0.33% annually). Based on this demand estimation, Figure 3 indicates that Japanese electric power generated annually by the coal will become 214.3 billion KWh in 2030 and 232.16 billion Kwh in 2060, while her import of coals mainly from Australia will become 46.93 million tons in 2030 and 50.84 million tons in 2060.

Figure 4 estimates that carbon dioxide of 1.307 billion tons in 2030 and 3.154 billion tons in 2060 will be additionally accumulated to the level of those in 2006 due to the coal-fired discharges in the air less a smaller amount of natural fixation. CO_2 is not the only coal-fired by-product. Figure 5 calculates that 680,535 tons of FGD gypsum in 2030 and 737,246 tons of FGD gypsum in 2060 will be discharged, while coal ash of 4.693 million tons in 2030 and 5.084 million tons in 2060 will be produced annually. Where do they go?

Eventually Japan, as isolated islands surrounded by the ocean, will be forced to deal with the disposal of such accumulating by-products. For instance, in the year 2000 8.43 million tons of coal ash was produced by industrial sectors including coal-fired power plants, among which 80% of coal ash was utilised in cement and concrete, civil engineering, building, agricultural and fishery and other applications, and the rest of which was disposed of as landfill. Meanwhile, all the FGD gypsum was used in wallboard and in cement manufacture.

In this way the disposal of coal-fired by-products, in particular coal ash, is the issue Japan is facing and need to be solved in the near future so long as her energy keeps depending on the imported coals.

[1] The words, coal ash and flyash, are equivalently used in this paper

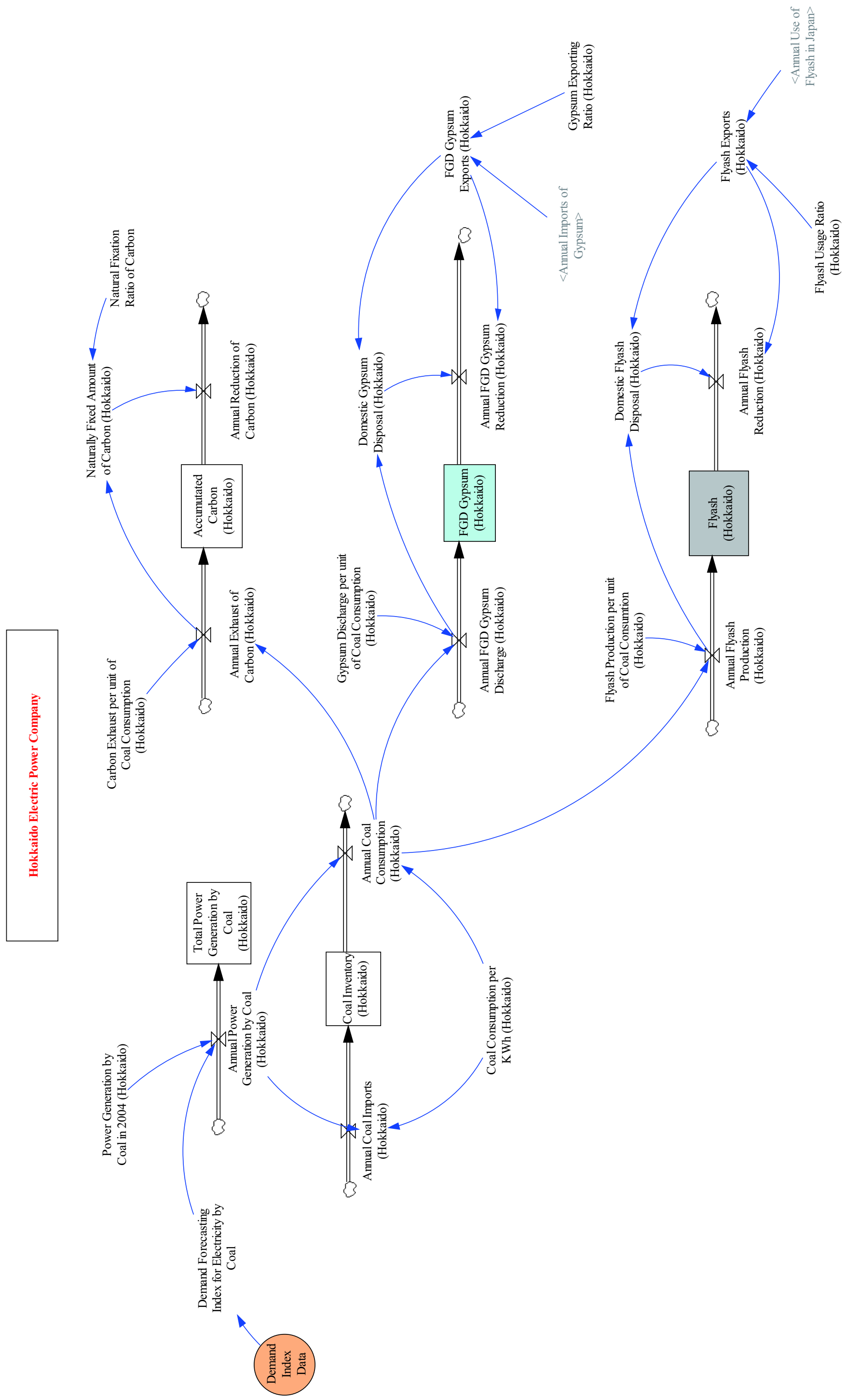

Figure 1: Power Generation and its By-products by Hokkaido Electric Power Company

