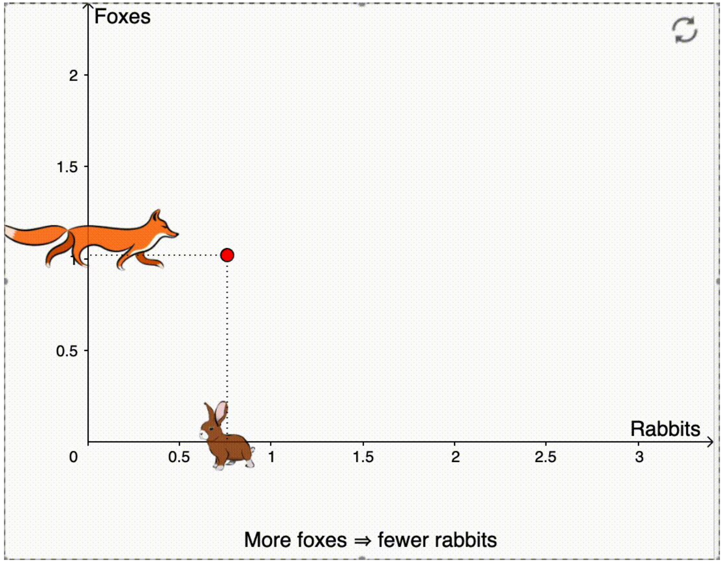
Game-based Understanding of Replication and Trophic cycles

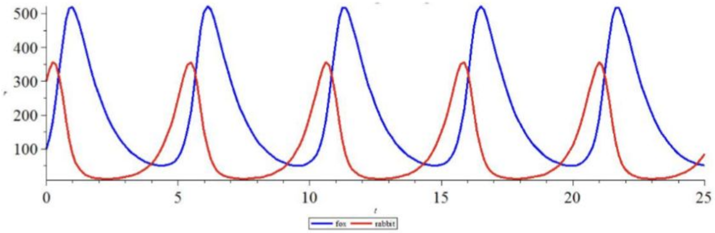
Group Dolores
Timofei Polivanov & Sami Rahali

Introduction - Problem description

- Predator-prey competition is commonly modeled using the Lotka-Volterra model.
- This model describes how predator and prey populations change over time through hunting and reproduction.
- We use an agent-based approach to simulate predator-prey dynamics with foxes and rabbits, based on local interactions without global control.
- Survival is the primary objective for all agents: foxes hunt rabbits, rabbits reproduce and avoid predation.
- The agent-based model starts from a Lotka-Volterra-inspired baseline and is extended with an energy mechanism to enable direct comparison.
- In the energy-enabled model, key parameters are systematically varied to analyze their impact on population dynamics.
- The challenge: how does introducing energy-based survival change population dynamics?



