INTEGRATED PLANNING TOOL FOR OPTIMISING BIOENERGY PRODUCTION FROM REGIONAL BIOMASS WASTE AND ITS APPLICATION IN THE MURRUMBIDGEE IRRIGATION AREA, AUSTRALIA

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ABSTRACT: This project is developing a new analytical tool that integrates energy and greenhouse gas accounting, materials flow analysis accounting, and a Geographic Information System (GIS) to provide a comprehensive analysis of alternative systems for optimizing bioenergy production. The type, quantities and location of feedstock, energy recovery technologies, and the kind of energy being produced can be evaluated against cost-effectiveness and environmental impact criteria. The goal is to design a system that will optimize the use of biomass waste in both energy and P recovery, while controlling Cd contamination of soils. In this paper, we describe an application of the modeling tool described above to one of the largest agricultural regions in Australia, the Murrumbidgee Irrigation Area. The scenario of installing the new bioenergy plants in the region yielded a number of benefits in term of renewable energy production, GHG emission reduction, increasing P cycling into land and reducing Cd contamination in to soil. However, it comes with the high cost of constructing a number of bioenergy plants in the region.

Keywords: Biomass; Material Flow Analysis; Resource Recovery

1 INTRODUCTION

The Australian economy faces a number of environmental sustainability issues. One is to reduce enhanced Greenhouse Warming Potential (eGWP) emissions from burning fossil fuels. Australia is one of the top GHG polluters (per capita) in the world, as Australia relies on their abundant fossil fuel, especially coal, to produce electricity. As a result, the Australian government has enacted the Mandatory Renewable Energy Target (MRET), requiring the generation of 9,500 GWh of extra renewable electricity per year by 2010. Moreover, a number of state governments now have an additional target; for example, the Victorian government requires that 10 percent of their electricity generation comes from renewable energy by 2016, and the NSW government will also commence a similar scheme. Bioenergy has a high potential to assist Australia to meet these targets [1].

Australia has an intensive agriculture and food industry and it produces large amounts of biomass waste such as straw, cotton gin waste, rice hulls, bagasse, fruit peel and pulp, grape marc, grape stalk and animal manure [2, 3]. These biomass wastes can be used as a source of renewable energy via incineration, gasification, anaerobic digestion or fermentation [4]. Or, after composting, it can be returned to improve the nutrient and drainage structure of agricultural soils, thereby reducing the demand for mineral fertilizer especially phosphate rock based fertilizers, and their associated toxic contaminants, particularly Cd. The Cd can contaminate in the soil, plant and food chain and in turn waste treatment processes residue such as ash, sludge and digestate. [5, 6]

However, to date Australia has utilized only a small amount of these biomass waste resources to produce electricity and industrial heat; most of them are baggase (by-product from sugar mill) and black liquor (by-product from paper mill). Large amounts of food processing waste and crop infield residue are not currently utilized [7, 8] There are many factors that may cause the slow utilization of biomass waste to produce bioenergy including: high capital cost, uncertainty in fuel supply security,

seasonal availability and competitive use such as fodder, not enough incentive from government and absence of regulation to control biomass waste disposal as large amount of wastes are disposed of on land without pretreatment and are burnt in the field in rural areas [2, 9]. All of these issues need to be evaluated before successful utilization of biomass waste to produce bioenergy can be achieved. Incorporating the value of Phosphorus from an organic source, the ability to reduce Cd contamination from by-product nutrient cycling to soil, and the reduction of Phosphate fertilizer application, into the cost and benefit analysis will make energy and nutrient recovery from biomass waste more attractive [10, 11].

The objective of this project is to develop a new analytical tool that integrates energy and greenhouse gas accounting, materials flow analysis accounting, and a Geographic Information System (GIS) to provide a comprehensive analysis of alternative systems for optimizing bioenergy production. The type, quantities and location of feedstock, energy recovery technologies, and the kind of energy being produced are evaluated against cost-effectiveness and environmental impact criteria. The goal is to design a system that will optimize the use of biomass waste in both energy and P recovery, while controlling Cd contamination of soils.

2 METHODOLOGY

The methodology to develop the integrated planning model is presented in Figure 1. The methodology consists of six main steps, with each step containing a number of sub-steps. The models developed in Step 3, 5 and 6 are the model components themselves and are evaluated together to plan the sustainable bioenergy system.