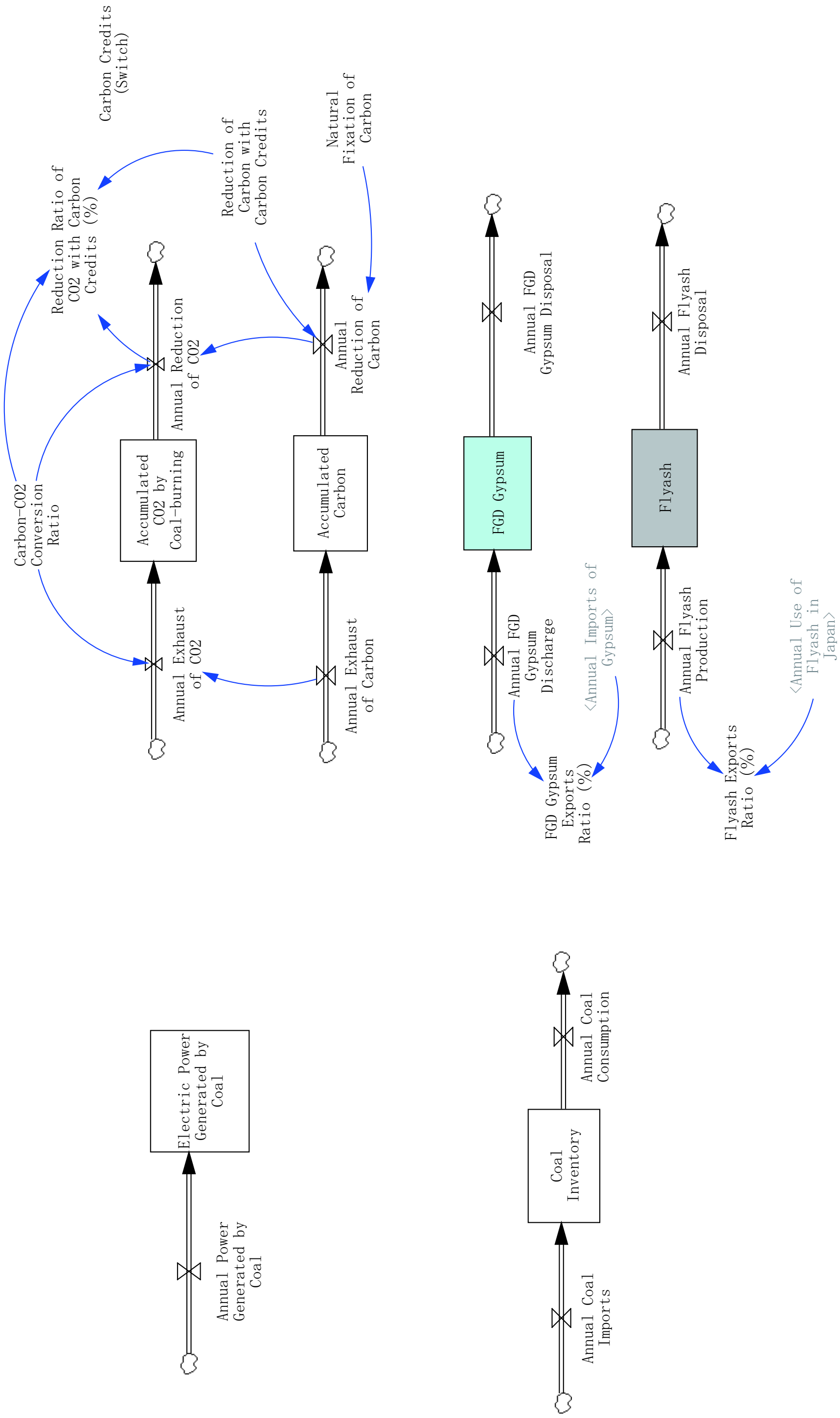

Figure 2: Total Power Generation by Coal and its By-Products in Japan

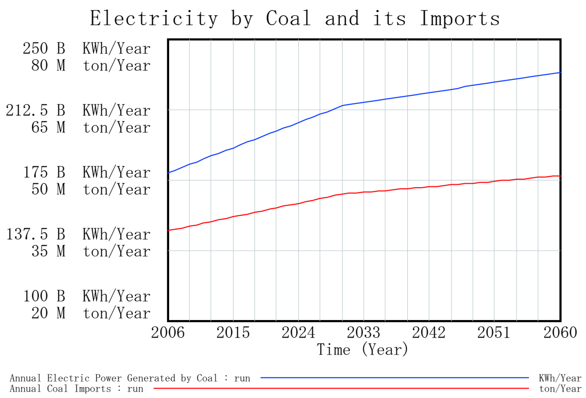

Figure 3: Japanese Power Generation by Coal and its Imports

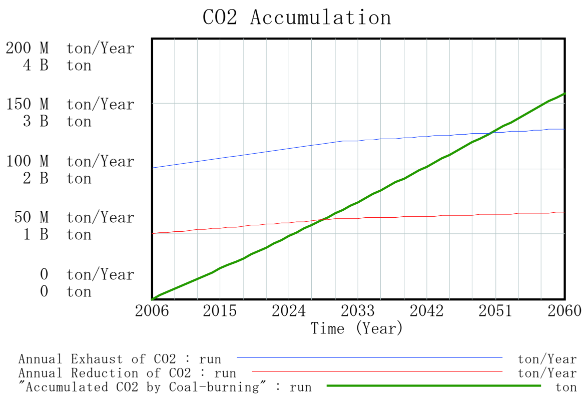

Figure 4: Accumulated Carbon Dioxide from Coal Imports

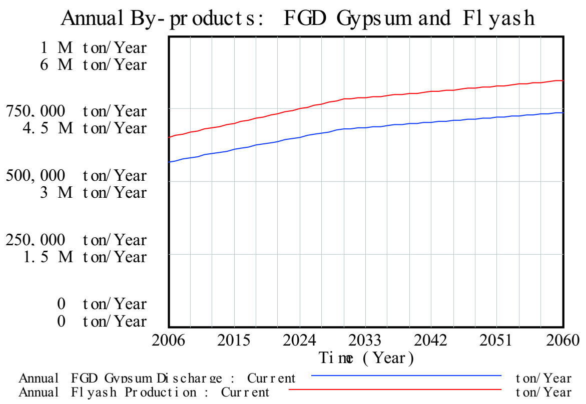

Figure 5: By-products of Coal: FGD Gypsum and Flyash

3 COALA Project: A Win-Win Solution

3.1 Objectives

Spending his research time mostly on the issue, Nitta one day hit upon the idea that the coal industry by-products such as FGD gypsum and flyash could be effectively applied to improve sodic and acid land, specifically in Australia, and if coal-fired by-products in Japan could be applied to it, the solution could be beneficial both to Japan (a volume consumer of Australian coals) and Australia (exporter of coal).

As a matter of fact, the encroachment of sodicity salinity and acidity on Australian land is of national concern. An estimated 580,000 hectares have been badly affected so far by sodium and 5 more million hectares of land will be expected to be seriously affected within the next 20 years. Meanwhile, total area of acidic soils is eight to nine times that of being affected by dryland salinity. 50 million hectares (50% of agricultural land) have surface pH ≤ 5.5 (or below optimum for extremely acid-sensitive agricultural plants)[2].

The COALA project aims to assess the feasibility of enhancing greenhouse gas reduction by sodic/acidic land reclamation in Australia using coal-fired by products in Japan such as FGD gypsum, which is obtained by removing sulphur dioxide in the flue gases, and coal-ash delivered fertilizer. The idea of using FGD gypsum for reclamation of sodic soils, and their subsequent use for forestry as carbon sinks has been proposed by Lu and Nitta (1). It has been eventually expanded to another idea of using coal-ash derived fertilizer for reclamation of acid land.

The proposal has several attractive features for trading partners of Australia and Japan. For Japan, shift of fuel from coal to natural gas has been discussed as one of the options for the reduction of greenhouse gases, which would yet require the early retirement of existing coal-fired power stations; a very expensive option. Instead, if Japan could gain credits for the additionally created carbon sink that is sufficiently enough to fully offset the emission differences between coal-fired and natural gas-fired power plants, there would be no greenhouse benefit in this fuel switching. In addition Japan could gain some extra time to attain a balance of energy resources by shifting from coal toward natural gas and nuclear power as a major energy source.

On the other hand, as a major supplier of some 60% of steam coal used in Japan, Australia could secure a major export market into the future. There would also be benefits to the agricultural and forestry sectors in Australia, being obtained from the reclamation of marginal or unusable land into productive service. In addition, both countries would gain advantages from the global environmental benefits of the increased carbon sink.

The aim of the COALA project is to demonstrate under Australian ecological conditions the feasibility of enhanced carbon sink by sodic/ acidic soil reclamation using coal-fired by-products. FGD gypsum is used for sodic soil

[2] This figure was pointed out through personal communications with Prof Roger Swift, University of Queensland

reclamation, while coal-ash delivered fertilizer is used for acidic soil reclamation.

