Climate Informatics for the Water-Energy-Food Nexus in the Indus Basin: A Scoping Study in Modeling Dairy Farms

Muhammad Farooq[1], Abubakr Muhammad[1], and Talha Manzoor[1]

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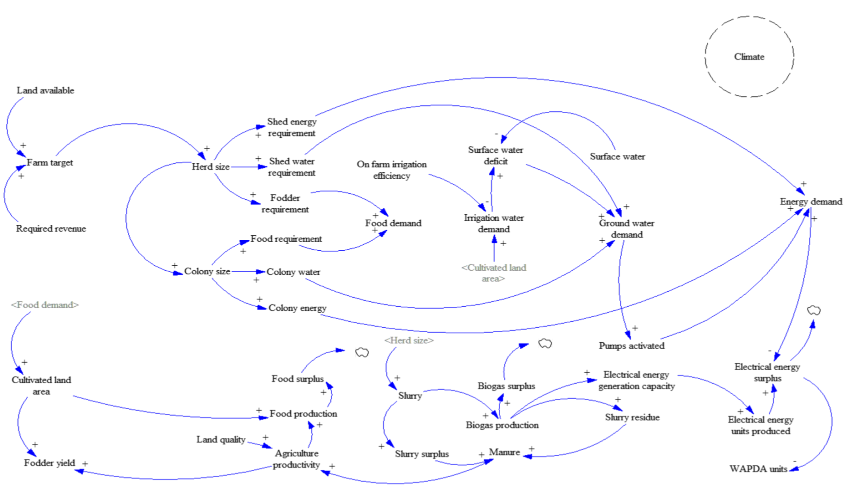
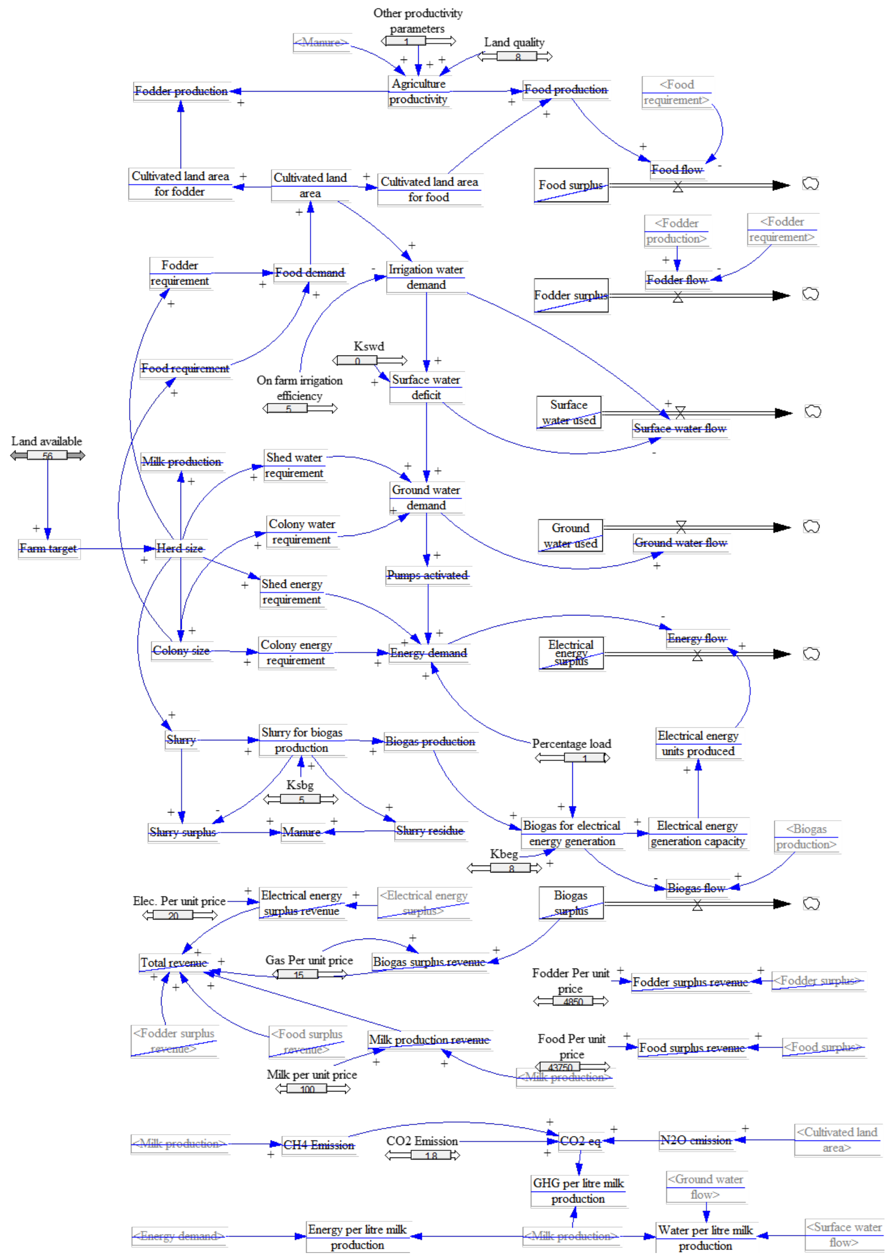
Abstract

Climate patterns in the agricultural zones of the Indus basin are predicted to undergo undesirable changes in the hydrological cycle. These changes are a threat to the widespread agricultural activity and associated livelihoods of the underlying population. Livestock, an essential sector for human sustenance in the basin, is also a major source of greenhouse gas emissions thereby contributing towards climate change. However, it is also a recipient of climate impacts, thus introducing feedbacks and uncertainties that are further accentuated by the Water-Energy-Food Nexus. Here we model and simulate the farm-level dairy operations of a single dairy farm by introducing informatics-driven precision measurements of water, energy, food, and carbon emissions in a system dynamics framework. We analyze the simulated trajectories for energy, water, and waste fluxes to under different interventive scenarios to identify actions that enhance productivity and minimize environmental impact. The model is constructed based on data gathered from two dairy farms located in rural Punjab, Pakistan. The farms have a livestock capacity of 300 and 134 animals respectively, with data related to water, energy, food, and climate gathered over a duration of two years. The simulated results may be used to uncover structural changes in dairy-farm operations which improve the economic structure of the farm while remining within the thresholds defined by Sustainable Development Goals (SDG) 3, 7 and 13 set by the United Nations. The model itself also helps in unravelling the complex interactions among water-energy-food flows along with their coupling to land-climate interactions in context of the dairy farm operations. Beyond the climate change adaptation measures extracted from this study, the system dynamics model that we construct in the process, can help develop economic tools that leverage the advantages of water/climate informatics driven data services and decisions under large variabilities to devise sound agricultural policy.

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Fodder requirement
Food demand
Irrigation water demand
Kswd
Food requirement
On farm irrigation efficiency
Surface water deficit
Surface water used
Surface water flow
Land available
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Ground water demand
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Ground water flow
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Colony water requirement
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Shed energy requirement
Electrical energy surplus
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Colony energy requirement
Energy demand
Slurry
Slurry for biogas production
Biogas production
Percentage load
Electrical energy units produced
Ksbg
Slurry surplus
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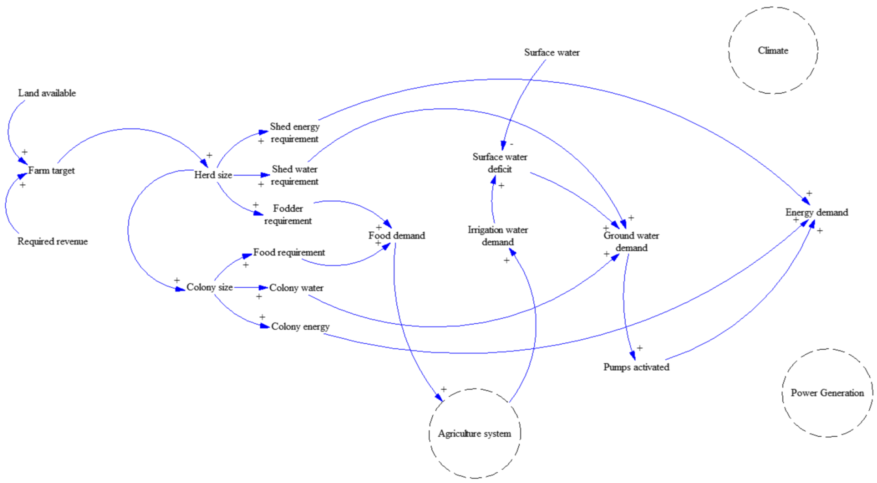
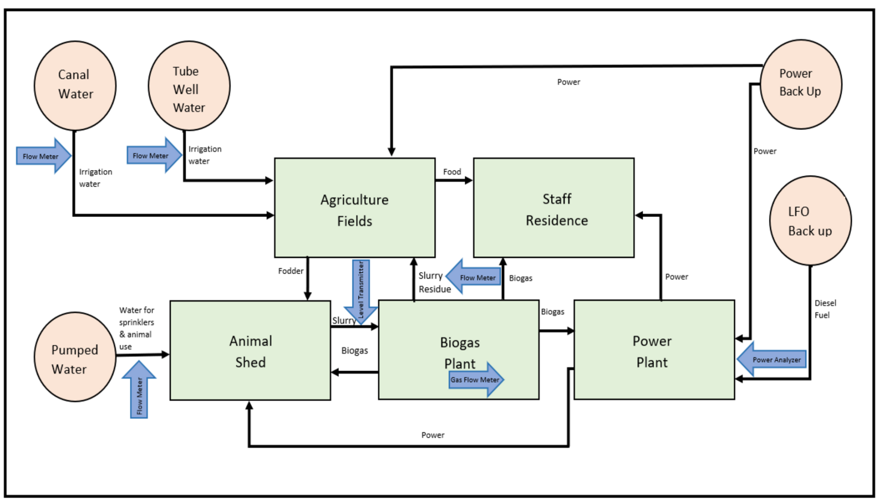
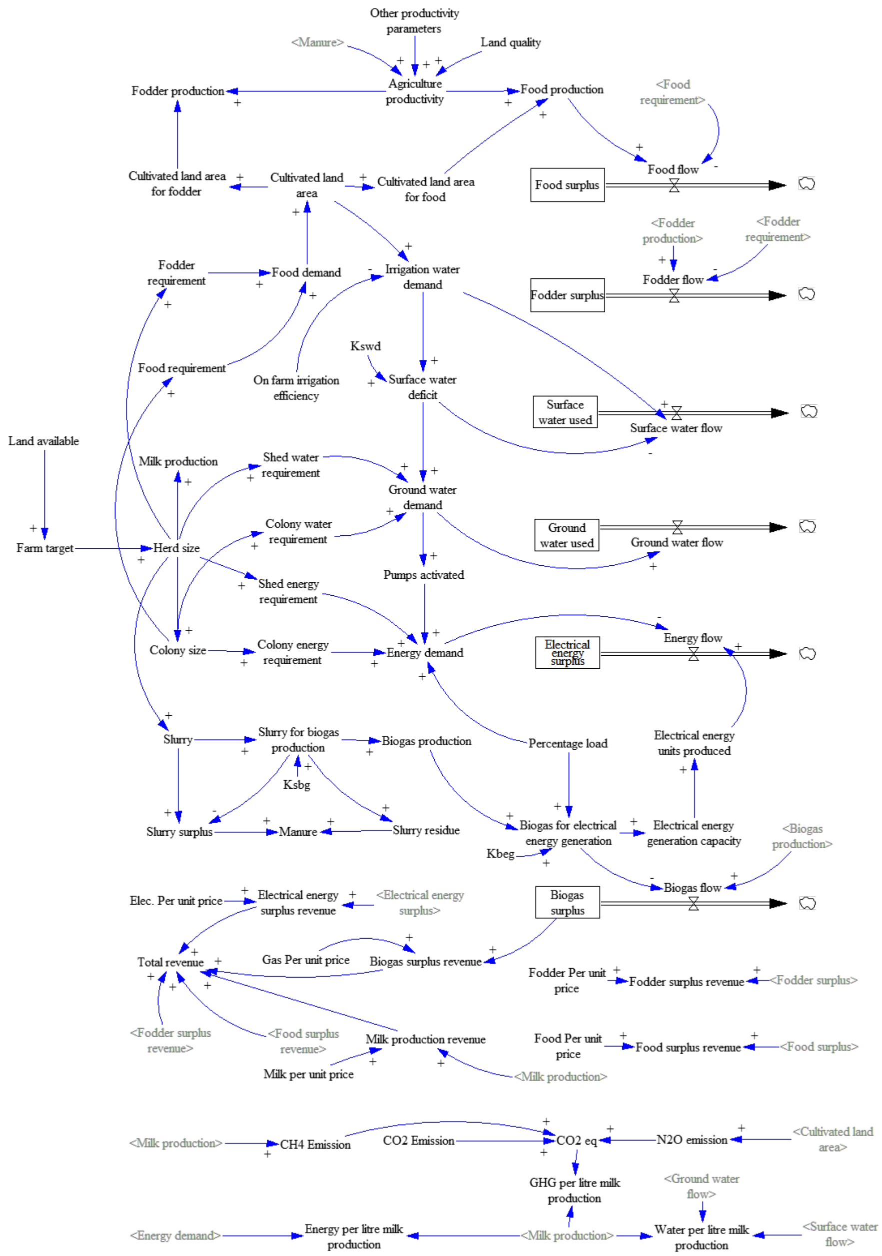