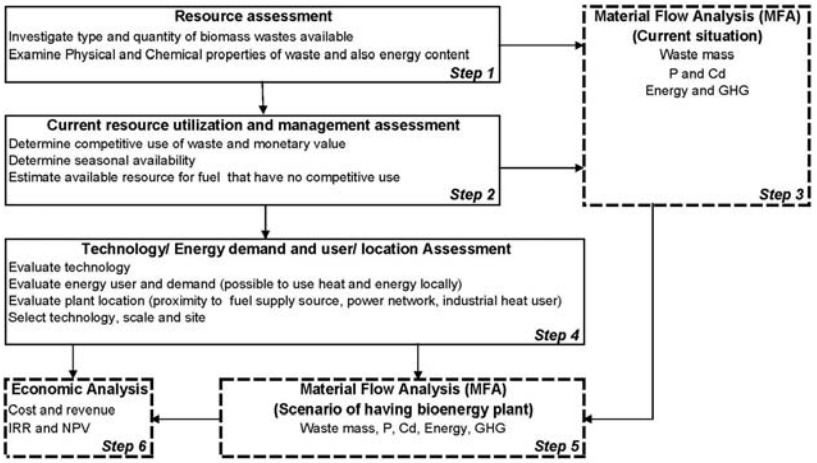

Figure 1 Diagram of methodology to develop the integrated planning model. The single-lined boxes represent the main steps. The dotted boxes are main steps and also the model components. The arrows show flow of data to the steps and model components

The quantity, type and properties of biomass waste and amount of biomass waste that have competitive use, obtained from literature research and interviewing with industries and local government in the region from step 1 and step 2, are used to conduct Material Flow Analysis (MFA) of biomass waste and Phosphorus, Cadmium, Energy and GHG associated with biomass waste flow in the study area in 2006, in step 3. Material Flow Analysis (MFA) is the environmental accounting tool that traces and provides accounts of valuable resources or toxic substances through a process or region [12, 13]. Here, MFA of biomass waste is conducted first then MFA of Phosphorus, Cadmium and Energy and Greenhouse gas (GHG) are conducted by multiplying substance's concentration and energy content, with the amount of each type of biomass waste. GHG flow is obtained from accounting for GHG emissions from current treatment of biomass, such as CH_4 emission from anaerobic lagoons.

In step 5, selected biomass conversion and energy production technology, scale and site obtained from step 4 are used to modify the MFA model in the current situation from step 3. Here, the "process boxes" of bioenergy plant are inserted in the model, and the flows of biomass waste that is available for bioenergy production are diverted to the biomass energy plant. Then the output from the bioenergy plant, in terms of digestate, ash, compost, P, Cd, energy and GHG are determined by multiply substance and energy flow in the waste input with appropriate "Transfer Coefficient". These transfer coefficients are obtained from a literature review and from the reports on the real operating plant in other regions [12].

In step 6, all of the estimated cost and revenue obtained from the literature and industry interviews are input into the cash flow and financial analysis model, which is a spreadsheet model. Moreover, the amount of energy and by product output, and GHG reduction potential obtained from MFA model are input into this Economic Analysis model. Then, the results of IRR, NPV and cash flow are shown in the model.

Finally, trade offs among costs, energy, GHG, P and Cd are evaluated using the data from the Material Flow Analysis model in step 3 and 5, and the Economic Analysis model in step 6. Moreover, new scenarios using new bioenergy technologies and new and changed inputs of biomass waste flow to the bioenergy plant can be assessed, by rearranging the flow and changing transfer coefficients in "bioenergy plants process box" in the MFA model. The new output from the plants can then be used to evaluate the trade offs among the criteria of costs, energy, and substances for this newly developed scenario.

3 RESULTS AND DISCUSSION

3.1 Study area

The Murrumbidgee Irrigation Area (MIA), one of the largest agricultural areas in Australia, is the study region in this project. The area is a major producer of rice, cereal, oilseed, citrus, winegrape and other fruit and vegetables. The MIA produces almost 20% of the total Australian winegrape production, 35% of the total Australian citrus production and almost 20 % of the total Australian rice production. A number of food factories are in this area including wineries, rice mills, juice making, and fruit and vegetable processing. Two intensive cattle feedlots and a beef processor which carry a total of 86,000 head of cattle, and one of Australia's largest poultry producer and processor, processing approximately 28 million chickens a year, are also located in this region [14]. The GIS map showing the location and type of food factories and crop production in MIA is illustrated Figure 2.