3.2 Soil Reclamation Experiments

The COALA project consists of 2 phases: sodic soils project in which sodic soil is reclaimed using FGD Gypsum, and acid soil project in which acidic soil is reclaimed using coal-ash delivered fertilizer.

Sodic Soils Project

This phase of the project is an international collaboration between Japan and Australia. Its participants are HEPCO(Hokuriku Electric Company), CRIEPI (Central Research Institute of Electric Power Industry) and the University of Queensland.

The trial field is located in Darbarala within a *salt pan*, which has formed in the Babcock block of the University of Queensland's Darbarala Farm. Approximately 1,000 Australian native trees were planted such as Casuarina glauca (Swanp Sheoak), Eucalyptus moluccana (Gray box) and Eucalyptus camaldulensis x grandis (Saltgrow). Specifically C. glauca was planted in November 2000, and E. molucanna and E. camaldulensis x grandis were planted in March 2001. The project is detailed in Wearing, Rudolph and Lu (2). Figure 6 is aerial photos of Darbarala trial field. They convincingly show that a sodic barren land in 2001 has been reclaimed to a growing green forest in 2004.

In this way, the Darbalara field trial has successfully demonstrated that FGD gypsum ($CaSO_4{\cdot}2H_2O$) produced from coal-fired power plant by-products could be used for amendment of a badly degraded saline- sodic soils in Australia, enabling the the sodic land for forestation.

The field trial has attracted wide interest as a showcase of the *before and after* benefits for rehabilitation of deteriorated land using FGD gypsum. It has been featured on TV, radio and in media print, as well as at a number of international conferences such as COP6 (2000), 9th APCChE Congress and CHEMECA (2002) and 4th Asia Pacific Conference on Sustainable Energy and Environmental Technologies (2003).

Acid Soils Project

This phase of the project aiming for acidic land reclamation by coal-ash delivered fertilizer is a research collaboration between CRIEPI and the University of Queensland. The objectives of the project is to demonstrate the usefulness of the flyash fertilisers in ameliorating the acidity of soils by assessing the following; (1) the effect of the flyash-fertilisers on the characteristics of selected acid soils (ferrosol, pdsol and acid sulphate soil), (2) the ability of the flyash-fertilisers to enhance the growth of selected agricultural crops on those soils, and (3) the nature and fate of nutrients and contaminants that are associated with the flyash-fertilisers or soils.

Figure 6: Aerial photos of Darbarala field trial (left 2001, right March 2004)

Figure 7 demonstrates how wheat and corn grow on different acid soils with 5 differentiated application of flyash fertilisers. All soils exhibit enhanced plant growth with additional increases in nutrients. The podosol showed the greatest improvement, while the ferrosol showed the least improvement.

In addition, UQ's laboratory analysis indicated that the flyash-fertiliser would not be considered a hazardous material under the Hazardous Waste (Regulation of Exports and Imports Act 1989) when assessed using the 4 criteria to assess waste materials and on advice from the Environment Australia (EA). The project was in this way terminated in August 2006 with the successful results. The project performance is detailed in Swift and Spark (3).

4 Land Rehabilitation in Australia

Sodic-degraded Land

We are now in a position to build a system dynamics model of the COALA project to see its economic feasibility when it is actually implemented. As demonstrated in the COALA showcase experiment above, FGD gypsum turned out to be very effective to reclaim sodic soils for plantation. In our model it is assumed that every year 1,000 hectare of sodic land is purchased at 2,500 Australian dollars (A$) per hectare and reclaim them for the duration of 25

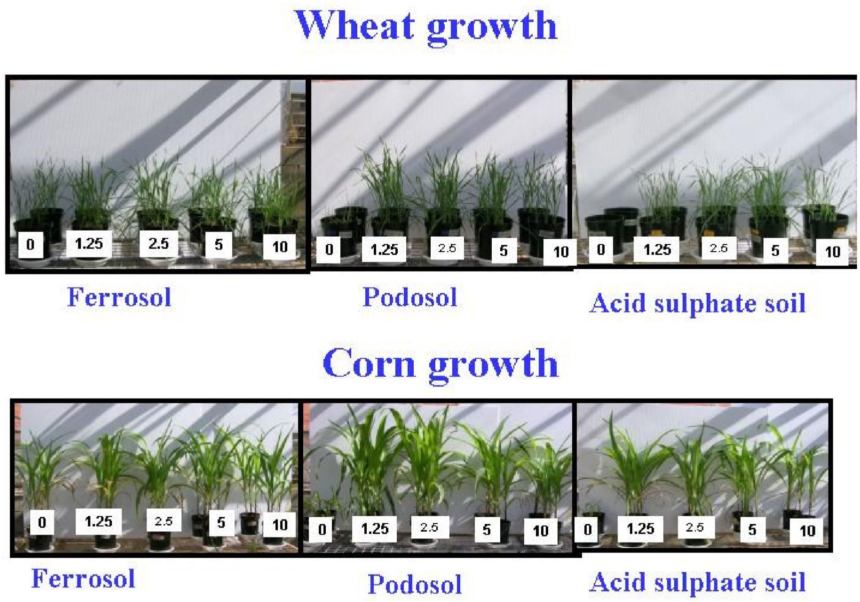

Figure 7: Plant Growth

years, starting the year 2006. It is also assumed that 5 tons of FGD gypsum is applied to reclaim one hectare of purchased sodic soils. Accordingly, 25,000 hectare of sodic lands will be reclaimed in total in 2030 for afforestation, as summarized in Table 2.

Acid-degraded Land

Currently 40 million hectare of land is estimated to be affected by acidity in Australia. Let us similarly assume that every year 1,000 hectare of sodic land is purchased at A$ 2,500 per hectare and reclaim them for the duration of 25 years, starting the year 2006. It is also assumed that one ton of flyash is needed to produce 1.1 tons of flyash fertiliser in Japan, and 20 tons of flyash fertilizers need to be applied to reclaim one hectare of acid land. Accordingly, 25,000 hectare of sodic lands will be reclaimed in total in 2030 for afforestation, as summarized in Table 2.

Figure 8 illustrates the structure of land reclamation processes of both sodic and acid soils.

	Sodic Soils (ha)	Acid Soils (ha)
2006	1,000	1,000
2007	1,000	1,000
2008	1,000	1,000
2009	1,000	1,000
2010	1,000	1,000
...	...	...
2028	1,000	1,000
2029	1,000	1,000
2030	1,000	1,000
Total	25,000	25,000

Table 2: Land Rehabilitation Plan of 25 Years

5 Sustainable Afforestation

Rotating Forests

Let us now assume that 1,000 trees are planted per hectare on the reclaimed land, and they are classified into three groups according to their growth stages: that is, seedlings (1-5 years), young trees (6-15 years) an matured trees (16-25 years). It takes 5 years for seedlings to become young trees, and their dying and pruning rate is assumed to be 3 % annually. It takes 10 years for young trees to become matured trees, and their dying and pruning rate is assumed to be 2 % annually. It takes another 10 years for matured trees to be logged, and their dying and pruning rate is assumed to be 0.5 % annually.