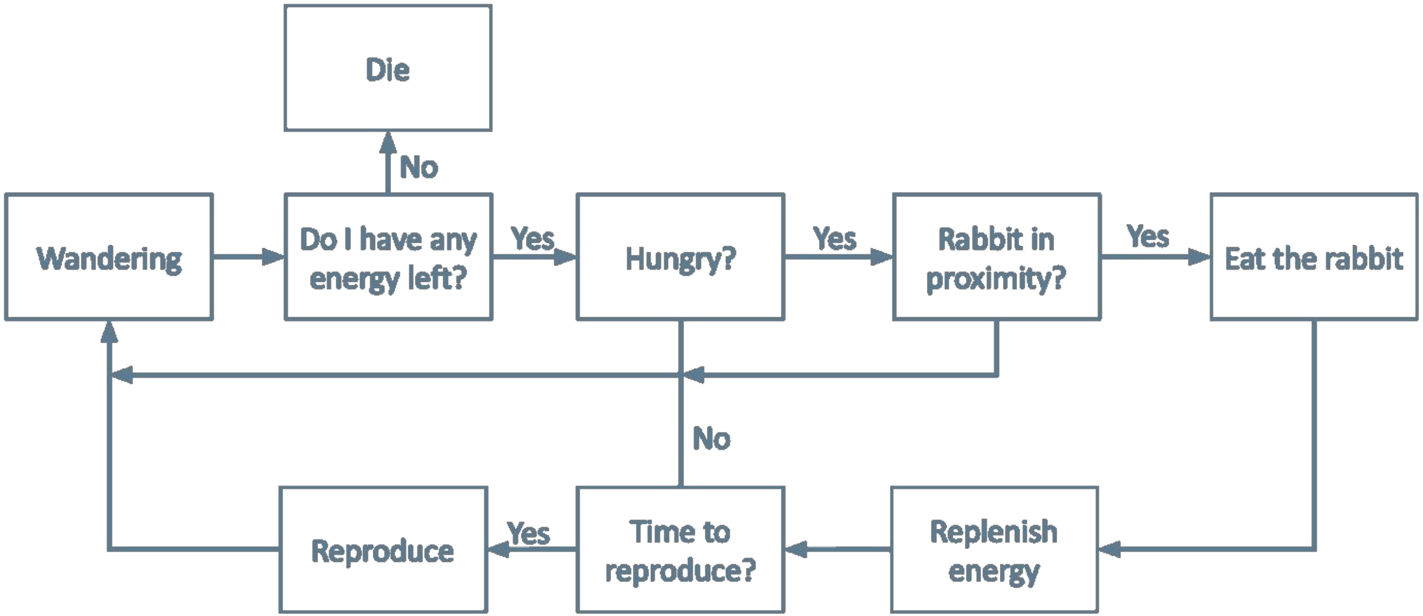
Possible Lotka-Volterra outcome, for some parameters



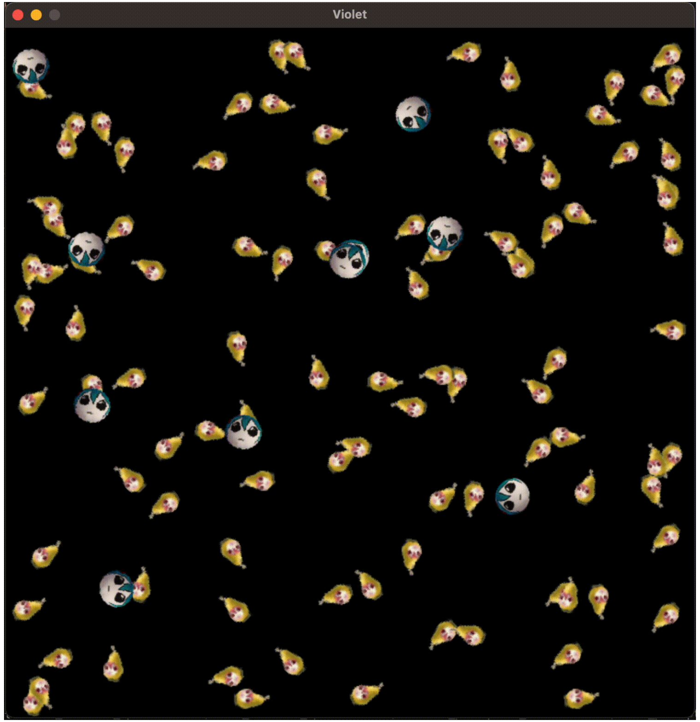
Introduction - Purpose of the simulation

- Explore how energy mechanisms affect predator-prey population dynamics.
- Analyze oscillations in ecosystems with and without energy-based survival.
- Investigate how different parameters influences extinction risk and population cycles.
- Understand the role of resource availability and hunting pressure on collective system behavior.

Introduction - Energy-based survival mechanism



Introduction - Simulation Explanation



Predator: Miku (fox) 

Prey: Pearto (rabbit) 

Environment: Agents move within a bounded area edges act as solid boundaries (agents bounce off).

Simulation termination conditions:

- All foxes dead
- All rabbits dead
- Maximum of 2000 ticks reached

Introduction - Parameters

Testing method: Grid search, vary one parameter at a time, others fixed.
Goal: Isolate effects on population dynamics, and extinction risk.