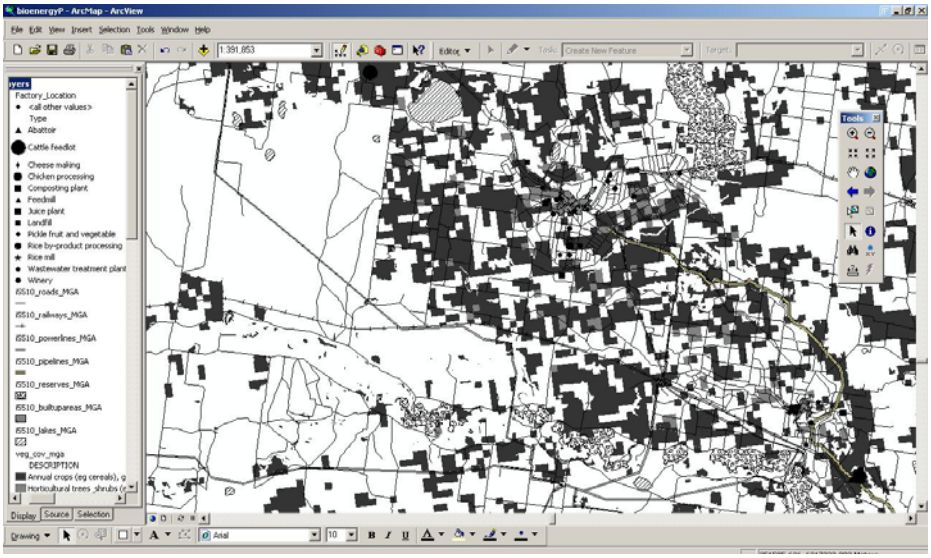

Figure 2 The GIS map showing the location and type of food factories and crop production in MIA

3.2 Current biomass, substance and energy flow

Total biomass waste from animal production and food processing produced in the region is 476,932 tonnes /y consisting of 147,833 tonnes of manure and bedding material; and 329,099 tonnes of food processing waste, which comprise of grape marc, fruit peel and pulp, rice husk and rice bran, whey and meat processing by product.

In terms of infield crop residue, rice straw is the only available and accessible biomass waste to use for energy production, because cereal straw is used for hay and left on the soil for animal grazing; wine and citrus pruning have a high moisture content and are left in situ. In contrast, rice straw are harvested together with paddy rice and are separated from paddy rice after threshing and are baled for sale as bedding material and compost feedstock[15]. Therefore, the focus will be on rice straw only. At present only 15% of rice straw is baled and sold; the rest is left on the soil and burnt.

The details of biomass wastes flow are presented in Figure 3. The flow of Phosphorus, Cadmium, energy and GHG are presented in Figure 4, 5 and 6 respectively.

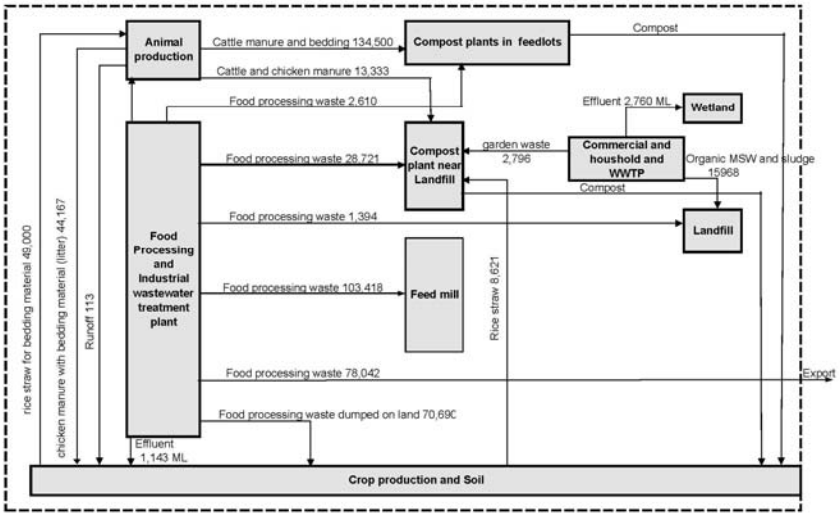

Figure 3 Current biomass waste flow diagram in MIA in 2006 (tonnes/year)