Furthermore, trees that die or get pruned are to be replanted annually so that a total number of forest trees are constantly maintained. Figure 9 illustrates a growth structure of afforestation in sodic land, with its rotation period of 25 years. Afforestation of acid land is similarly structured in the model.

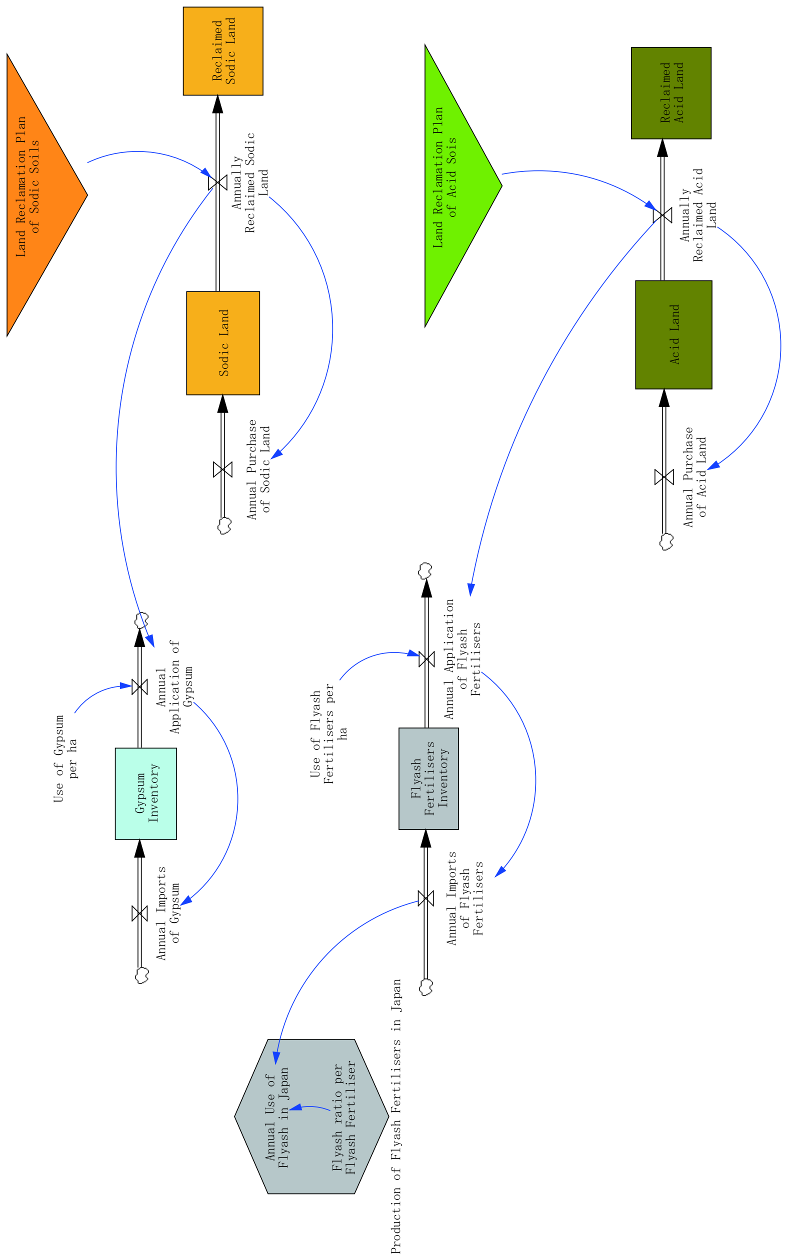

Figure 8: Land Reclamation of Sodic and Acid Soils

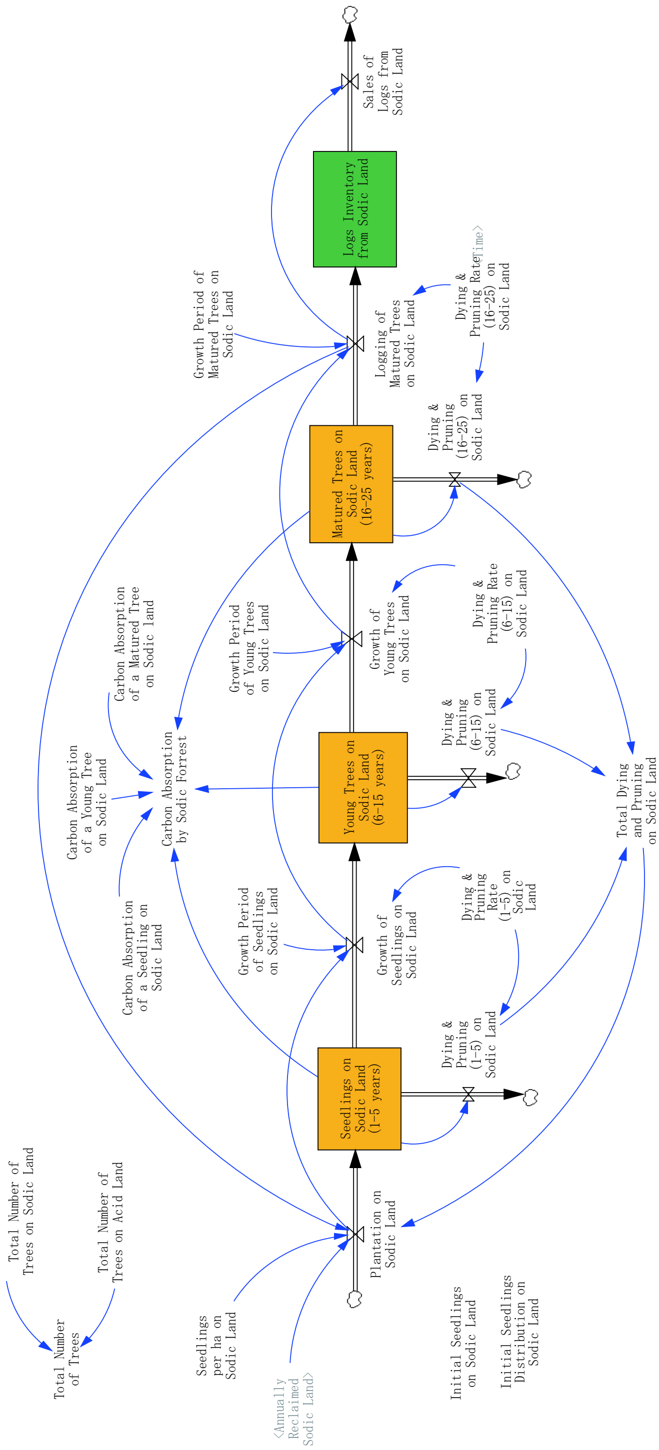

Figure 9: Afforestation of Sodic Land

Figure 10 shows how planted trees grow annually. Thick blue line indicates annual number of seedlings plantation, red and green lines show annual growth of young and matured trees, respectively. Meanwhile, dotted line shows a number of matured trees being cut down annually.