Land available
Farm target
Required revenue
Herd size
Colony size
Shed energy requirement
Shed water requirement
Fodder requirement
Food requirement
Colony water
Colony energy
Food demand
Surface water
Surface water deficit
Irrigation water demand
Ground water demand
Pumps activated
Energy demand
Climate
Power Generation
Agriculture system



Canal Water
Tube Well Water
Pumped Water
Power Back Up
LFO Back up
Flow Meter
Flow Meter
Irrigation water
Irrigation water
Power
Power
Agriculture Fields
Staff Residence
Food
Fodder
Level Transmitter
Slurry Residue
Flow Meter
Biogas
Power
Diesel Fuel
Water for sprinklers & animal use
Flow Meter
Animal Shed
Slurry
Biogas
Biogas Plant
Gas Flow Meter
Biogas
Power Plant
Power Analyzer
Power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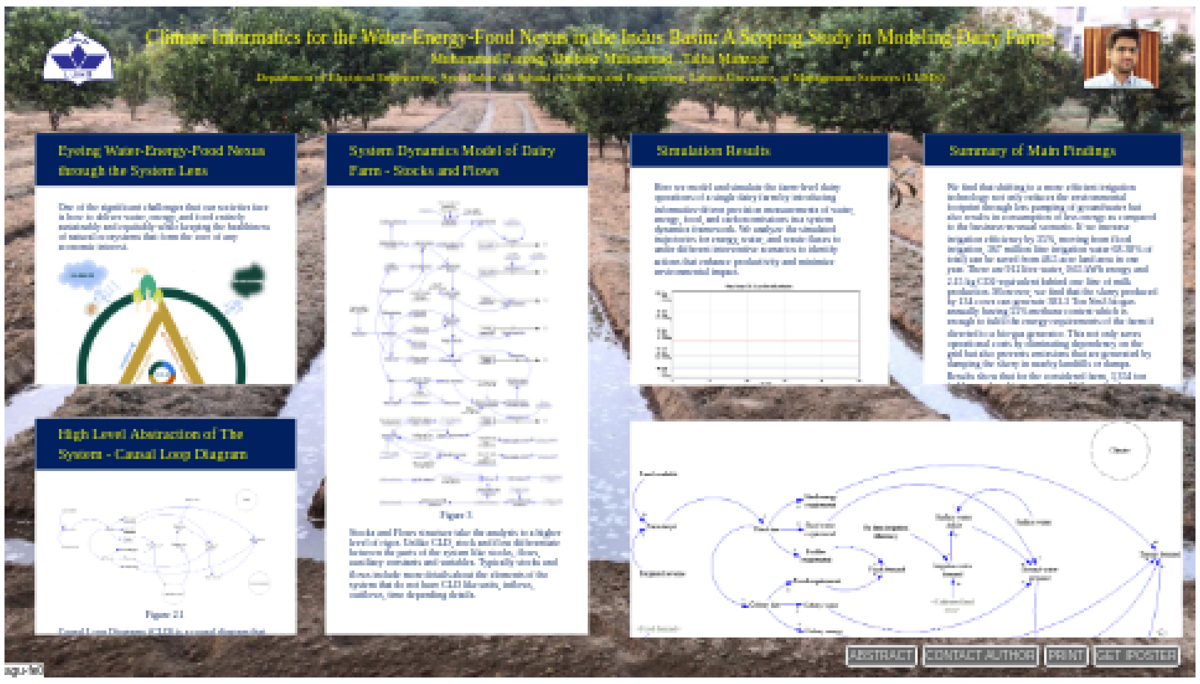

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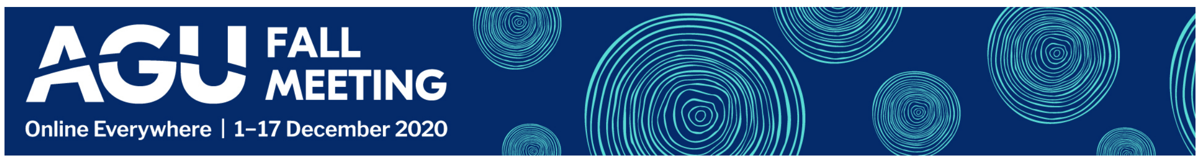


EYEING WATER-ENERGY-FOOD NEXUS THROUGH THE SYSTEM LENS

One of the significant challenges that our societies face is how to deliver water, energy, and food entirely sustainably and equitably while keeping the healthiness of natural ecosystems that form the core of any economic interest.

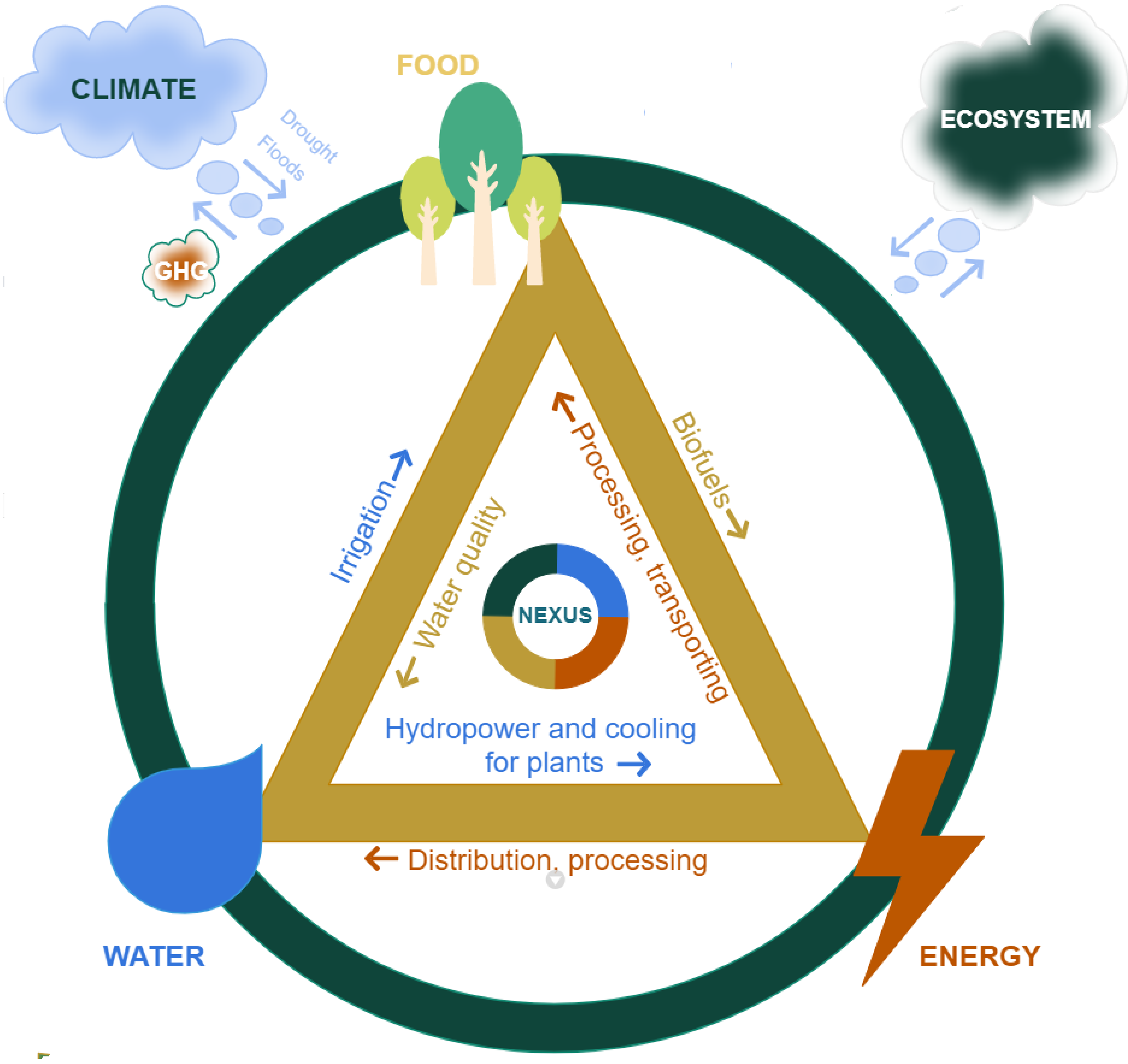


Figure 1.1

The Nexus approach begins with the realization that water, energy, agriculture, and natural ecosystems exhibit intense and multi-dimensional interlinkages. Under a traditional fragmented system, attempting to achieve resource security independently would not only be sub-optimal; still, it will often compromise sustainability and safety in one or more of the other sectors.