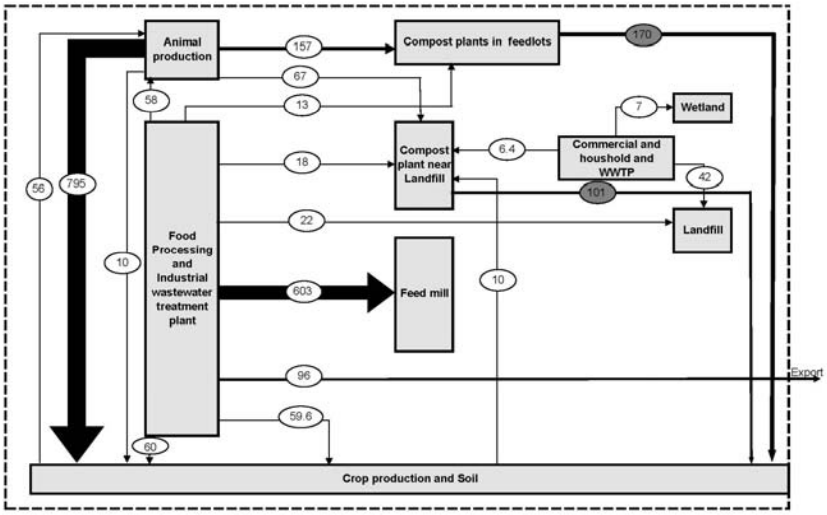

Figure 4 Current Phosphorus flow diagram in MIA in 2006 (tonnes/year), as associated only with biomass waste flows from Figure 3.

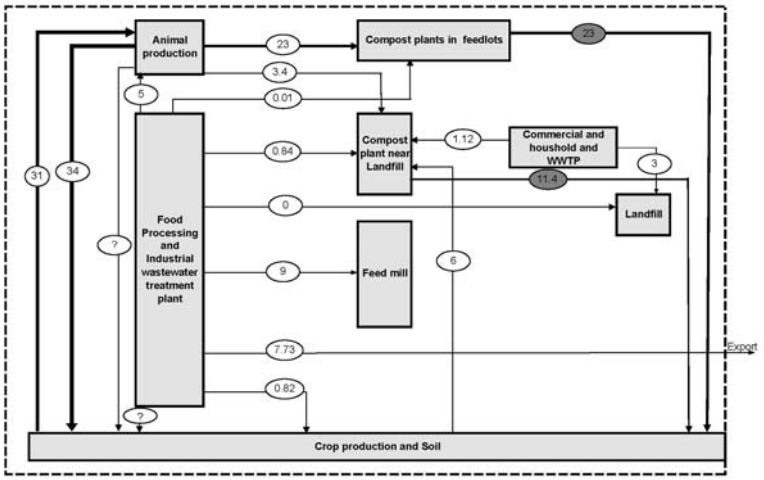

Figure 5 Current Cadmium flow diagram in MIA in 2006 (kg/year)), as associated only with biomass waste flows from Figure 3.

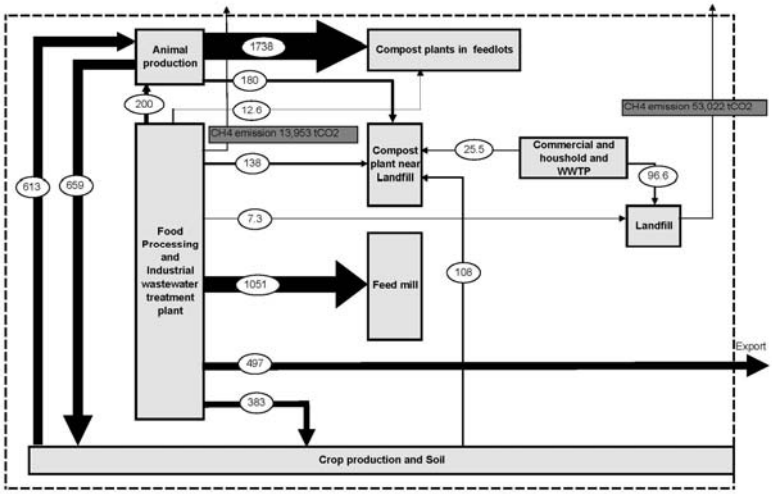

Figure 6 Current energy/GHG flow diagram in MIA in 2006 (TJ/year and tCO_2/y), as associated only with biomass waste flows from Figure 3.