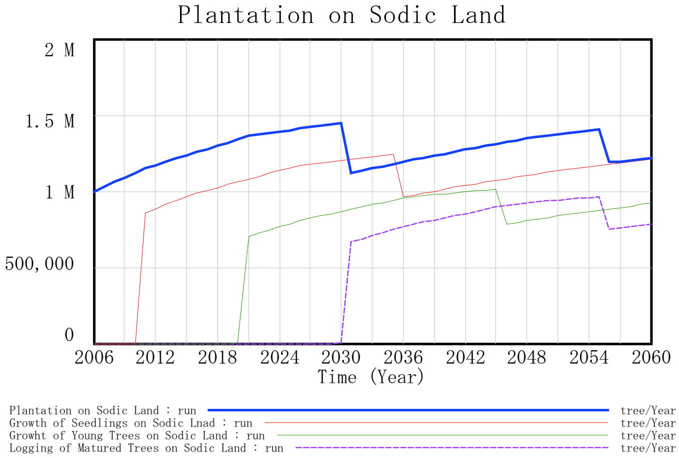

Figure 10: Plantation on Sodic Land

Figure 11 illustrates the number of trees in stock at three stages of growth on the reclaimed sodic land of 25,000 hectare; that is, blue, red and green lines represent the numbers of seedlings, young trees and matured trees in stock. Meanwhile, a gray thick line indicates the total number of trees on the reclaimed sodic land, which will be stabilized with 25 million trees from the year 2031; that is to say, a complete recycling and sustainable forest will be attained after 25 years of afforestation.

Carbon Credits

We are now in a position to show how many tons of carbons (not CO_2) are absorbed annually from the forests on the reclaimed land. For the calculation we have assumed that a seedling can absorb 0.0065 tons of carbon per year, while young and matured trees can absorb 0.0061 and 0.0054 tons of carbons, respectively.

Left-hand diagram of Figure 12 indicates that the total amount of carbon absorbed by the forest is about 300,000 tons per year after the year 2030. Yet it constitutes only less than 1 % of Japanese annual carbon exhaust caused by coal-firing as illustrated in the right-hand diagram.

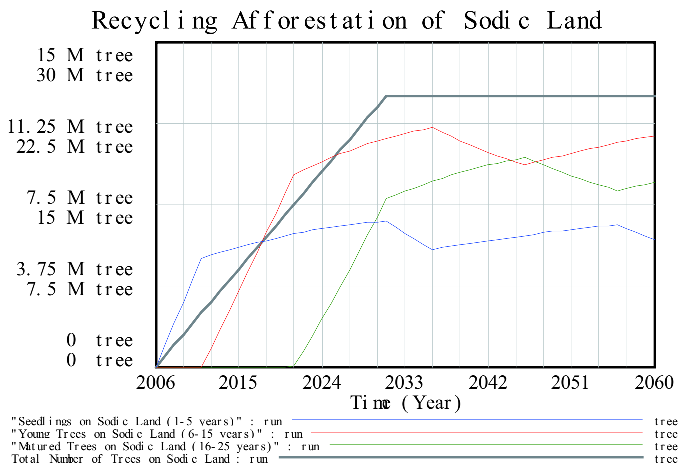

Figure 11: Recycling Afforestation of Sodic Land

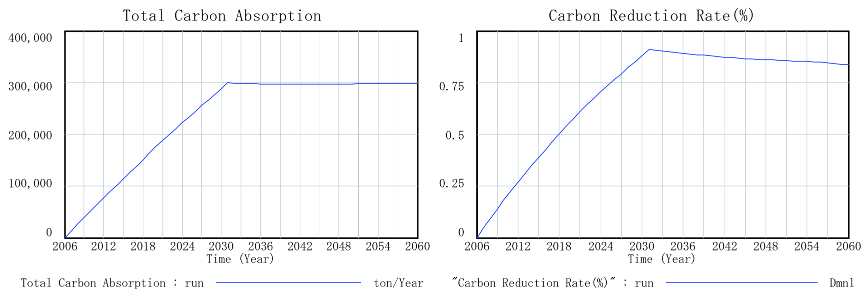

Figure 12: Carbon Absorption and its Ratio to Carbon Exhaust in Japan

6 An Economic Feasibility Analysis

Plantation Costs

Is the COALA project, if jointly implemented by Australia and Japan, sustainable and profitable? To answer these questions we need to perform an economic feasibility analysis. The analytical method employed in this analysis is based on a principle of accounting system dynamics developed by Yamaguchi (4).

Let us start with the analysis of costs. Plantation costs of the project consist of (1) cost of producing flyash fertilisers in Japan, (2) transportation costs of FGD gypsum and fertilisers from Japan to Australia, (3) land establishment and planting costs, (4) plantation maintenance costs, and (5) logging and shipping costs of forest trees. Table 3 indicates our estimated unit cost of major plantation costs.

One remark needs to be made on the treatment of the plantation costs. These costs are not recovered until forest trees are logged and sold out. Therefore,

Fertiliser and Transportation	
Flyash fertiliser production (per ton)	$25.00
Surface transportation (per ton)	$100.00
Domestic transportation (per ton)	$45.00
Establishment and Planting	
Fertilizing cost (her ha)	$10.00
Seedling price (per tree)	$1.00
Labor cost per seedling	$2.485
Plantation Maintenance	
Maintenance (per ha)	$1,000.00
Logging and shipping	
Logging (per tree)	$36.00

Table 3: Plantation and Logging Costs (Investment)

until their sales revenues are realized these costs are booked as afforestation investment and accumulated into forest assets in our balance sheet in Figure 13. Only when logs are sold out, they are subtracted from the forest assets as cost of goods sold.

Sales Revenue

On the other hand, sales revenue of the project consists of three sources; that is, flyash allowance, sales of carbon credits and logs. For the disposal of flyash per ton, A$62 are expected to be paid by electric companies in Japan, which become the project revenue. Price of carbon credits is daily fluctuating and hard to predict. In the model we assumed A$18 for carbon per ton. Price of logs when trees will be logged in 2030 or later is still harder to predict. We assumed A$60 per cubic meters and a volume of each tree is 3 cubic meters in average.

In addition to sales revenue, we could also expect non-operational revenues such as appreciation of reclaimed land due to the improvement of land quality and interest receipts if cash income is to be deposited in the future. Figure 14 illustrates the income statement of the project. Income taxes are not brought into consideration in our model due to the lack of income tax data in Australia (which could be easily fixed in our revised model in the future.)