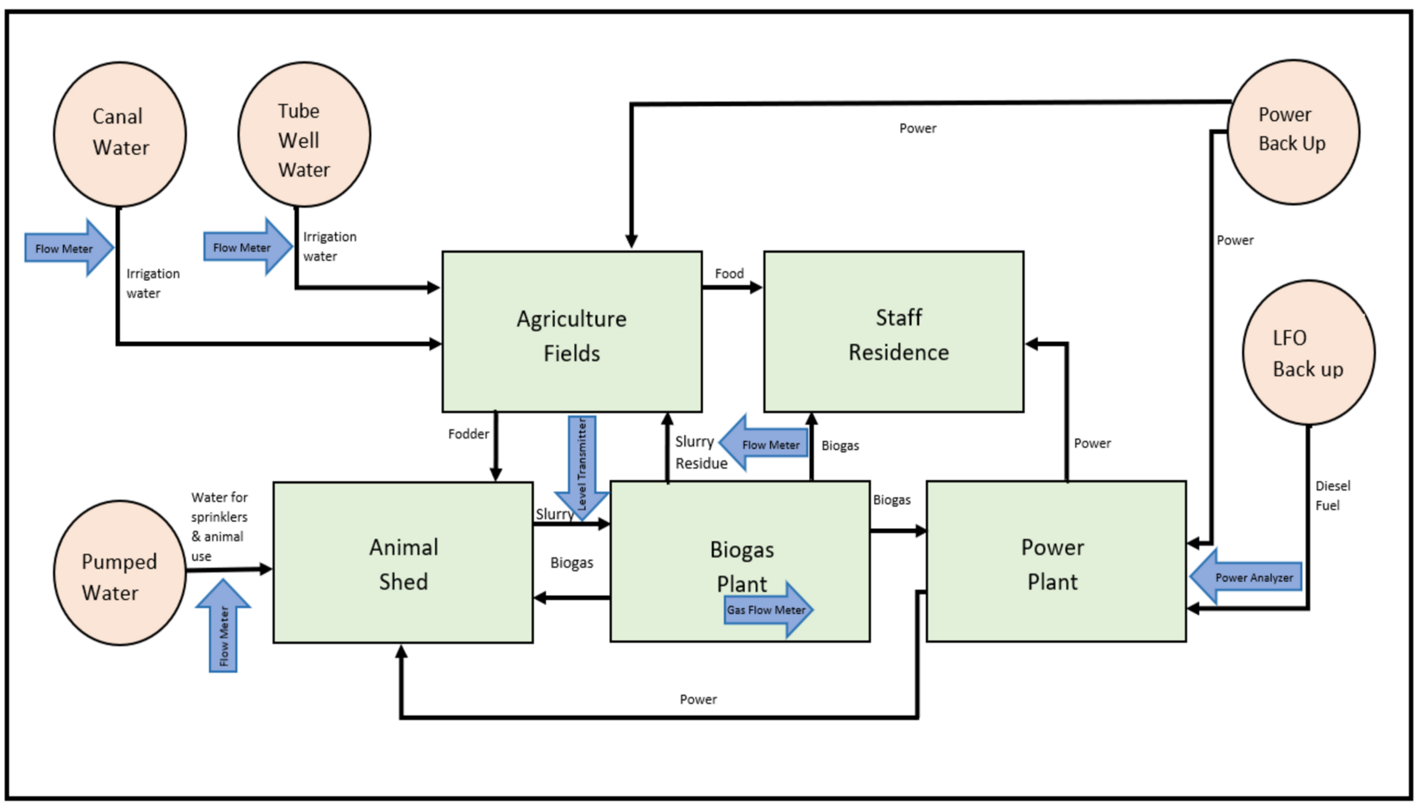


Figure 1.2

Dairy farm is inherently multifaceted structure comprising different fragments such as animal shed, agriculture system, biogas plant, power generation and climate parts; ground water, surface water and surrounding atmosphere in which dairy farm cross interact. All fragments are entangled collectively so each resource need to observe how it is interacting and what is its impact on other parts of the dairy farm.

HIGH LEVEL ABSTRACTION OF THE SYSTEM - CAUSAL LOOP DIAGRAM

This is foundational structure of system dynamics model of dairy farm operations. Dairy farm is divided into different blocks. Entire dairy farm is considered as a system and its sub-sections considered as subsystems (Figure 1.2). After formulating system and subsystems related to dairy farm, subsystems are further explored and modeled with the help of Causal Loop Diagram (CLD). CLD is built step by step. In first step only subsystems; essential parts of the system are modeled. In further steps, subsystems opened one by one and completed the CLD structure.

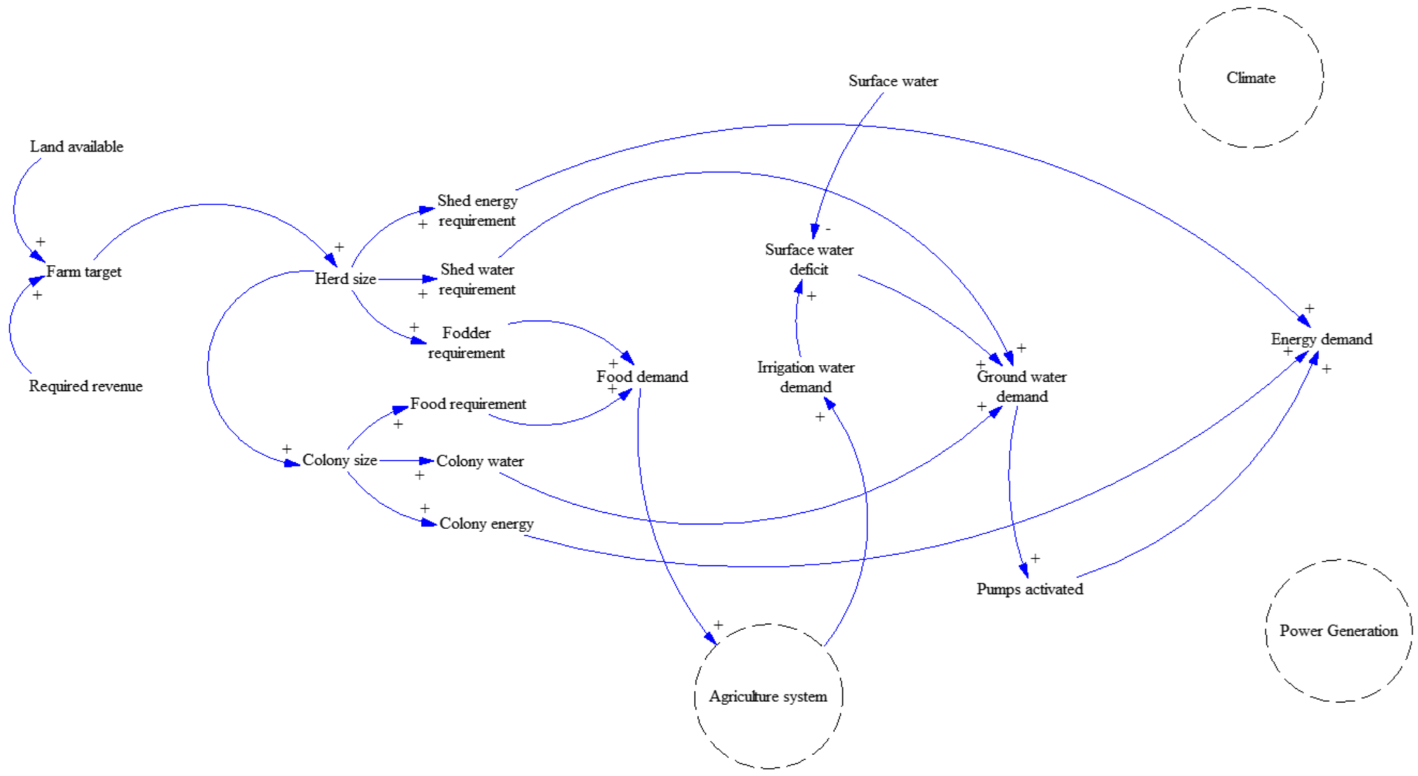


Figure 2.1

Causal loop diagrams (CLD) in Figure. 2.1 is useful for communicating high level overview of a system since causal loop diagrams are easily understandable and can interpret a good first step for the system analysis of a problem [15]. The diagram consists of a set of nodes and edges. Causal loop diagrams structure has used because CLD are useful for communicating high level overview of a system and easily understandable so can provide a good first step for the system analysis of a problem.