Shared between both scenarios:

- rabbit_movement_speed: how fast rabbits move. Values: [1.0, 2.0, 3.0]
- fox_movement_speed: how fast foxes move. Values: [2.0, 3.0, 4.0]
- rabbit_perception_radius: how far rabbits can detect foxes. Values: [40, 60]
- fox_perception_radius: how far foxes can detect rabbits. Values: [60, 80]

Energy-free scenario only:

- fox_spontaneous_death_chance: chance of fox dying spontaneously. Values: [0.005, 0.01]
- rabbit_reproduce_chance: chance for rabbits to reproduce. Values: [0.005, 0.01]

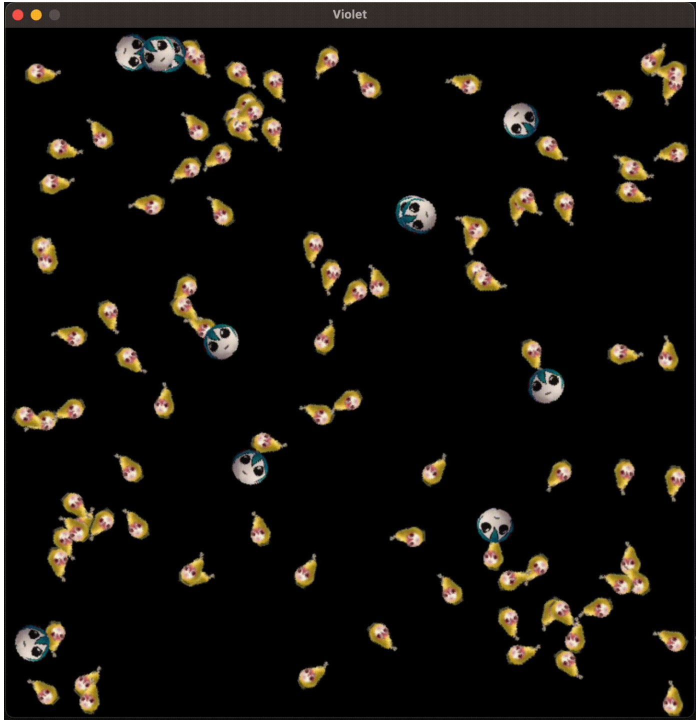
Energy-enabled scenario only:

- fox_initial_energy: initial energy level of foxes. Values: [50.0, 100.0, 150.0]
- fox_energy_decay_rate: rate at which foxes lose energy over time. Values: [0.25, 0.5, 0.75]
- rabbit_energy_gain: energy gained by foxes after hunting a rabbit. Values: [5.0, 10.0, 15.0]
- fox_starvation_threshold: energy level at which foxes die. Values: [0.0, 10.0]

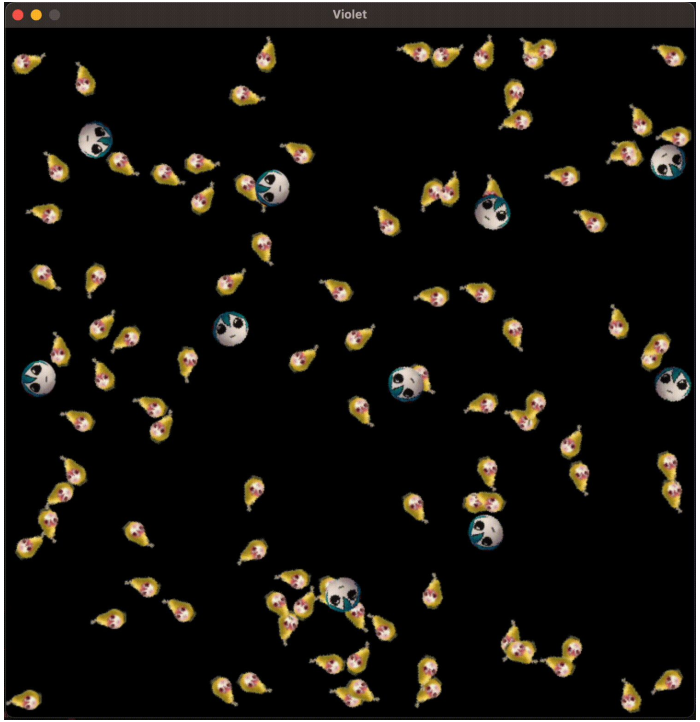
Introduction - Type of analysis being done

