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Systems Modelling of Technological Opportunities for a Sustainable and Profitable Dairy Sector in New Zealand

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The dairy sector is New Zealand's (NZ's) largest export earner, generating over 20 billion New Zealand dollars (NZD) annually over the past five years (40–45% of total agricultural export revenue). Over this period, total milk solids processed remained steady at 1.87–1.95 billion kilograms (kg) annually, despite reductions of 6.2% in herd numbers and 4.5% in milking cows. This stability is driven by productivity gains due to genetic advancements in cows, with average milk solid (MS) yields increasing from 385 to 400 kg per cow per year, alongside improvements in milk quality. However, dairy cattle account for 25.7% of NZ's total greenhouse gas emissions [22.4% from methane (CH_4) and 3.3% from *Nitrous oxide* (N_2O)] and contribute significantly to water quality degradation through nitrogen (N) and phosphorus (P) leaching. Addressing these challenges requires rapid transformation of current agrifood systems. Digital and technological innovations can play a crucial role in enabling this change which has historically driven advances in productivity, resource use efficiency, and environmental sustainability in the agrifood sector.

Identifying and understanding current and emerging technologies, along with their adoption levels, is a critical first step toward achieving future national economic and environmental sustainability targets in NZ (e.g., reduce CH_4 by 24 – 47% below 2017 levels and net zero emissions by 2050 except CH_4, double the value of exports from agrifood sector by 2034). At present, a clear knowledge gap remains regarding the role of technological innovations and their contribution level in reaching those productivity and environmental targets within the agrifood sector.

Models can be used for analysing technology contributions and to develop target-oriented policies in agrifood sector from regional to national scale. Although farm-level models are available to analyse the technological adoption and impacts, there are no known models currently available to evaluate benefits at regional or national scales. To address this, a prototype decision support tool (DST) focused on NZ dairy sector was developed using a system dynamics modelling approach to estimate the contribution of current and emerging technologies to economic returns and environmental sustainability. The DST was built using Stella Architect software, which offers a useful online platform to engage with stakeholders. The model parameters, their interactions and equations were captured in a "conceptual framework" to translate knowledge and parameters from an extensive literature review into the model (Figure 1).

In this DST, simulations can be run under different adoption scenarios, policy interventions, and timeframes (2020–2050) that might affect the system's future behavior. The effect of the feedback loops can be positive (e.g., technology adoption) or negative (e.g., emission reduction), explaining system's rate of change over the defined period. A web-based graphical interface was integrated with the DST, allowing users to run "what-if" scenarios using either pre-defined database values gathered from literature or customised inputs. Model input parameters are related to the dairy sector (e.g., effective area, cow population, average milk solid yield, etc.) and the selected technology (e.g., adoption rate, yield increase percentage, emission reduction percentage, etc.). Model outputs include production (e.g., yield), environmental indicators (e.g., water quality, emissions), and socio-economic outcomes (e.g., export revenue, domestic value) (Table 1).

A "business as usual" and alternate scenario analyses were conducted to evaluate national-level policy pathways. The "business as usual" scenario was established using 2020 NZ dairy sector data with zero new technology adoption. Alternative scenarios were simulated with various technologies and adoption rates while maintaining dairy sector input data constant at Year 2020. Technology inputs were adjusted according to each selected option (see Table 1). For example, the model was projected from 2020 to 2030 for the adoption of "Pasture.io" (a pasture management system) at an annual adoption rate of 2.0% and an average MS yield increase of 2.0% per cow, with other parameters held constant (i.e. alternate scenario 1). Results showed an additional 75.8 million kg MS production, a domestic value of NZD 663.9 million, and an export revenue of NZD 805.0 million compared to the "business as usual" scenario.

This DST provides valuable insights into how various technologies and policy pathways can drive sustainable growth in NZ's dairy sector, while achieving production, environmental and socio-economic targets.