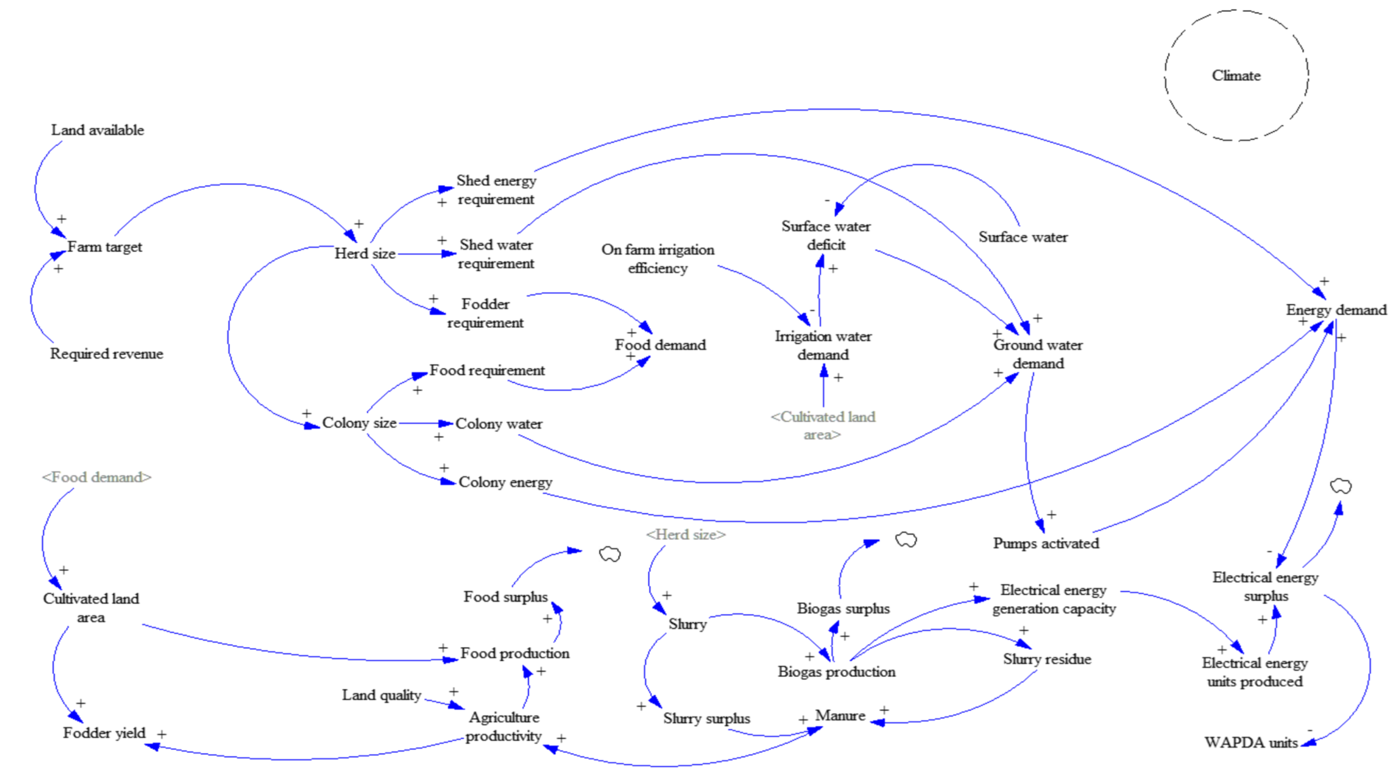


Figure 2.2

SYSTEM DYNAMICS MODEL OF DAIRY FARM - STOCKS AND FLOWS

Stocks and Flows structure take the analysis to a higher level of rigor. Unlike CLD, stock and flow differentiate between the parts of the system like stocks, flows, auxiliary constants and variables. Typically stocks and flows include more details about the elements of the system that do not have CLD like units, inflows, outflows, time depending details.

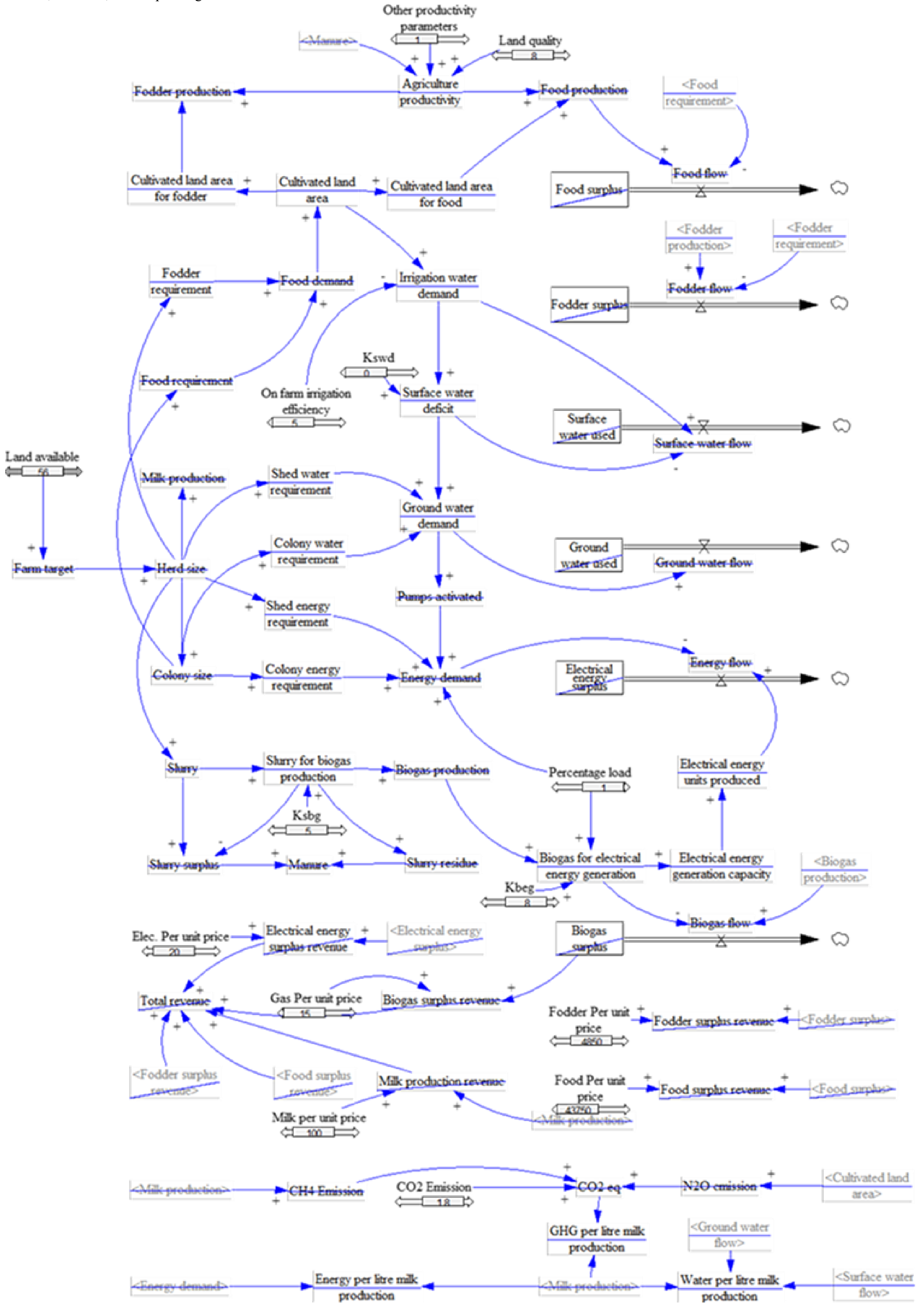


Figure 3

SIMULATION RESULTS

Water, GHG (Greenhouse Gases CO2 - eq), and electrical Energy consumption per litre of milk production:

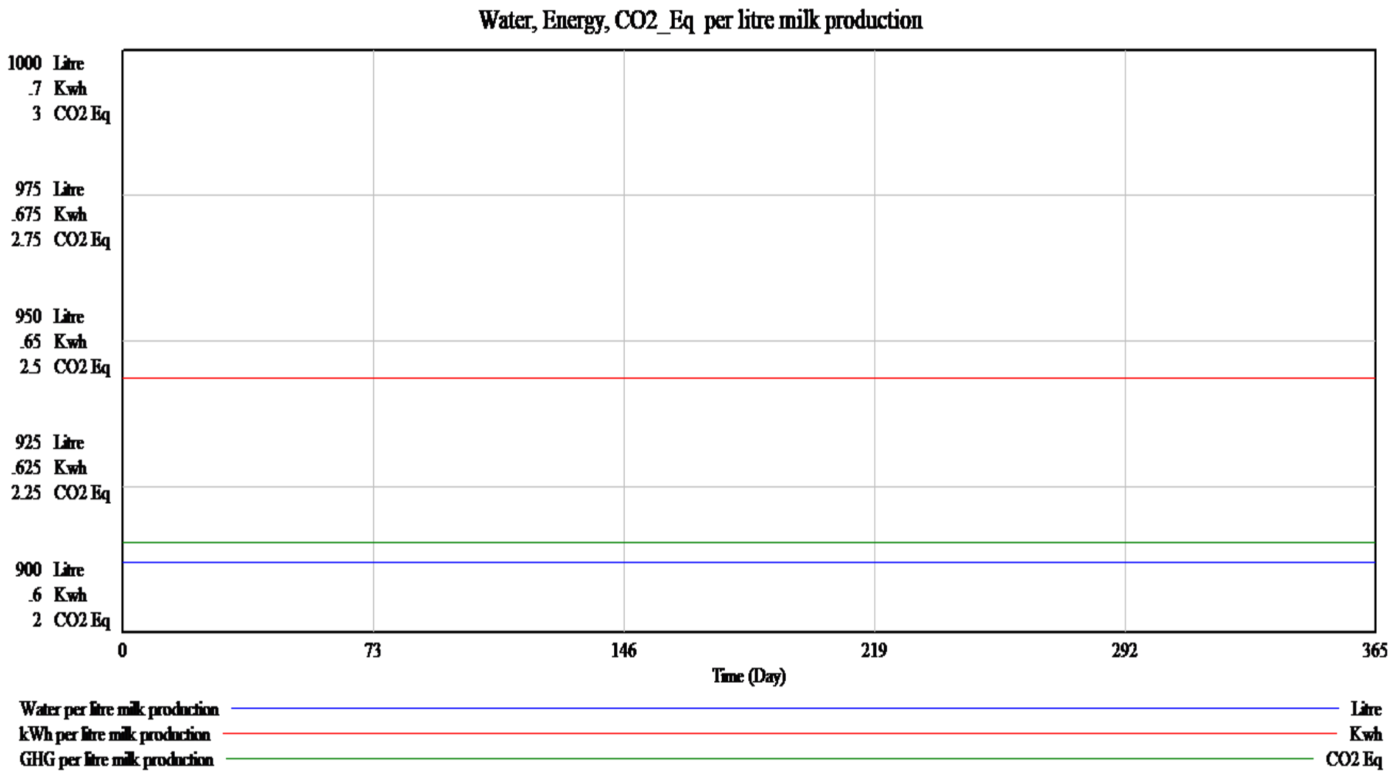


Figure 4.1

Greenhouse Gas Emissions: Methane (CH_4), Carbon dioxide (CO_2), Nitrous oxide (N_2O), and (CO_2-eq):