- Two experimental conditions:
  - Energy-free baseline.
  - Energy-enabled model with fox energy-based survival mechanism.
- Systematically test one parameter at a time, keeping others constant.
- Observe population dynamics:
  - How do population cycles and extinction risks change?
- Metrics used:
  - Population time series.
  - Extinction times.
  - Peak populations.
  - Average fox energy (energy-enabled only).
- Plot results using various metrics and comparisons across scenarios.

Introduction - Example of two simulation scenarios

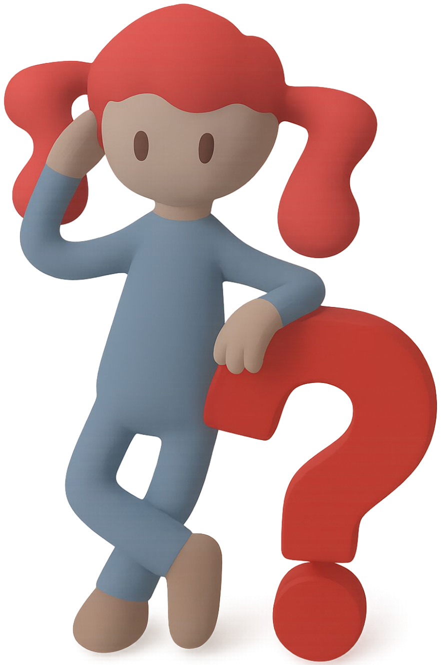


energy_free



energy_enabled

Introduction - Research Question



- How does introducing energy-based survival in predators affect population dynamics and extinction risk in an agent-based predator-prey model?

Methodology

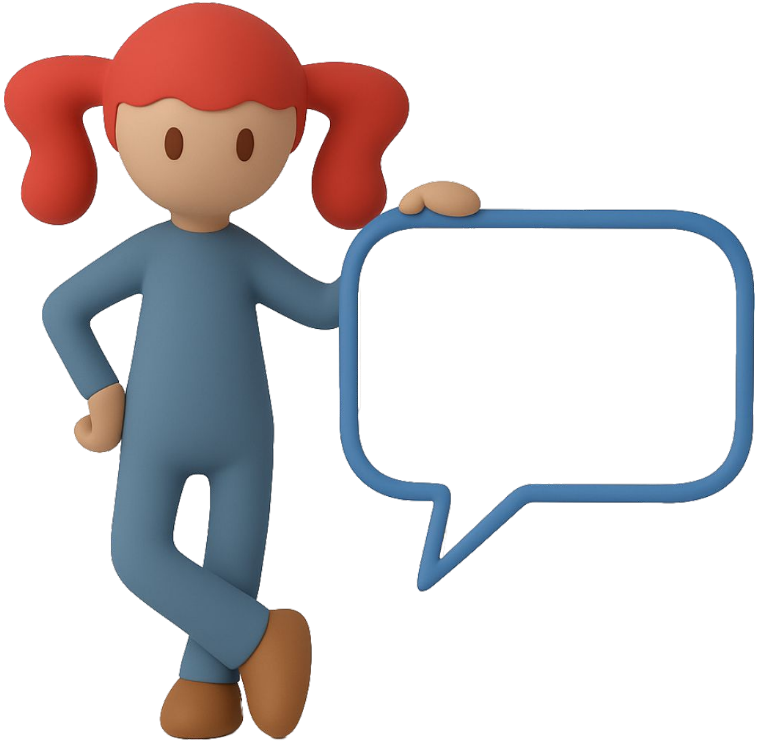
Agents simulate predator-prey dynamics in a 2D environment:

- Foxes (predators) hunt rabbits (prey).
- Rabbits reproduce probabilistically.
- Agents’ behaviour is determined by multiple parameters.