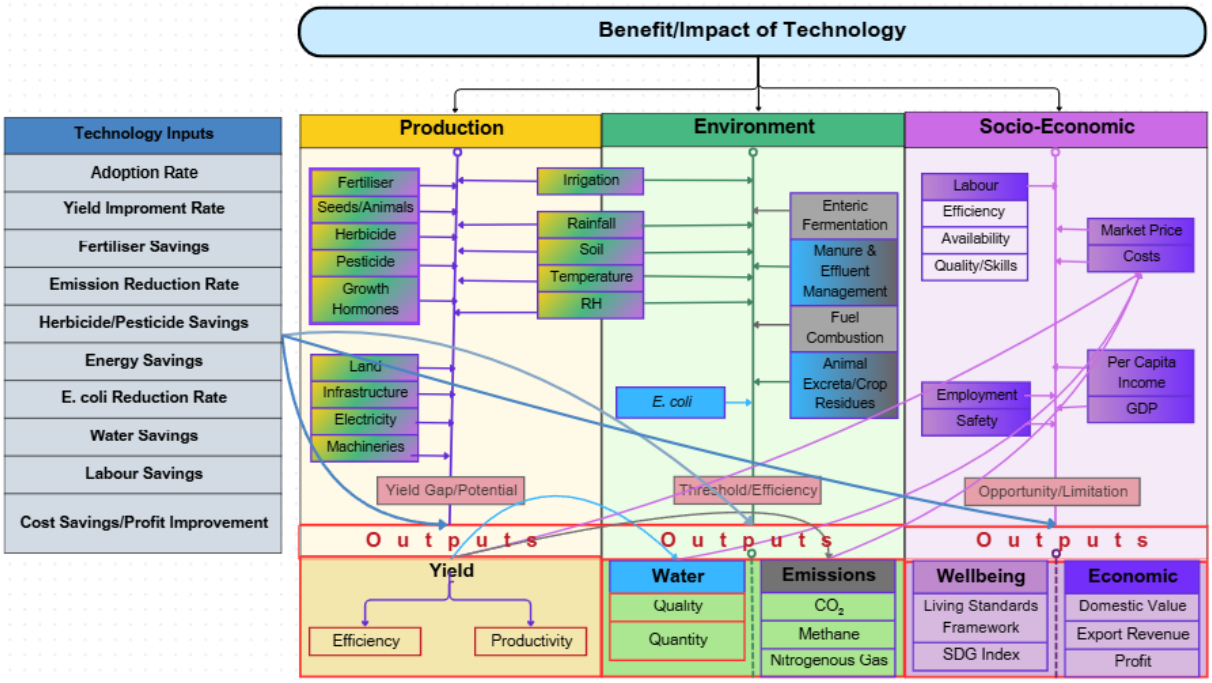

Figure 1: A conceptual model of the benefits and impacts of technology adoption on production (e.g. yield), environment (e.g. emissions, water quality and quantity) and socio-economic (e.g. domestic value, export revenue) facets and their interactions.

Table 1: Key input and output parameters used in the DST designed in the Stella Architect software customised for the NZ's dairy sector.

Dairy Sector Baseline Parameters (i.e. for 2020)	**Technology Input Parameters**	**Output Parameters**
Effective Area (ha)	Adoption Rate (Percentage/Year)	Dairy Total Production (kg MS/Year)
Average Milk Solid Yield (kg MS/Head/Year)	Yield Increase (Percentage/Year)	Dairy Total Domestic Value (NZD/Year)
Total Dairy Cattle Population (Animals/Year)	CH_4 Reduction Enteric (Percentage/Year)	Dairy Export Revenue (NZD/Year)
Total Cows in Lactation (Animals/Year)	N_2O Reduction Manure (Percentage/Year)	Dairy Total CH_4 Emissions from Enteric (kg CH_4/Year)
Milk Solids Payout (NZD/kg MS/Year)	N_2O Reduction Fertiliser Use (Percentage/Year)	Dairy Total CH_4 Emissions from Manure & Effluent (kg CH_4/Year)
Dairy Export Unit Value (NZD/kg MS/Year)	CO_2 Reduction Fertiliser Use (Percentage/Year)	Dairy Total CH_4 Emissions (kg CO_2-e/Year)
Lactating Cow Percentage (Percentage/Year)	CO_2 Reduction Electricity (Percentage/Year)	Dairy Total N_2O Emissions (kg CO_2-e/Year)
Dairy Export Percentage (Percentage/Year)	CO_2 Reduction Fossil Fuel (Percentage/Year)	Dairy Total CO_2 Emissions (kg CO_2-e/Year)
	E. coli Reduction (Percentage/Year)	Dairy Total Emissions (kg CO_2-e/Year)
		Water Quantity (Billion m^3/Year)
		Water Quality Score (Dimensionless)

Keywords: *Dairy sector, New Zealand, technologies, decision support tool (DST), system dynamics modelling, economic returns, environmental sustainability.*