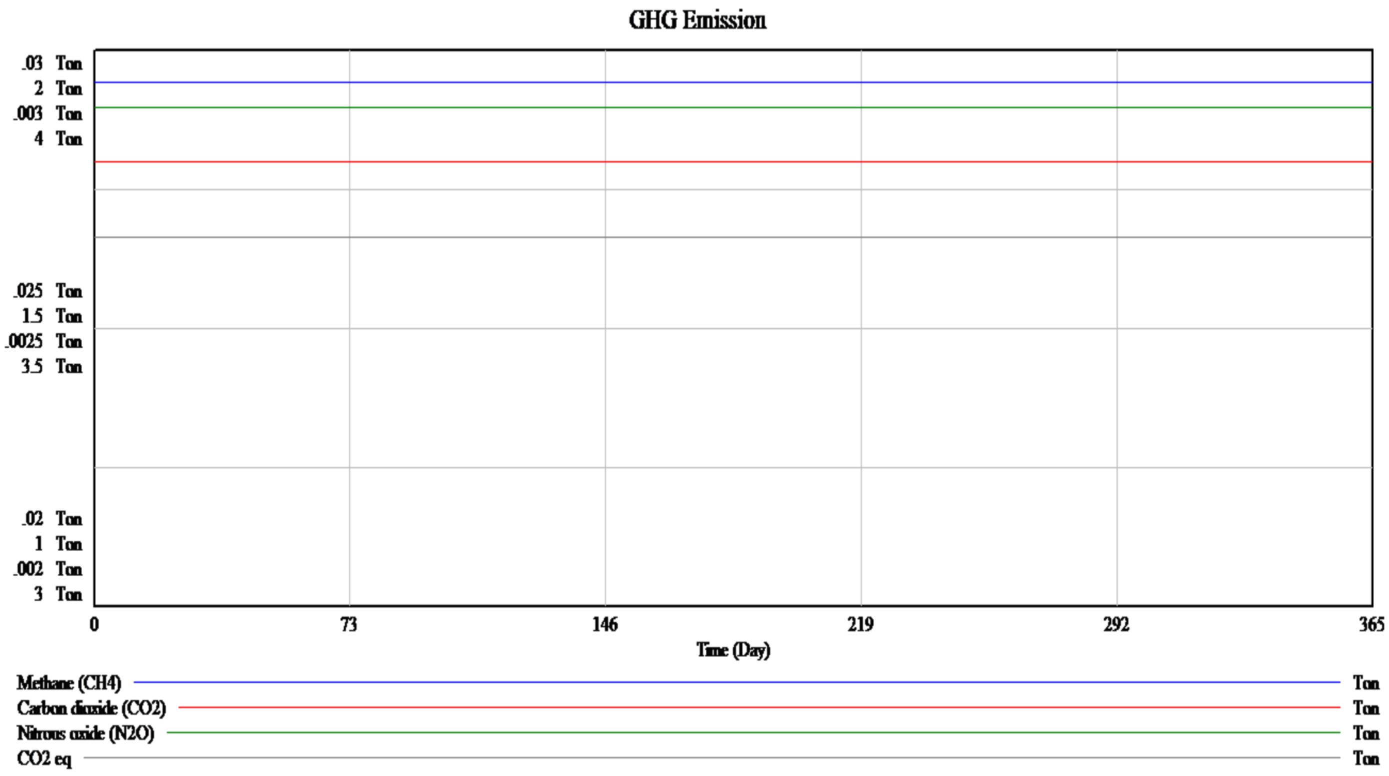


Figure 4.2

Biogas produced from slurry, and power generation from biogas:

(a) Business as usual (When partial slurry and partial biogas used for energy generation)

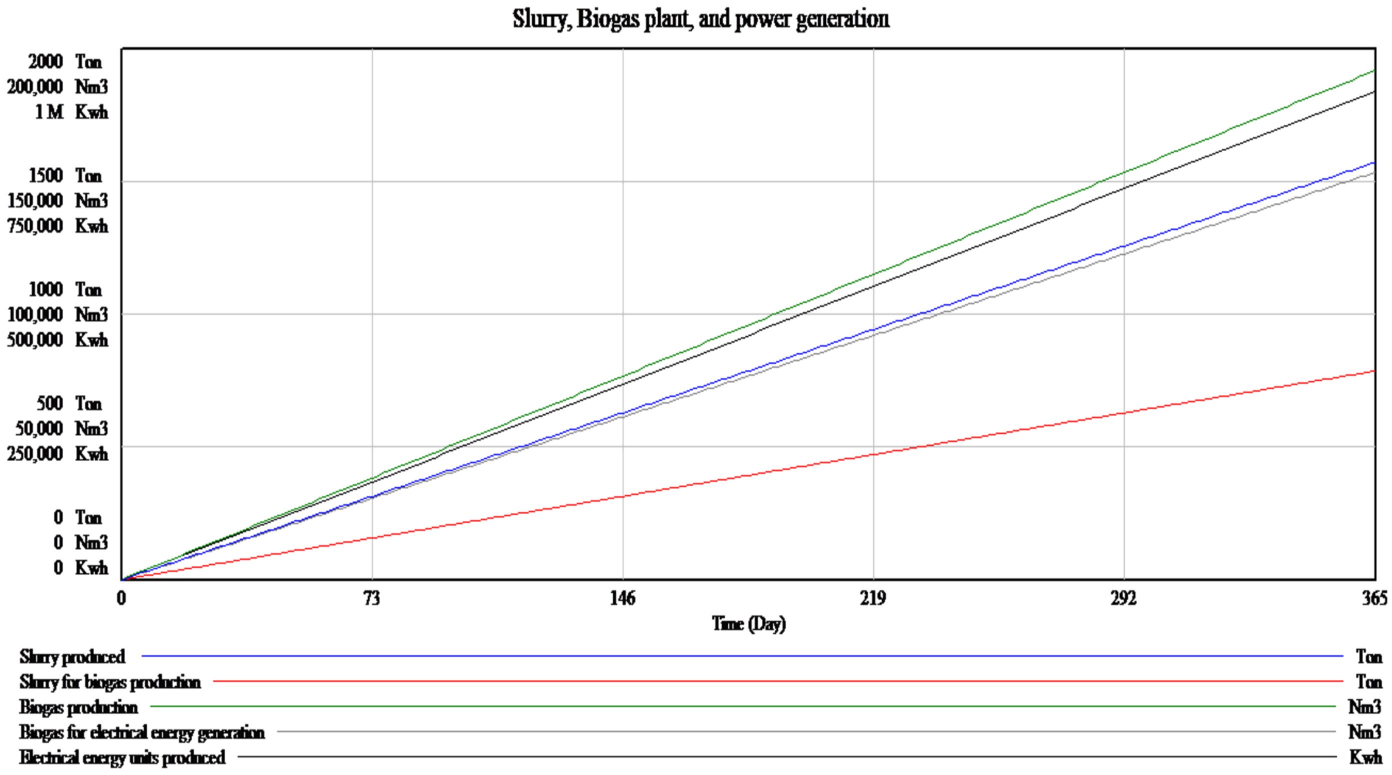


Figure 4.3

(b) When entire slurry and biogas used for energy generation

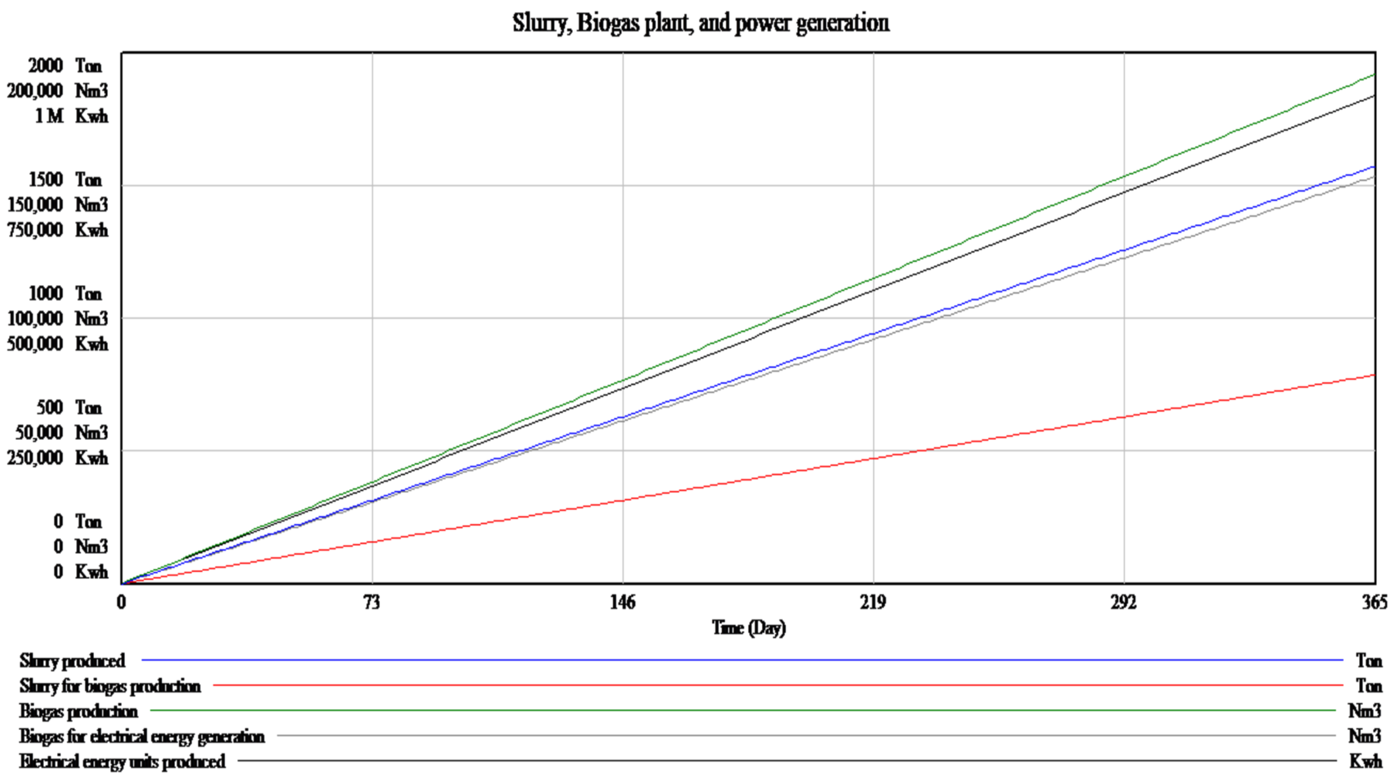


Figure 4.4

Water, energy, and on-farm irrigation water efficiency:

(a) Business as usual results

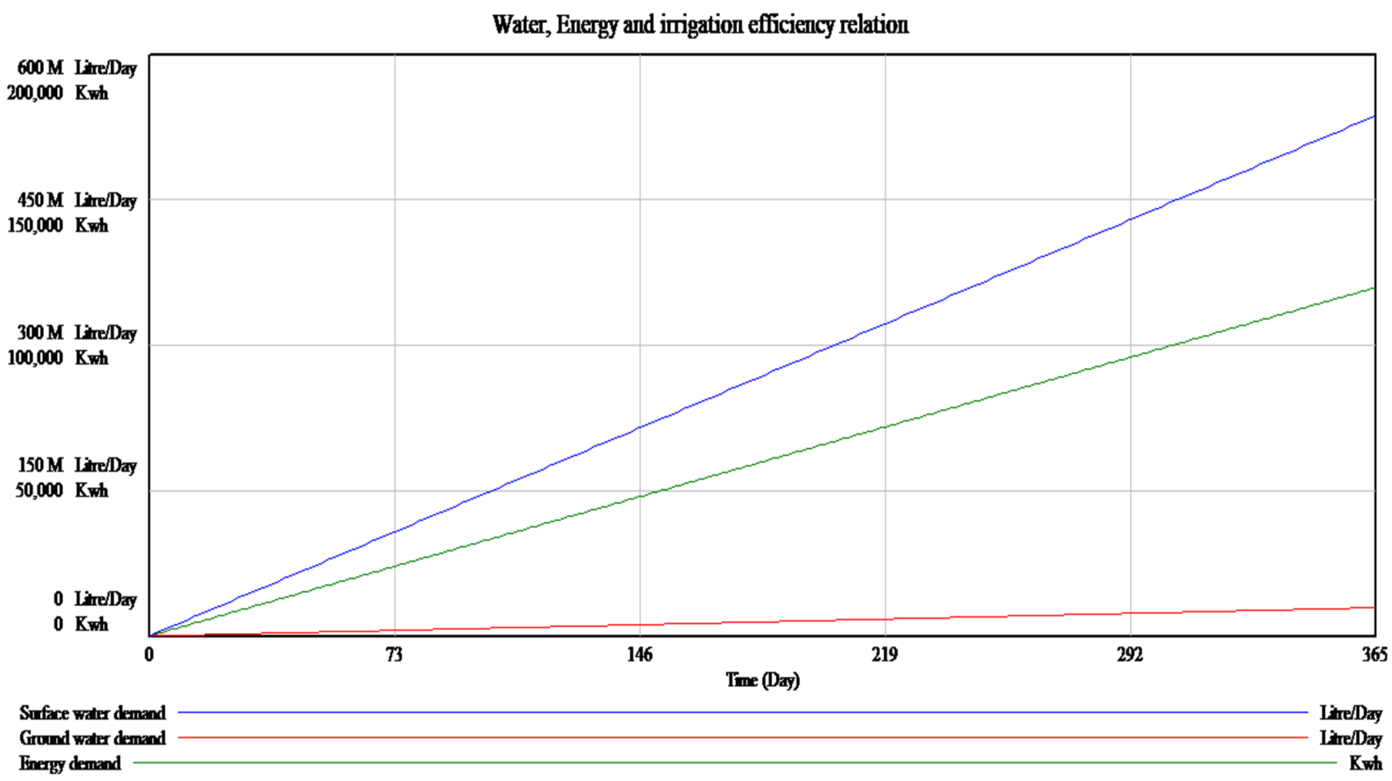


Figure 4.5

(b) With increasing load and increasing surface water deficit

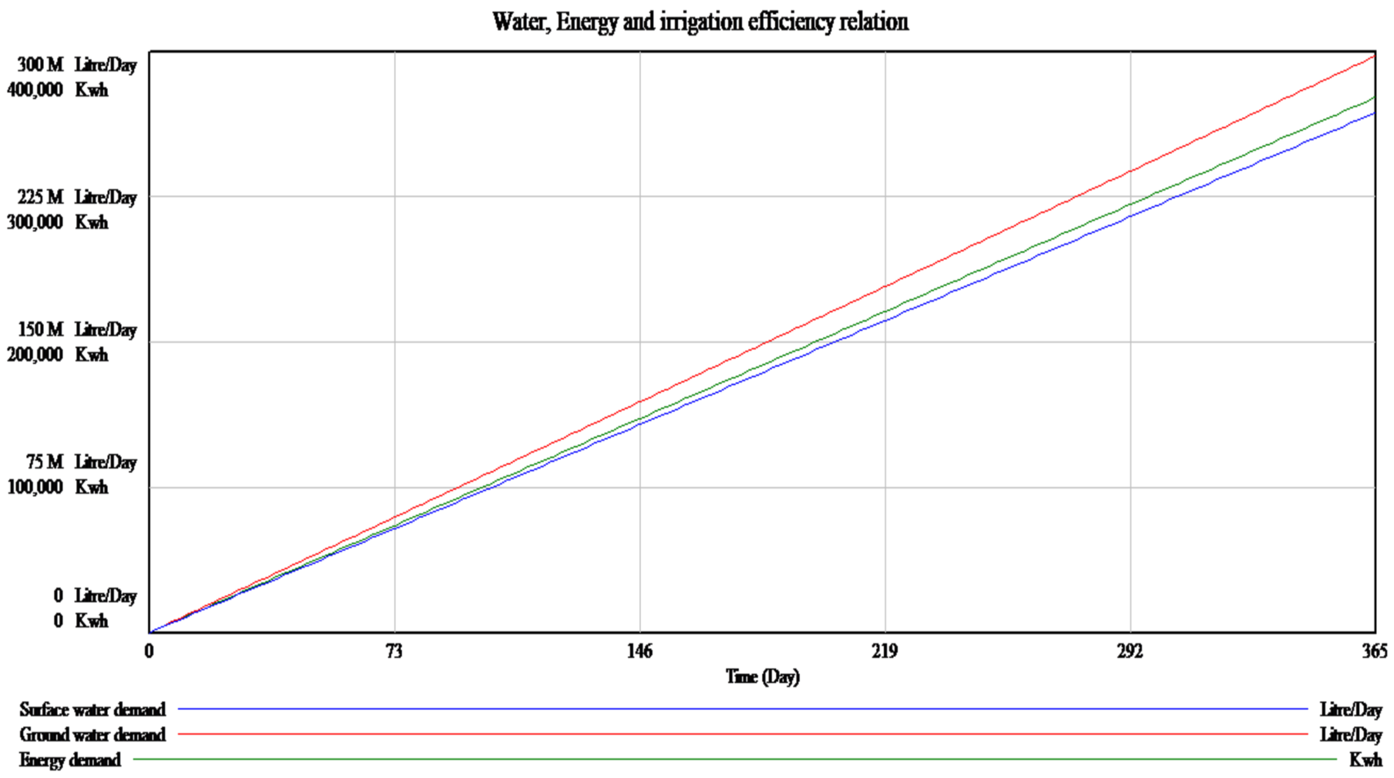


Figure 4.6

(c) Worst case scenario with maximum load and maximum surface water deficit

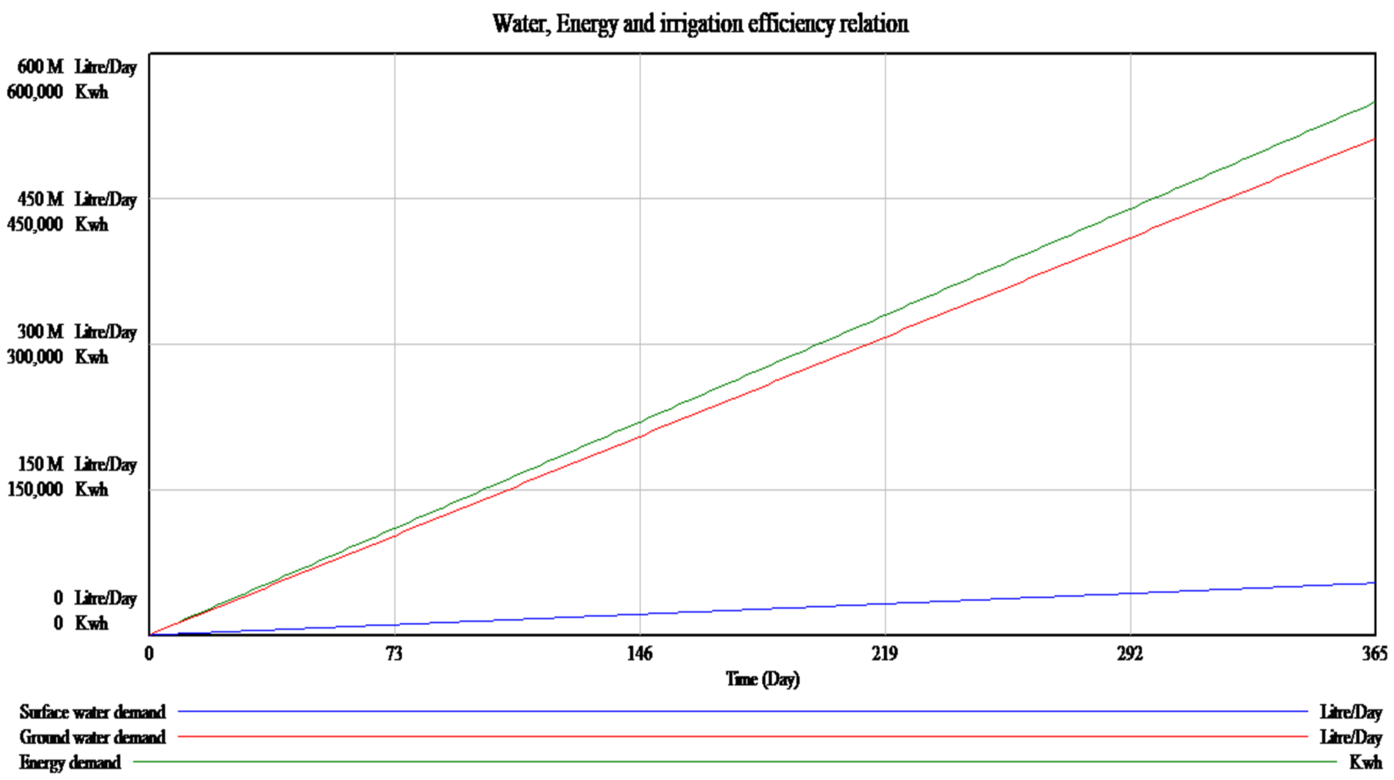


Figure 4.7

(d) Improvement by increasing on farm irrigation efficiency

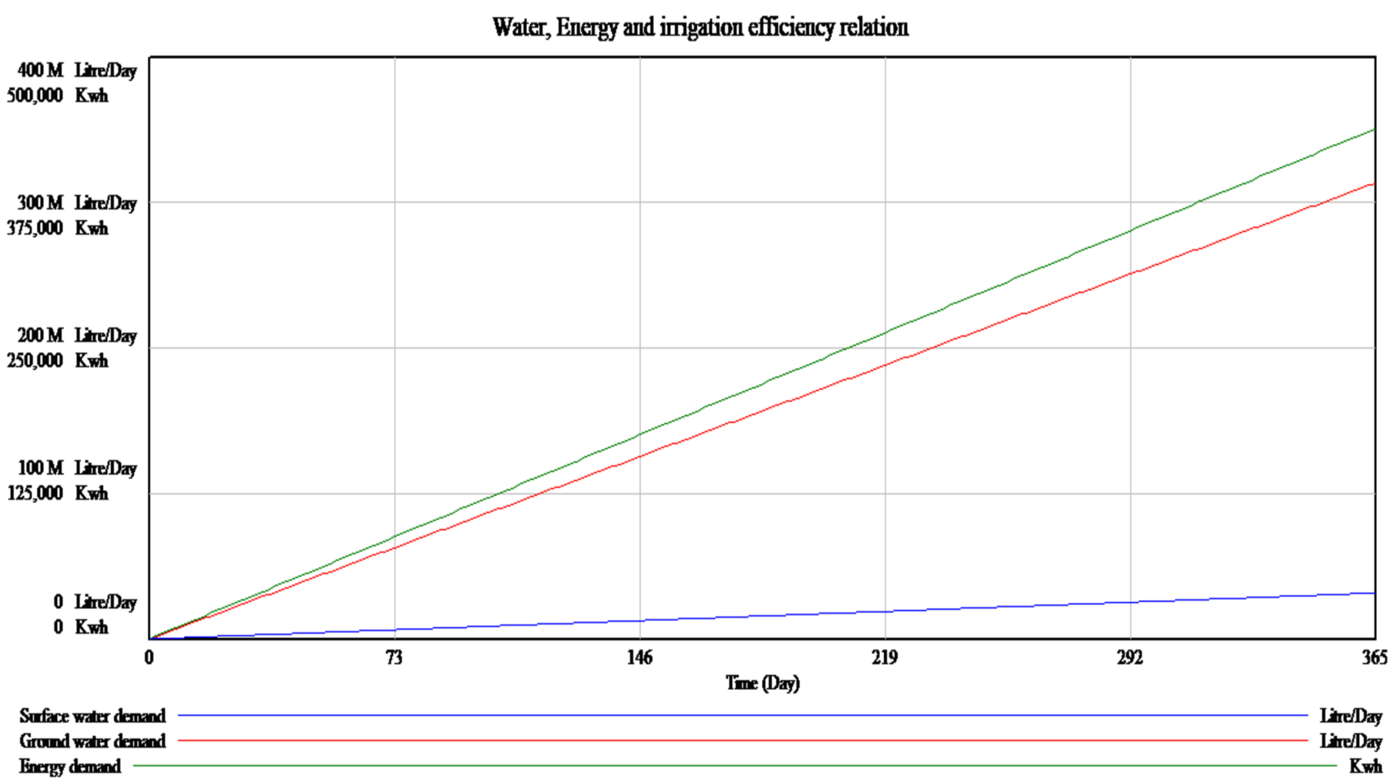


Figure 4.8

Fodder demand, production, and surplus or deficit

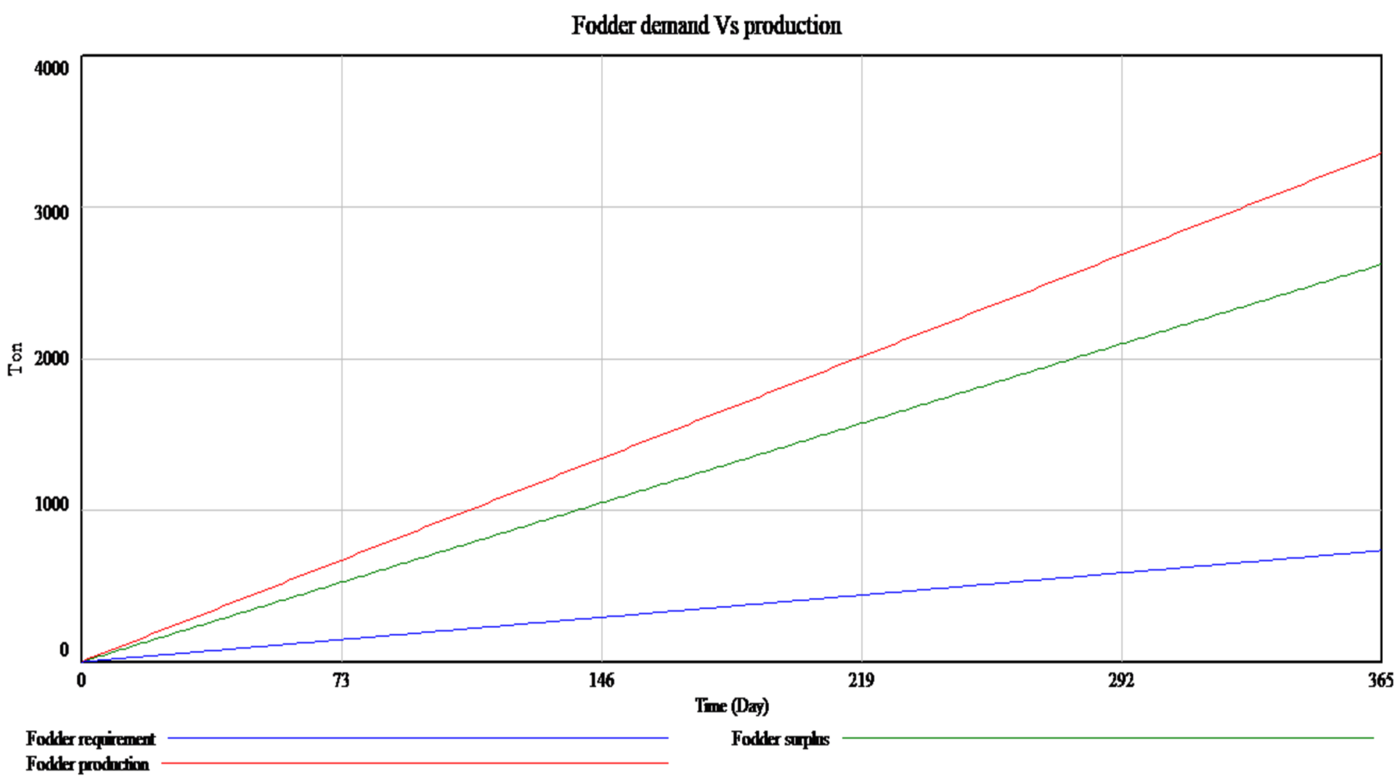


Figure 4.9

Economic benefits from operational farm outputs

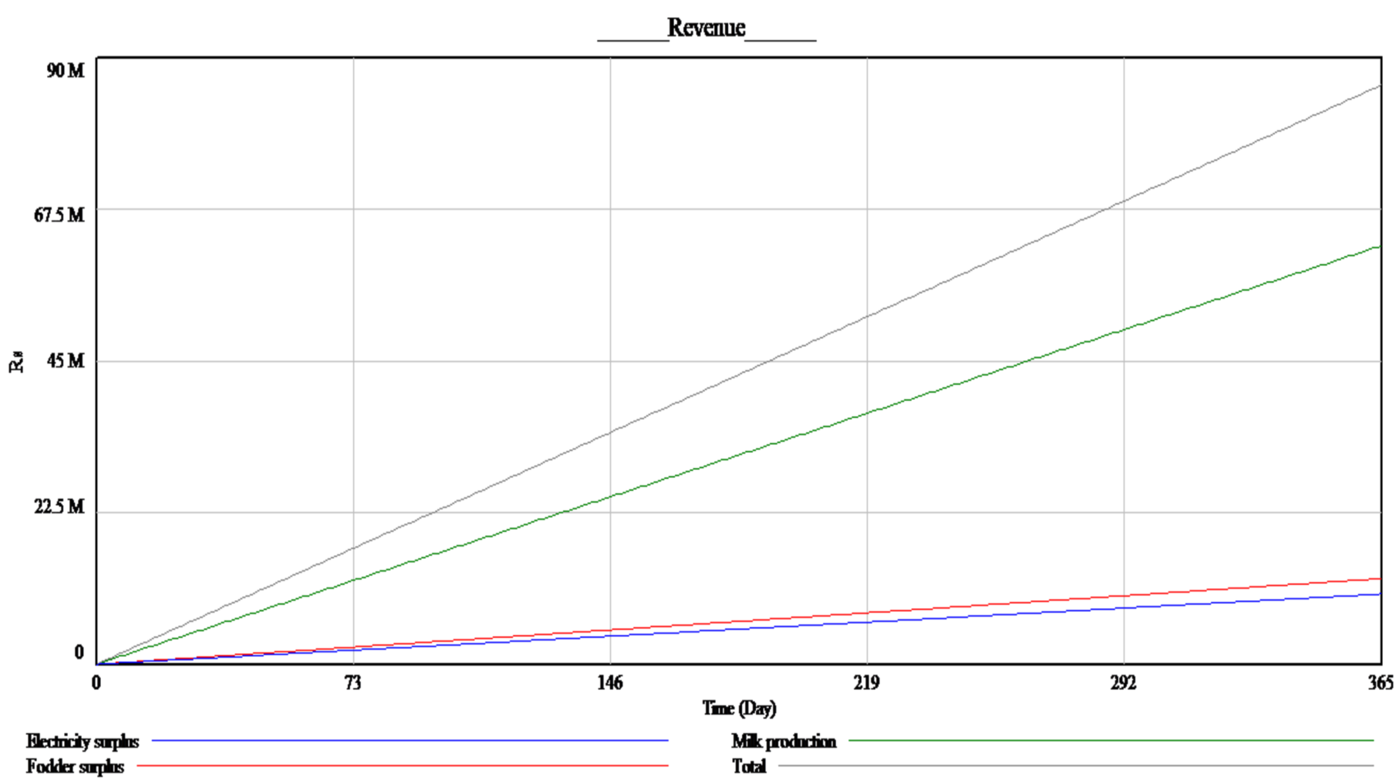
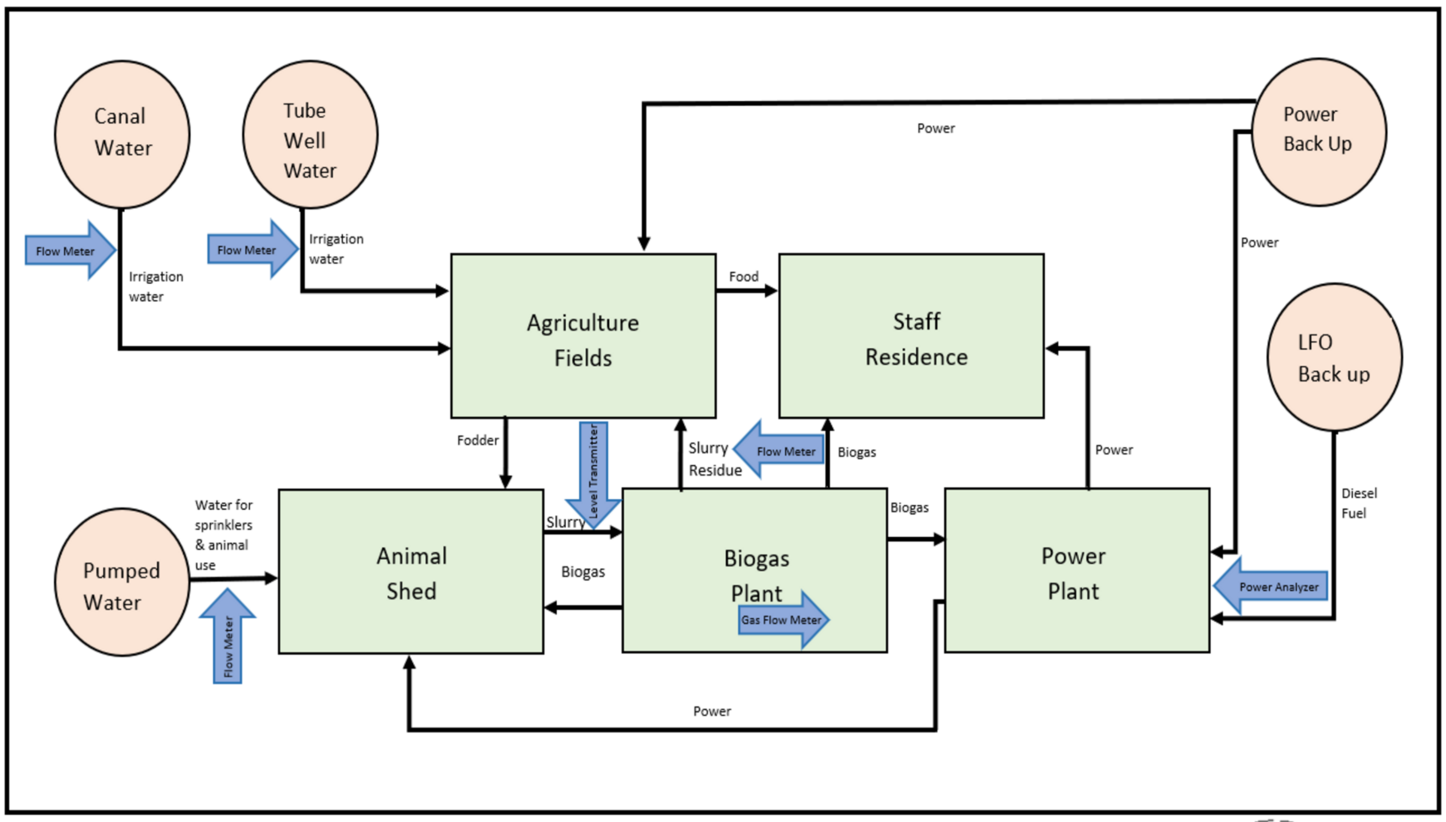
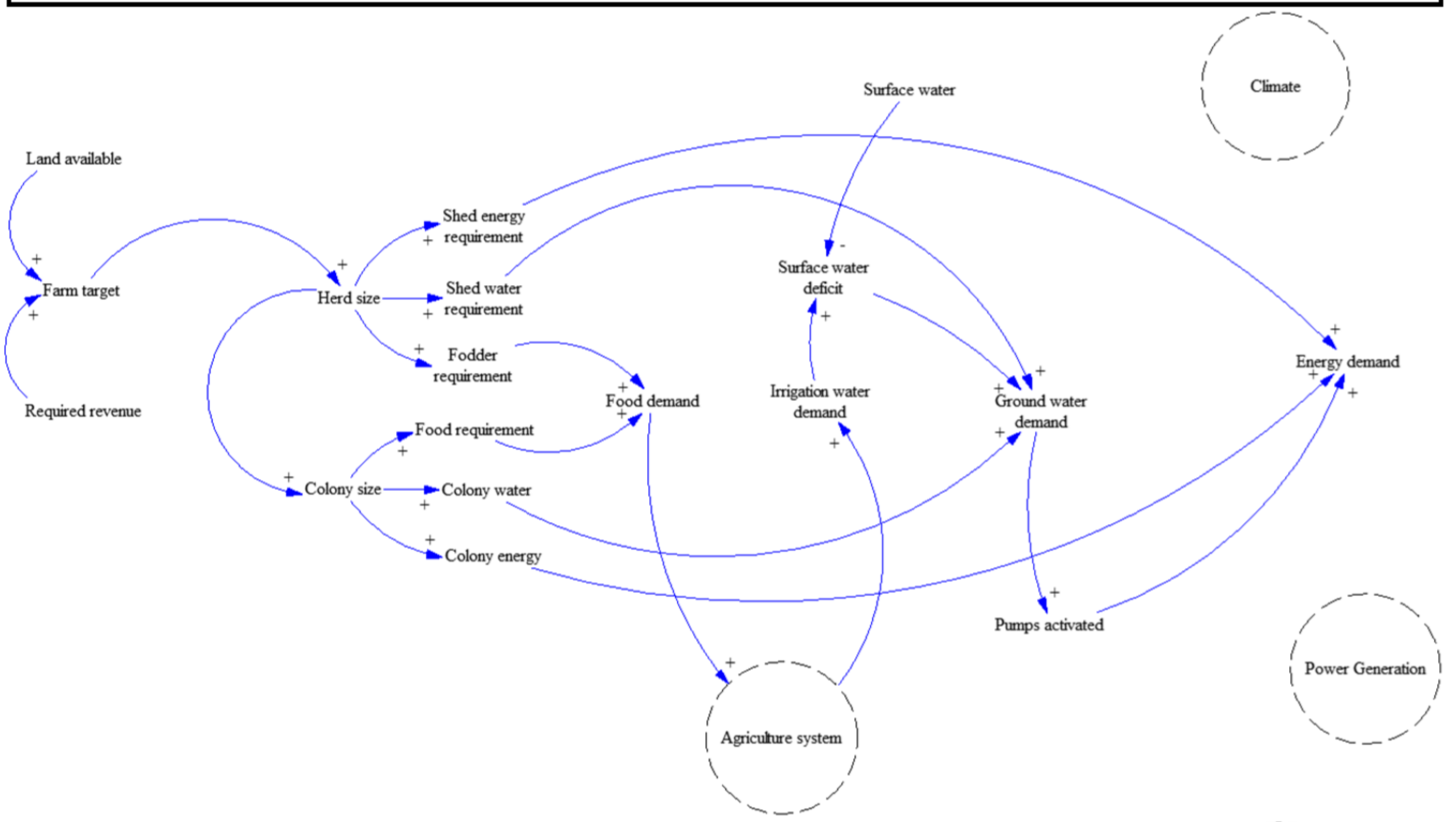


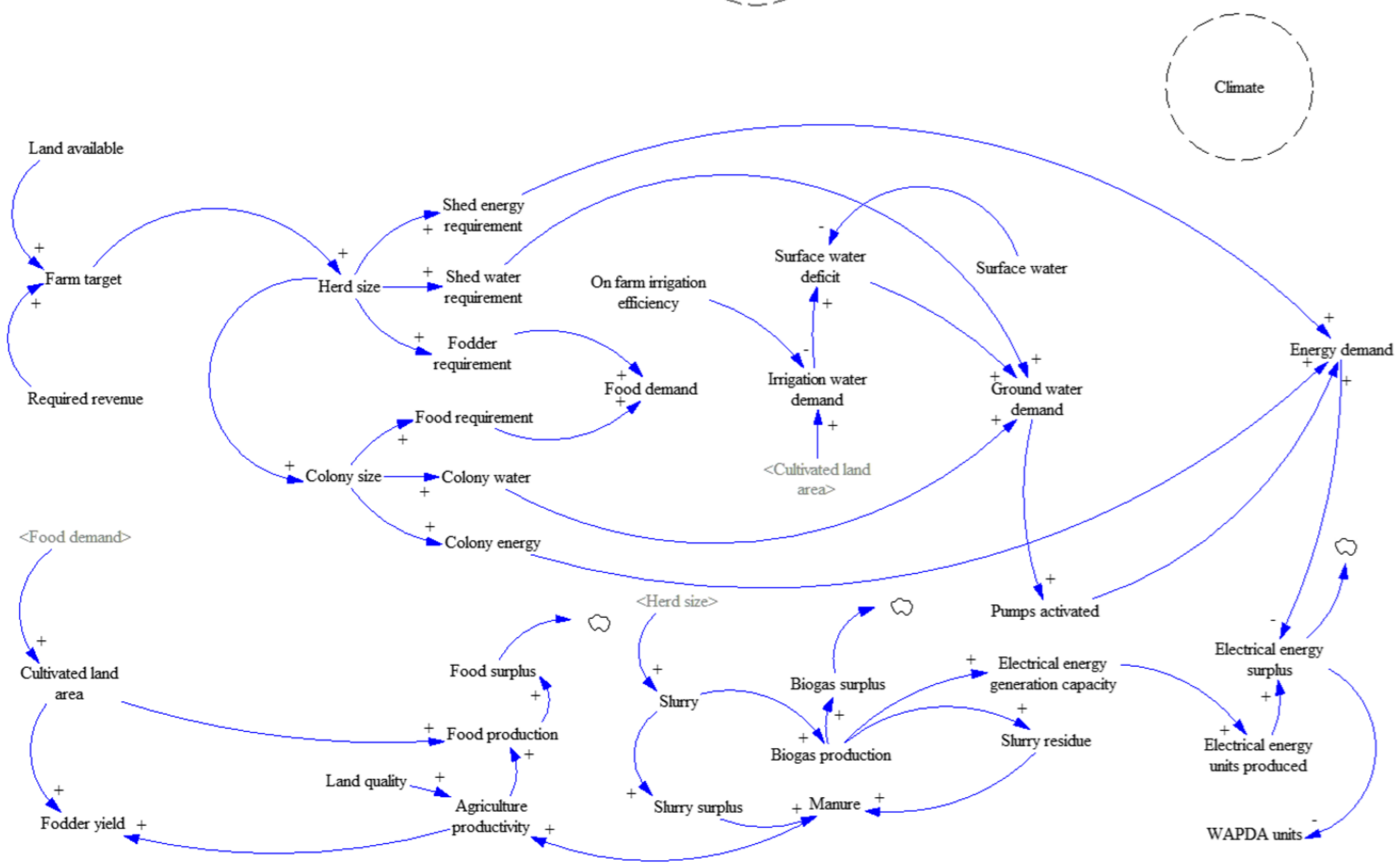
Figure 4.10

SUMMARY OF MAIN FINDINGS