Scenarios:

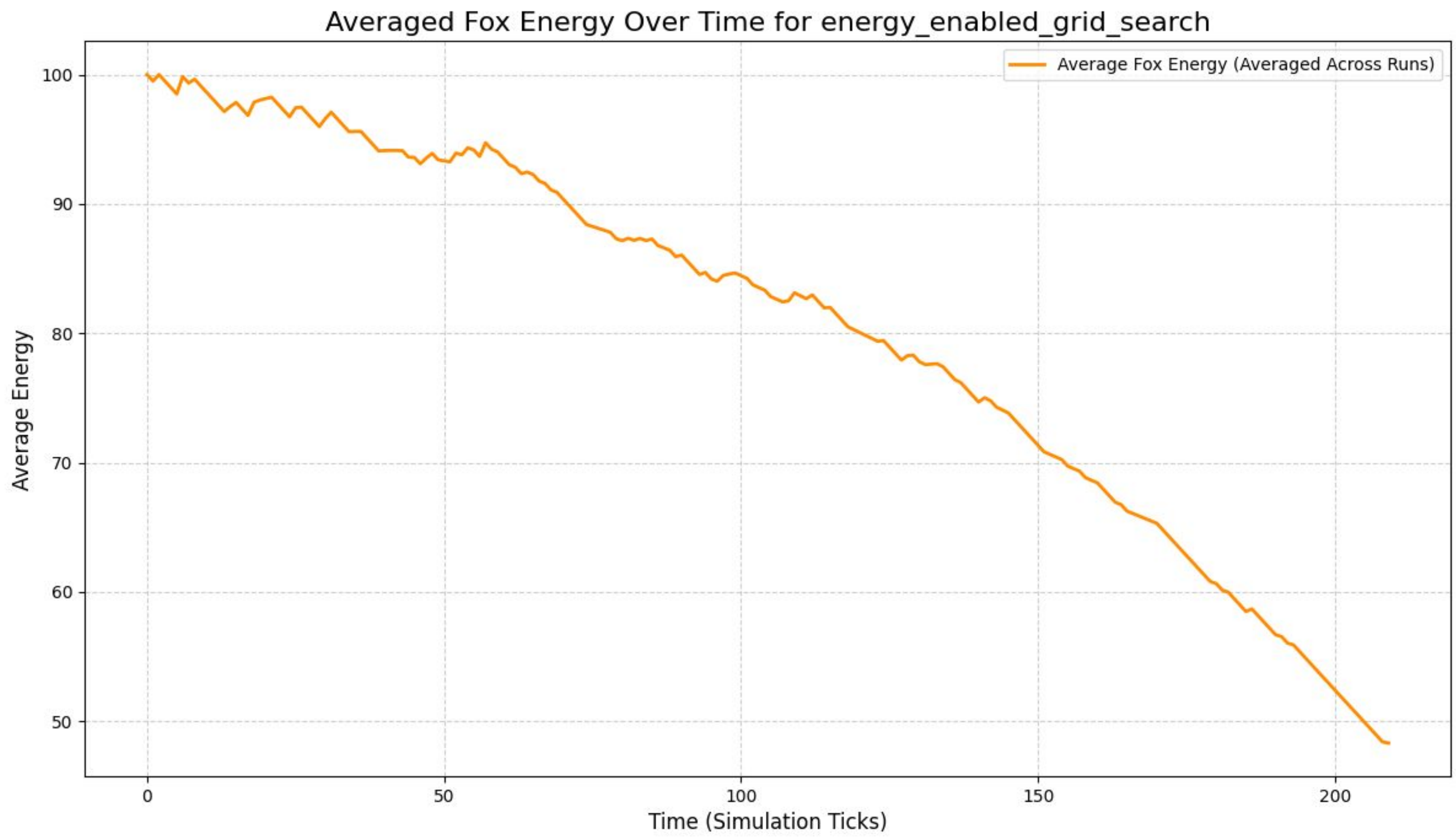
- Baseline test: energy-free.
    - Grid search on combinations of probabilistic parameters.
    - Multiple runs per combination, results averaged.
    - One parameter varied at a time, others fixed.