As presented in Figure 4, the major flow of Phosphorus in the biomass waste flow in the region is the flow of chicken manure applied on land as fertilizer, which account for 795 t/y or 40% of total Phosphorus flow associated with biomass waste. The second largest flow of P is in the flow of food processing waste sent to the feed mill, which accounts for 603 t/y or about 30% of total P flow. The flow of P associated with cattle manure and bedding sent to compost plant represent the third largest flow of P, and accounts for only 157 t/y or 8% of total P flow. About 5% or 96 t/y of P in total biomass waste in the region is exported as feedstock, and 3% or 59.6 t/y of P in food waste are disposed of on land which yields no benefit to crops.

In term of Cadmium as presented in Figure 5, the majority of cadmium flow associated with biomass waste flows of 613 kg/y is in the flow of rice straw to be use as bedding material, as rice straw has a high contamination of cadmium. As a result, chicken litter (chicken manure with bedding material) applied to land as fertilizer, and cattle manure and bedding material collected together and sent to compost plants in the feedlot are the second and third largest flows of Cadmium in the region. This in turn makes a compost product flow from the compost plant in feedlot, and the compost plant near landfill, having Cadmium of 37 kg/y and 11.3 kg/y respectively.

In terms of energy and GHG flow in Figure 6, the highest energy flow of 1,738 TJ/y is the flow of manure and bedding material to compost. The second highest energy flow is in the flow of biomass waste to the feed mill, representing an energy flow of 1,051 TJ/y. The diagram also shows that 497 TJ/y of energy flow is in exported food waste, and 254 TJ/y of energy flow is in food waste disposed of on land. These waste have very high potential to produce energy, but at present none of these waste are used to produce bioenergy. In term of GHG emission, CH_4 emission from anaerobic lagoon type of industrial wastewater treatment account for 14,000 tCO_2 equivalent and CH_4 emission from landfill account for 53,000 tCO_2 equivalent.

3.3 Biomass, substance and energy flow for a scenario of having a bioenergy plant in the region.

In the scenario, we assumed that the compost plants in each of the cattle feedlots are replaced with In-vessel anaerobic digesters. Therefore, all cattle manure is processed in anaerobic digestion plants to produce electricity and steam to use in their feed mill, and also a by-product of anaerobic compost for sale. Food processing waste streams that are dumped on the land are diverted to co-digest with manure in the anaerobic digestion plant in the feedlots. Sludge resulting from Dissolve Air Flotation (DAF) process in the chicken processing plant is diverted from land injection to an onsite anaerobic digestion plant to produce biogas, to displace the use of natural gas in their boiler. Moreover, we assumed that all of anaerobic lagoons for industrial wastewater treatment in the region are covered, and biogas is recovered to produced electricity or steam. About half of Landfill gas is also captured and uses to produce electricity.

In terms of infield residue, we assume that about 25% of rice straw in the field can be collected and baled and sent to the rice straw gasification plant with cogeneration, to produce both electricity and steam for some food factory nearby.

The capacity, cost and revenue of bioenergy plants are presented in Table 2. Revenue in terms of electricity is 8 c/kWh, assumed to increase 1 c/kWh every 5 years. Steam is $6/GJ, and assumed to increase $1/GJ every 5 years. Compost product is assumed to be $50/t; Renewable Energy Credits is $30 /MWh produced and gate fee for food waste to co-digest with manure is $ 60/t, with the assumption of having stringent legislative control of disposal of putresible waste on land in the near future. The NPV and IRR of an anaerobic digestion plant in the chicken processing plant in the last case are not available, because all the data in this plant was obtained from other study [8] where NPV and IRR was not analyzed.

Table 2. Bioenergy plant in the scenario with their capacity, energy, GHG benefit, cost, revenue and economic analysis.