We find that shifting to a more efficient irrigation technology not only reduces the environmental footprint through less pumping of groundwater but also results in consumption of less energy as compared to the business-as-usual scenario. If we increase irrigation efficiency by 35%, moving from flood irrigation, 367 million litre irrigation water 68.38% of total can be saved from 46.5 acre land area in one year. Furthermore, there are 912 litre water, 0.65 kWh energy and 2.15 kg CO2-equivalent behind one litre of milk production. Moreover, we find that the slurry produced by 134 cows can generate 383.3 Nm3 biogas annually having 55% methane content which is enough to fulfil the energy requirements of the farm if diverted to a bio-gas generator. This not only saves operational costs by eliminating dependency on the grid but also prevents emissions that are generated by dumping the slurry in nearby landfills or dumps. Results show that for the considered farm, 3,354 ton fodder produced in a year from 46.5 acre land area assigned to 134 cows have 2,620 ton fodder surplus which is enough to accommodate 478 more dairy cows. Hence, managing crops in the cultivated land-area not only fulfills the fodder requirements for the farm animals but also results in production of excess fodder which can be sold to generate economic surplus. We also found that, besides milk, the main product of a dairy farm, fodder surplus produced, and electricity surplus produced add a revenue which have more than 50% value of milk revenue.







ABSTRACT

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