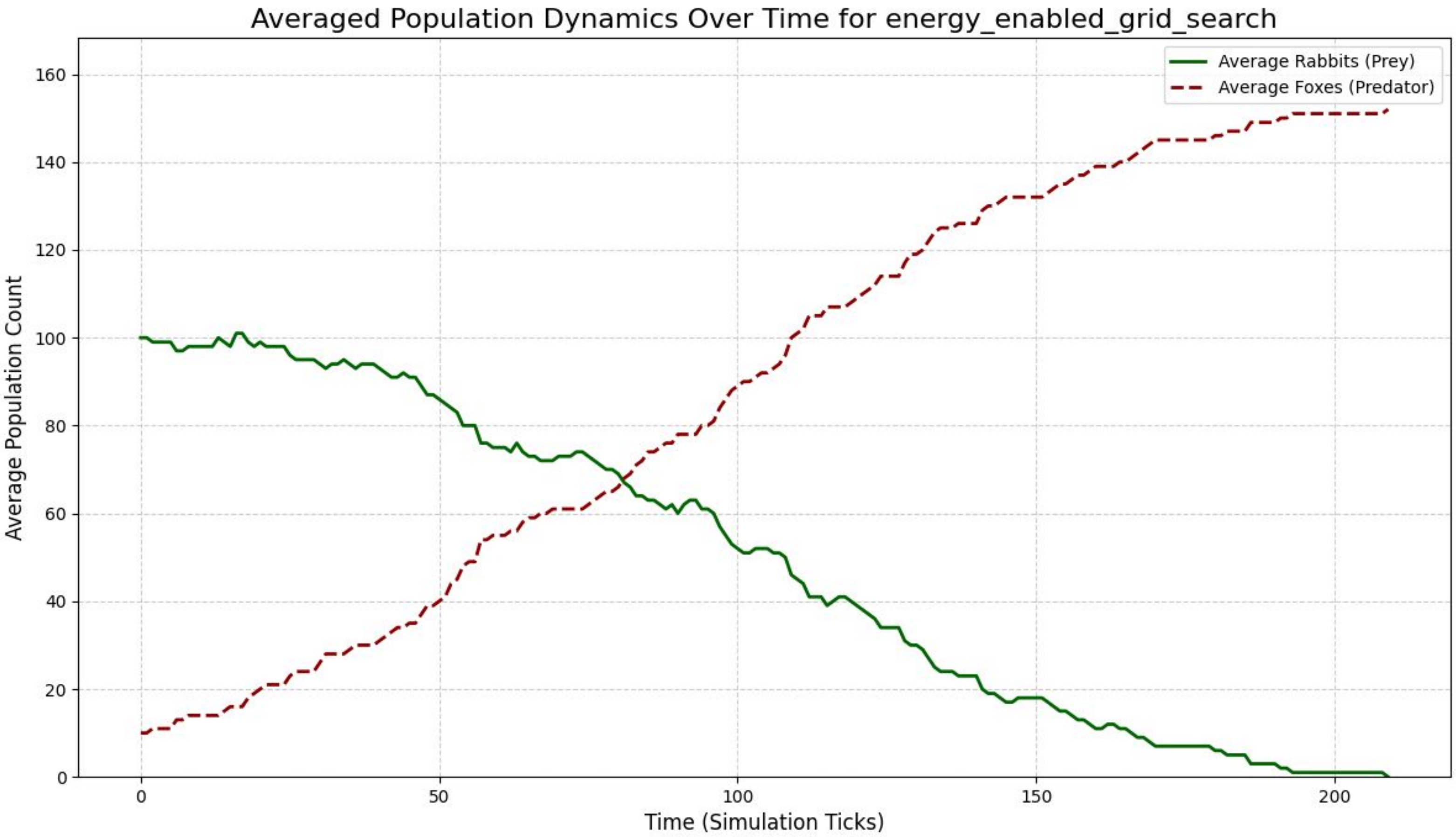
- Control test: energy-enabled.
    - Same approach, but with energy-based survival mechanism enabled.
    - Grid search energy related parameters.