Items	1.Anaerobic digestion plant in feedlot 1	2.Anaerobic digestion plant in feedlot 2 (co-digestion with food waste)	3. Rice straw gasification plant and gas turbine	4.Anaerobic digestion plant in chicken processing plant
Total waste input quantities (t/y)	85,000	112,000	96,768	8,190
Type and quantities (t/y) of waste input	Manure-85,000	Manure-49500 Food waste-62500	Rice straw-96,768	DAF sludge-8190
Energy / GHG benefits				
Electricity potential (MW)	6	5.5	10.7	n.a.
Electricity production (MWh/y)	54483	47821	94080	n.a.
Heat recovered (GJ/y)	118556	104059	483,840	145
GHG abatement(t CO_2)	61,973	54,395	124,644	3898
Cost				
Capital cost ($ millions)	40.3	54.3	37.4	0.77
Annual O&M ($ millions/y)	2	2.8	1.3	0.01
Fuel cost($ millions/y)	0	0	1.9	0
Fuel collection and storage cost ($ millions/y)	0	0	4.2	0
Revenue				
Electricity sale ($ millions/y)	4.9	3.8	7.5	0
Stream sale ($ millions/y)	0.8	0.6	2.9	0.26
Renewable energy credits($ millions/y)	1.6	1.4	2.8	0
Digestate sale ($ millions/y)	0.4	0.57	n.a.	0.04
Gate fee ($ millions/y)	0	3.75	0	0
Economic analysis				
Pay back period (years)	9 to 10	9	7	3
NPV($ millions)	0.2	2	7.6	n.a.
IRR(%)	12	14	22	n.a.

The MFA diagrams for biomass waste, P, and Cd, and energy and GHG flow diagram of the newly constructed bioenergy system scenario are presented in the Figure 7, 8, 9, 10 respectively.

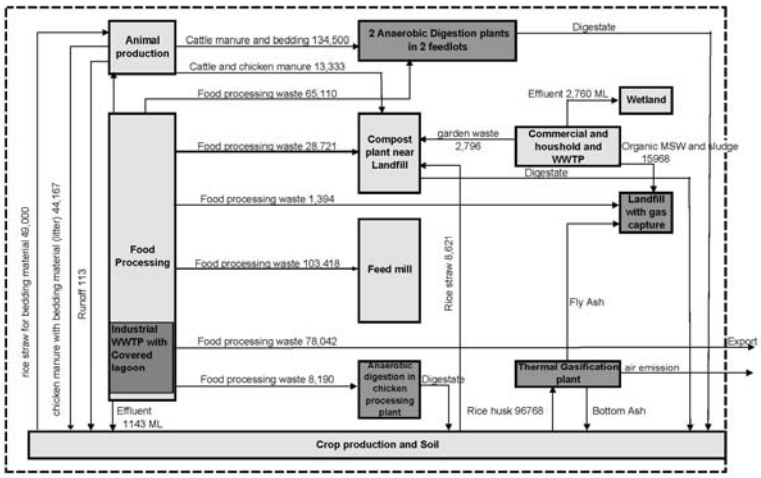

Figure 7 Scenario biomass waste flow diagram in (tonnes/year)

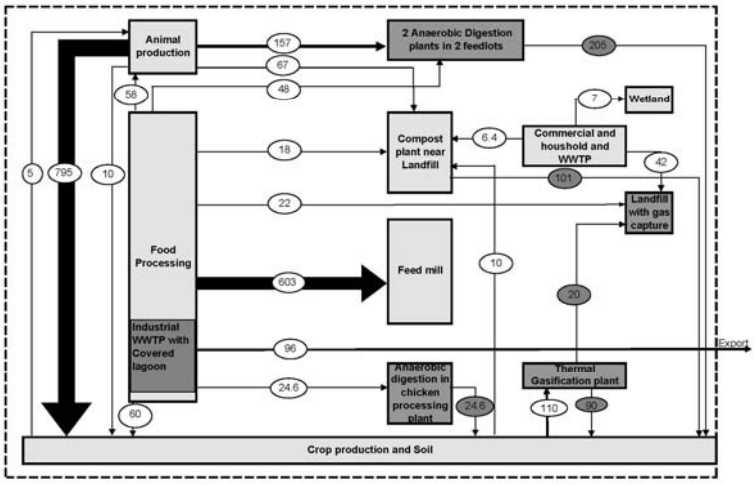

Figure 8 Scenario Phosphorus flow diagram in MIA (tonnes/year), as associated only with biomass waste flows from Figure 7.