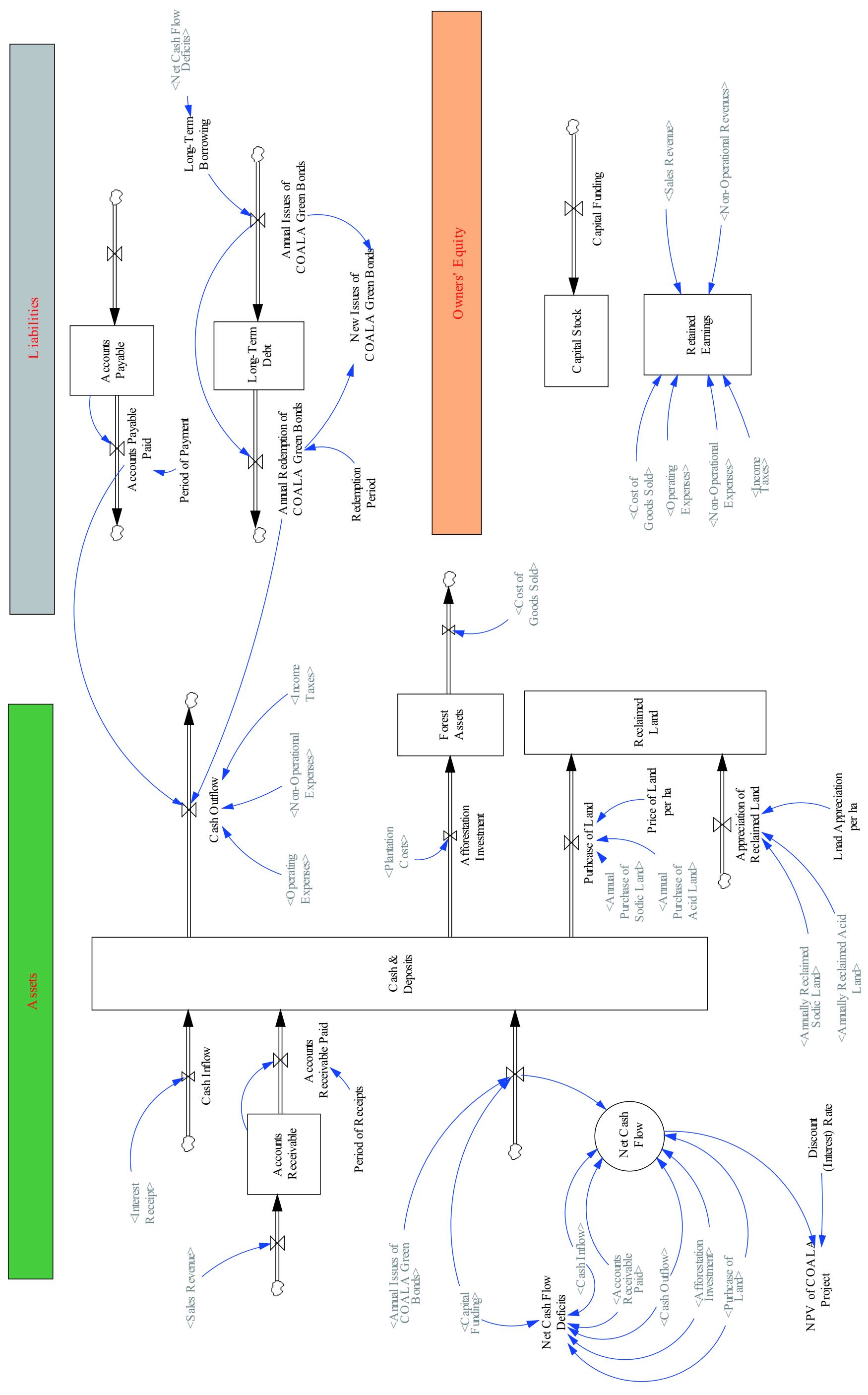

Figure 13: Balance Sheet

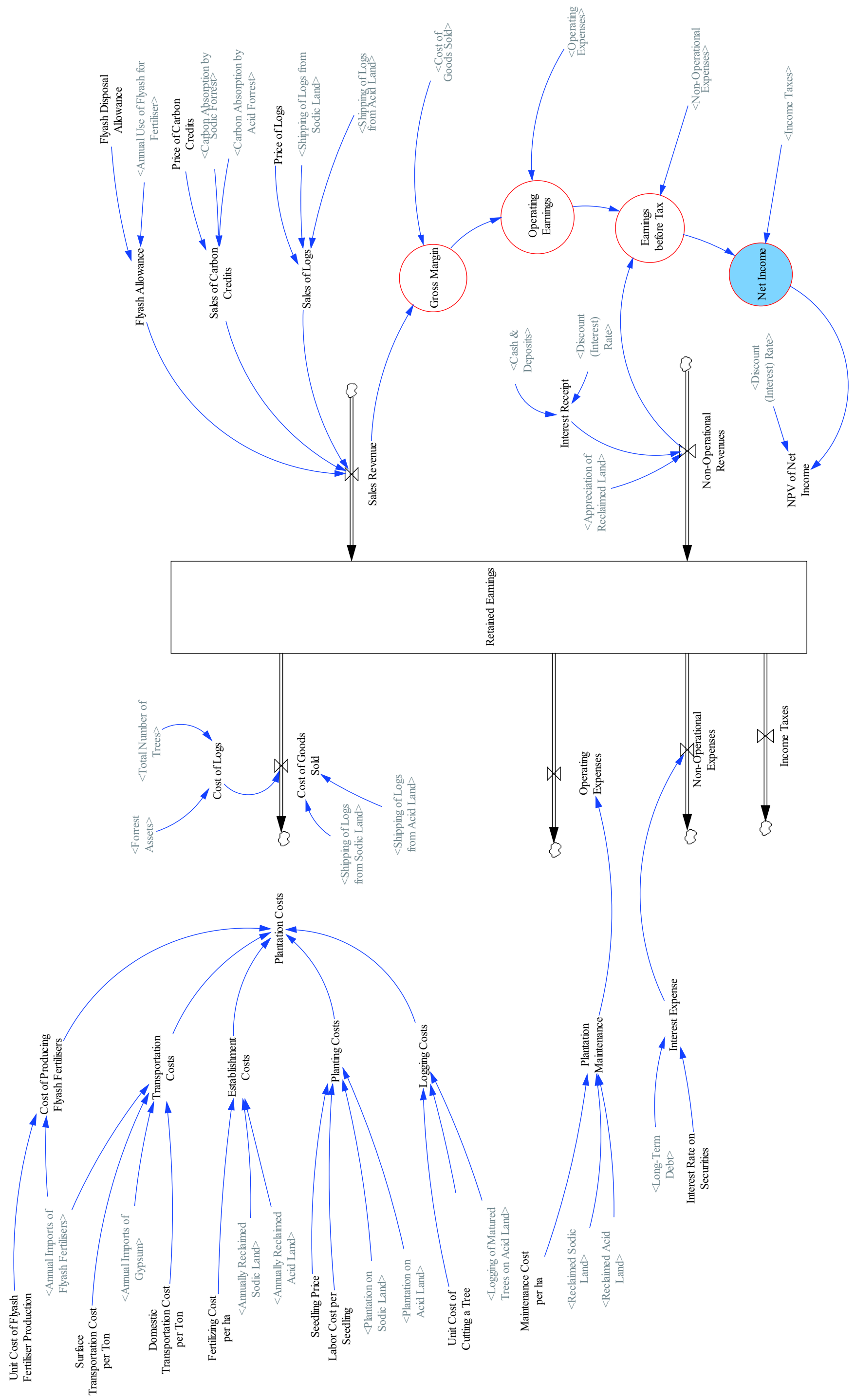

Figure 14: Income Statement

Figure 15 shows a breakdown of sales and non-operational revenues in which flyash allowance (blue line), sales of carbon credits (red line) and appreciation of reclaimed land (green line) have the same scale of 6 million A$, while sales of logs (thick gray line) and interest receipt (gray line) have a scale of 400 million A$. As forest trees keep growing they absorb carbon simultaneously, and our revenues from carbon credits in red line also keep increasing until it will stabilize around 5.3 million A$ in 2031 when our forest starts recycling with a constant number of total trees.

Meanwhile, sales revenue of logs jumps to 240 million A$ in 2031 and keeps increasing to 346.7 million A$ in 2055. Compared with this, sales revenue from carbon credits is almost negligible against our expectation before the simulation of the model is run.