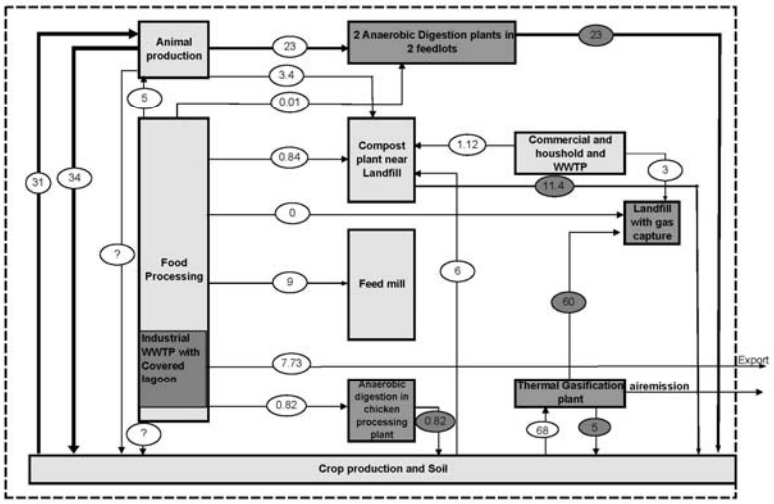

Figure 9 Scenario Cadmium flow diagram in MIA (kg/year), as associated only with biomass waste flows from Figure 7.

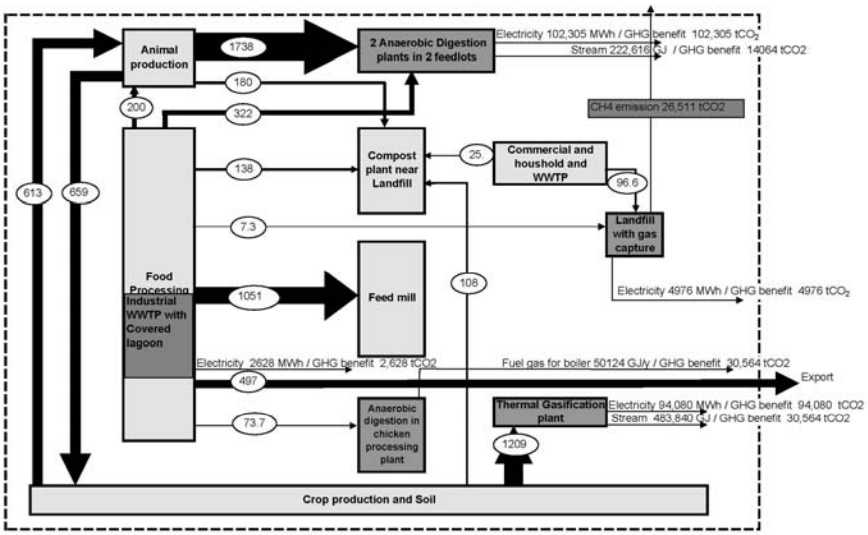

Figure 10 Scenario Energy/GHG flow diagram in MIA in 2006 (TJ/year and tCO_2/y), as associated only with biomass waste flows from Figure 7.

In the scenario in Figure 8, Phosphorus in waste is used more efficiently, as P in waste dumped on land (no use) is transformed to digestate or anaerobic compost via anaerobic digestion, and can be sold to farmers to use in the region. The amount of P in the total product of anaerobic compost from 3 anaerobic digestion plants is 330.6 t/y, compare to 271 t/y of P in compost product in the current situation. In the rice straw thermal gasification plant, there is an input of 110 t/y of P in rice straw but only 90 t/y of P in all bottom ash is recycled back to the soil, as 20 t/y of P in all fly ash has to go to landfill because it has a high cadmium concentration (assuming that this plant is equipped with fractionate technology as in Gratwein Plant, in Austria that can concentrate most of the Cd in the fly ash, with low Cd in the bottom ash [16].

In terms of the Cadmium flows in Figure 9, Bioenergy plants in the scenario have no effect on the flow of Cd, and Cd concentration in anaerobic compost produced from the anaerobic digestion plant is almost the same as Cd flow in the compost output in the current situation. Because Cd is low in waste dumped on land in the current scenario, therefore when these wastes are converted by anaerobic digestion plants in the scenario, the Cd in digested or anaerobic compost output is also low. In the rice straw thermal gasification plant, there is an input of 68 kg/y of Cd in rice straw and an output of 60 kg/y of Cd concentrated in fly ash, which is sent to landfill, leaving only 5 kg/y of Cd in bottom ash recycled back to soil (because of its P value).