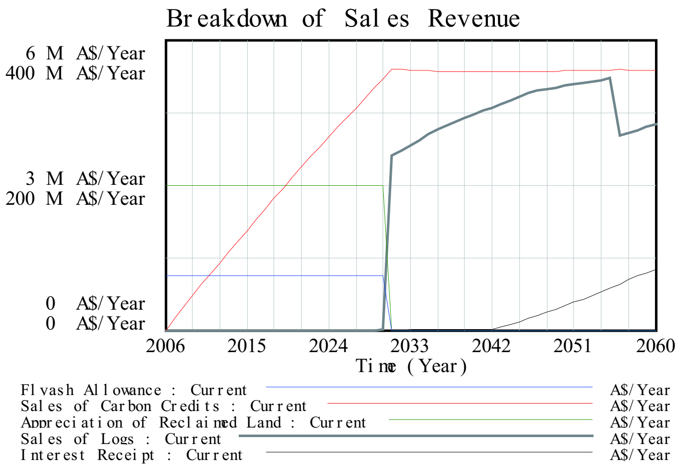

Figure 15: Breakdown of Sales Revenue

Let us further examine net income for the detailed analysis of economic feasibility. Figure 16 reveals that sales revenue (blue line) is not enough even to cover operating expenses of plantation maintenance, so that net income (red line) becomes negative till 2030, even though cost of goods sold is not subtracted in the calculation of net income until logs are sold in 2030.

More serious problem for the implementation of the project is the lack of cash flow (green line) till 2031 as shown in Figure 16. Since we need to keep spending plantation costs as afforestation investment, a constant flow of cash for the investment till 2031 is absolutely required. Accordingly, the success of this project depends on how we can raise fund to cover the afforestation investment until our forest gets matured for recycling in 2030.

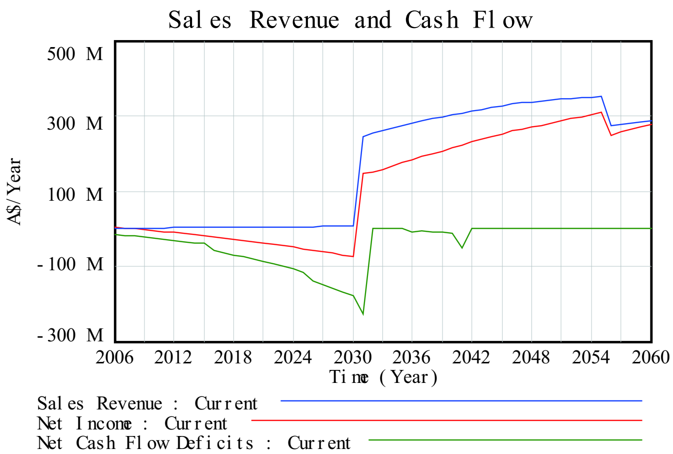

Figure 16: Sales Revenue, Net income and Cash Flow

COALA Green Bonds

For financing the afforestation investment of 25 years long, we like to recommend that the net cash deficits of the project are to be financed by issuing project bonds, called here the COALA green bonds, whose redemption period is 10 years. Such green bonds, we believe, could be purchased by socially responsible investors or ecologically conscious investors. However, it could be more favorable, without appealing to such conscientious investors, if the green bonds were to be attractive in competitive financial markets.

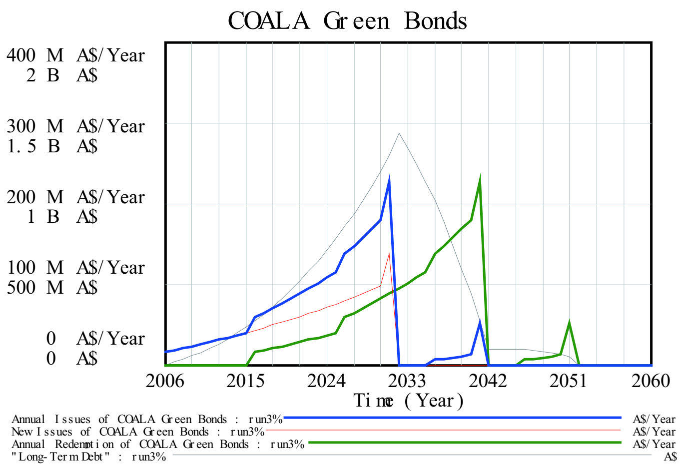

Figure 17: COALA Green Bonds

Therefore, the question is whether COALA green bonds can be competitive against corporate long-term bonds and government long-term securities in financial markets. They could become very attractive if we could offer 3% of yield or interst rate, specifically in Japanese financial markets, since current yield of Japanese government bonds (10 years) is 1.656%. Figure 17 illustrates how green bonds of 3% yield are planned to be issued and redeemed. Blue line indicates the amount of annual issues of the bonds, among which new issues are shown in red line. Bond issues will end in the year 2031 with the amount of 226.47 million A$, followed by some adjustment issues between 2036 through 2041.

On the other hand, bond redemption, shown in green line, starts in 2016 with the amount of 16.11 million A$, which keeps increasing and ends in 2041 with 226.49 million A$, followed by some adjustment redemption between 2046 through 2051. Total long-term debt of the project shown in gray line peaks at 1.434 billion A$ in 2032, but will be completely cleared in 2051.

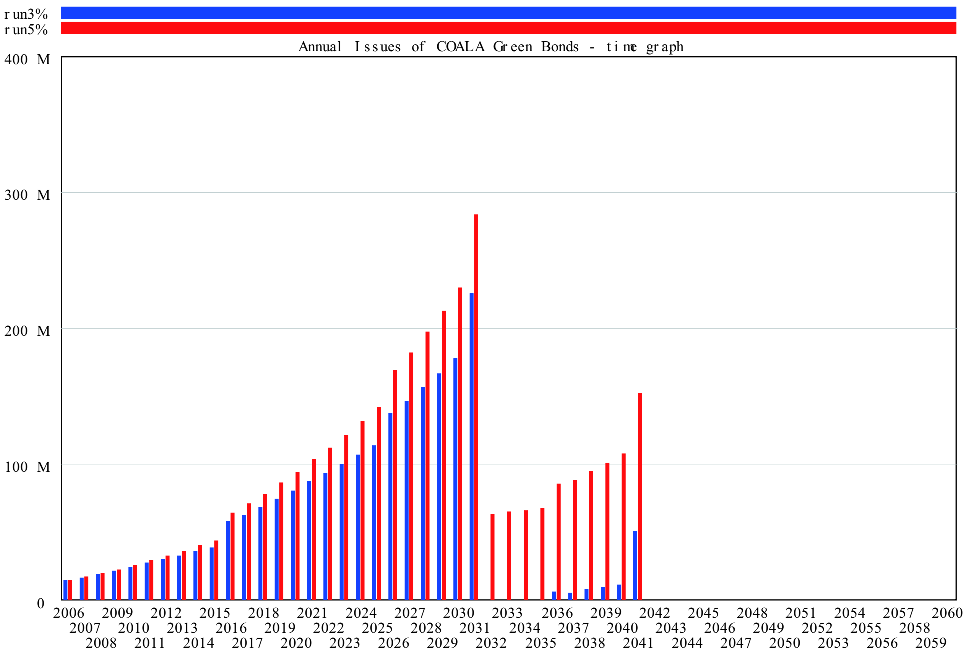

Figure 18: Annual Issues of COALA Green Bonds

Blue bar line in Figure 18 illustrates a detailed look at the figures of annual issues of COALA green bonds. Figure 19 shows that total assets of the project exceeds liabilities in 2036 with the assets value of 1.048 billion A$, and keeps increasing far beyond liabilities later on.

Blue line in Figure 20 illustrates that a return of assets (ROA) from the project becomes 27.85 % in 2031 and maintain a higher ratio of more than 10% till 2047, beyond which it still keeps a comparatively higher level of around 5% compared with those in other industries. For instance, ROA of the world largest

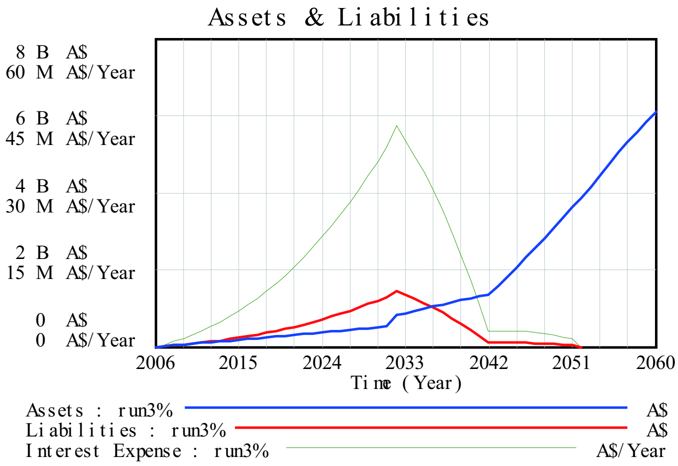

Figure 19: Assets and Liabilities

and best performance automobile company, Toyota, between 2000 through 2005 were 4.021%, 5.553%, 7.378%,6.594%, 6.111%, and 7.729% according to the calculation by the author Yamaguchi.

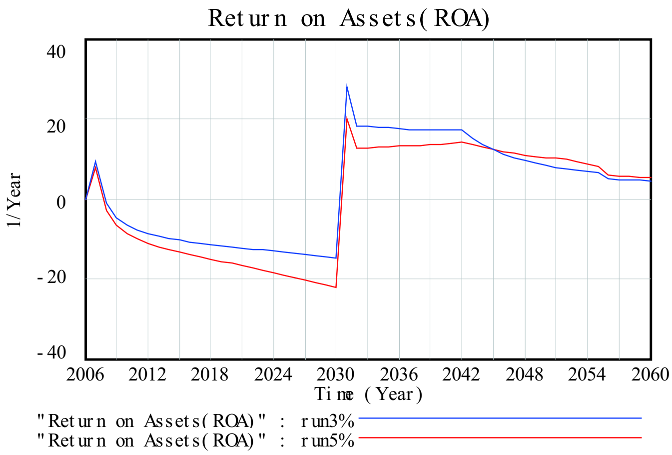

Figure 20: Return on Assets

To make our bonds attractive in global financial markets, we have tried another simulation with 5% of yield or interest rate. Red bar line in Figure 18 illustrates a detailed amount of annual issues of COALA green bonds, and red line in Figure 20 illustrates returns of assets (ROA) in this case. With this higher and globally more competitive yield of 5%, returns of assets from our project still indicate better profitability in the long run.

In this way, the green bonds of the project are shown to be attractive enough in competitive financial markets. Yet, the success of the project would be more secured, we strongly believe, if the green bonds were to be underwritten by the central or local government as a part of their sustainable public policies. Sustainable business warranted partially by the government would provide a new business model for creating sustainable futures, and the COALA project could be its first case.

Green Management with Simulations

Our feasibility analysis need not be confined to what is presented in this paper. Suspicious investors could run their own simulations by making their own convincing assumptions on the parameters of the model used in the model such as costs and prices before they make financial commitments. Project managers could also adjust parameter values at each stage of the project implementation to examine whether its actual performance is following the behavioral path of the project predicted by the model, and judge its economic feasibility and profitability by themselves.

Along this future-oriented way of thinking, let us try Monte Carlo simulation for the price of logs that will be normally distributed with a mean price of A$180 and standard deviation of A$50. The min-max range of distribution is confined between A$80 and A$280. Figure 21 demonstrates a sensitivity range of the net present value of net cash flow from the project, called NVP of COALA Project, in which mean value is shown in red line. This indicates that from 2032 on, net present value of the project keeps increasing rapidly at any risk.

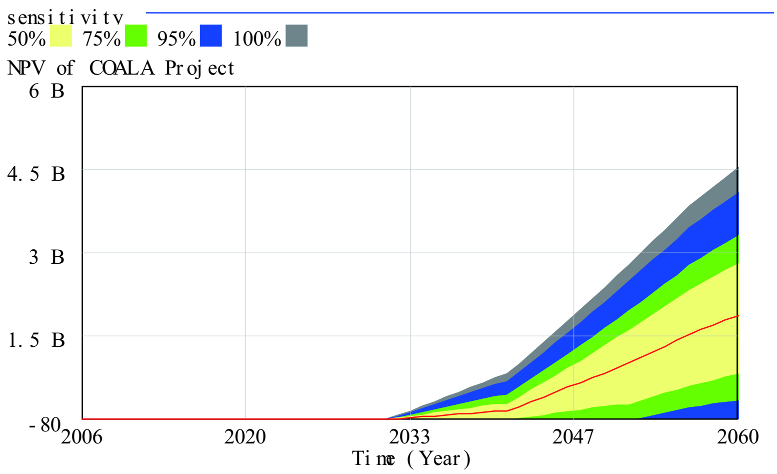

Figure 21: Monte Carlo Simulation of NPV of COALA Project

Open and flexible style of repeated simulations is absolutely necessary for sustainable project management which usually takes longer time compared with business-as-usual management. Project information and model need to be open to the public all the time for consistent evaluation by simulations so long as the project is warranted by the government. This is a new management style and strategy we recommend for green management.

System dynamics modeling method meets this need very effectively. Model-based management is absolutely necessary for green management to attain public consensus as well as investors' support. We are pleased to provide our model to the concerned reader of the COALA project.

Conclusions

We have demonstrated that the COALA project is first of all beneficial to both Australia and Japan in the sense that coal-fired power plant by-products in Japan will help improve Australian land for afforestation, and the forest trees on the reclaimed land could absorb carbons which are discharged by burning coals, though not so much. Then it is shown that the project is sustainable in the sense that forest on the reclaimed land can recycle itself with the improvement of land quality. Finally it is shown that, if the project is actually implemented in Australia jointly with Japan, it becomes profitable in the long run in the sense that not only the green bonds of the project can offer attractive yield to the investors in competitive financial markets, but the project constantly provides competitive returns of assets and best performances to the green managers.

Business as usual decisions are based on short-term economic activities, yet our economic feasibility analysis demonstrates that sustainable business is indeed as profitable or better in the long run. More than that, recent climate change or global warming environment would not allow us to waste time for implementing the project to create ecologically friendly futures.

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