In term of energy and GHG flow in Figure 10, in the scenario, most of the biomass wastes in the region are recovered to produce energy; manure and bedding material and also food processing waste are processed in anaerobic digestion to produce electricity of 102,305 MWh/y and steam of 222,616 GJ/y, the GHG benefit is a total 116,370 tCO_2/y, which results from avoiding burning of fossil fuel for electricity generation and combustion of natural gas for steam production. DAF sludge from chicken processing waste is processed in an onsite in-vessel anaerobic digestion plant, and produces biogas to use in the boiler, replacing some of the natural gas. This energy account for 50,124 GJ/y with a GHG benefit of 30,564 tCO_2/y. Anaerobic lagoons in the region are also covered, and biogas is collected to generated a total electricity of 2,628 MWh/y, with a GHG benefit 2,628 tCO_2 including reduced direct CH_4 emission of 13,953 tCO_2 equivalent. About 50% of Landfill gas can be captured, giving a benefit of 26,511 tCO_2 equivalent and production of electricity of 4,976 MWh. Rice straw is collected and putt into a thermal gasification plant, producing electricity of 94,080 MWh/y and steam of 483,840 GJ/y, with total GHG benefit of 124,644 tCO_2/y.

On the whole, in this scenario, the bioenergy plant performed well in energy and nutrient recovery processes, with large amounts of energy from biomass being recovered, compared with no energy recovered at all in current situation. Large amounts of GHG emissions are reduced as by reducing direct methane emissions from anaerobic lagoon and landfills, and reducing indirect GHG emission reduction from replacing fossil fuel energy with bioenergy. Extra Phosphorus is also

recovered in the form of anaerobic compost through anaerobic digestion, with Cadmium flow associated with anaerobic compost being almost the same amount as Cadmium flow in compost product in current situation. Moreover, in the rice straw gasification plant, most Phosphorus is recycled back to the soil in form of bottom ash. A small amount of the Phosphorus input is 'lost' because the P in the fly ash is disposed of in landfill because of its high cadmium concentration. Therefore, this rice straw gasification plant has a cadmium benefit, because a large amount of cadmium in rice straw is removed from the soil partitioned to the fly ash and sent to landfill.

4 CONCLUSION

Biomass wastes in the Murrumbidgee Irrigation Area have a high potential to produce bioenergy and to be the source of nutrients for soil conditioning. However, at present, there is no bioenergy produced from these biomass wastes because of constraints in terms of; high capital cost, uncertainty in bio-fuel supply security, no strict regulation to control biomass waste disposal and not enough incentives from government. Therefore, currently these biomass wastes are disposed of on land without pretreatment, burnt in the field, composted, and used as stockfeed. Combining a Material Flow Analysis model and a Economic Analysis model can assist us in planning for new bioenergy plants, in term of analyzing the amount and type biomass that are available for bioenegy production, and to evaluate bioenergy technology in terms of their costs and their effect on Phosphorus and Cadmium flows associated with the product output. In this case, the scenario yielded a number of benefits in term of renewable energy production, Greenhouse gas emission reduction, increasing Phosphotus cycling into land and reducing Cadmium contamination in to soil. However, it comes with a high cost of constructing a number of bioenergy plants in the region. However, the IRR for these plants of 12 to 22 % are attractive.

More work in sensitivity analysis of energy price, renewable energy credits, and compost price on the economic feasibility of the plant should be conducted to assist in evaluating the viability of the plants, and to assist the government to evaluate the effect of incentives to the development of a viable bioenergy system. Moreover, STAN, the MFA software developed by TU Vienna, Institute for Water Quality, Resources and Waste Management, will be used with the MFA model assembled here to facilitate the evaluation of different bioenergy technologies, and scenarios of changing the flow input into the bioenergy plants. For example, the anaerobic digestion plant can be replaced with a pyrolysis plant. The changed conversion factors of the new plant will be inserted into the MFA model, with resulting changes in energy and substance flow outputs from the plant. Similarly, some biomass waste flows that are exported as feedstock, may be changed to input to any bioenergy plant in the region.

5 ABBREVIATIONS

GHG	Greenhouse gas
MFA	Material Flow Analysis
P	Phosphorus
Cd	Cadmium
IRR	Internal Rate of Return
NPV	Net Present Value
MIA	Murrumbidgee Irrigation Area

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