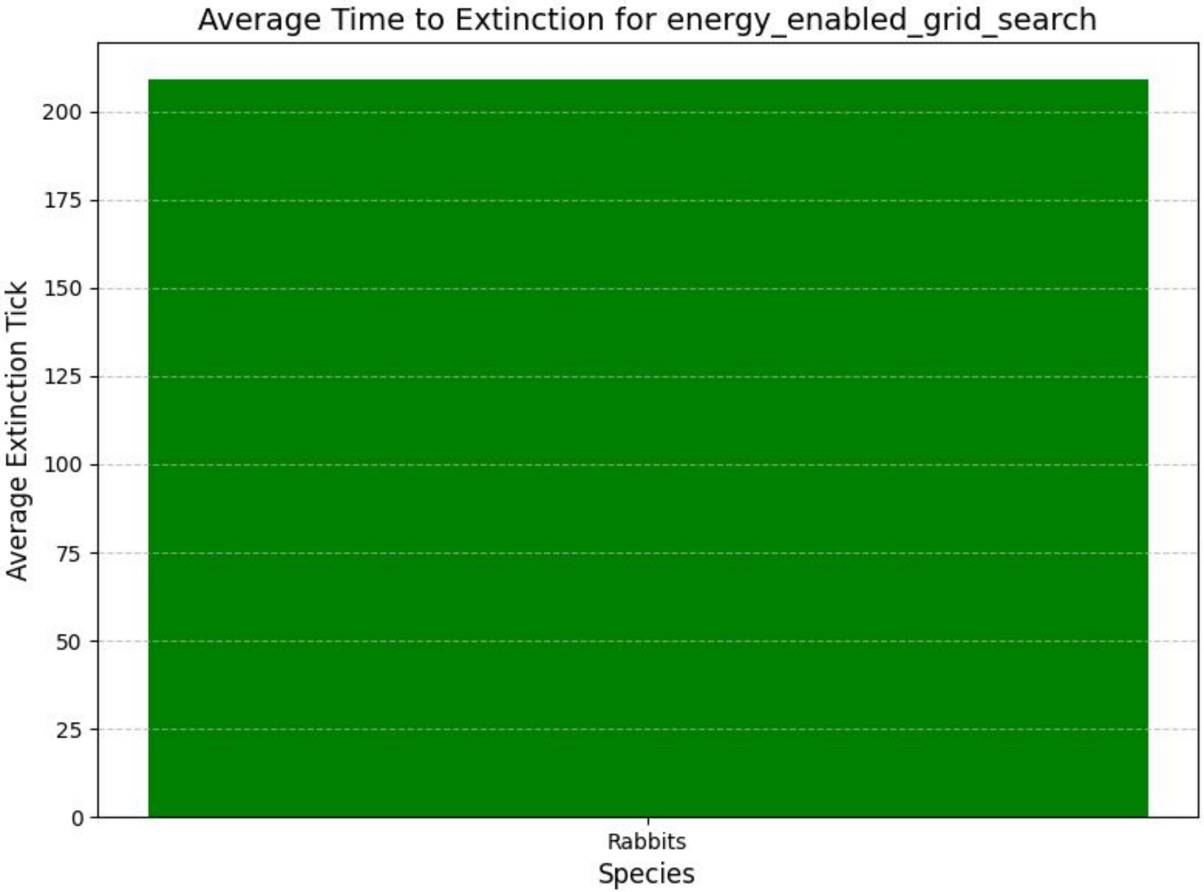


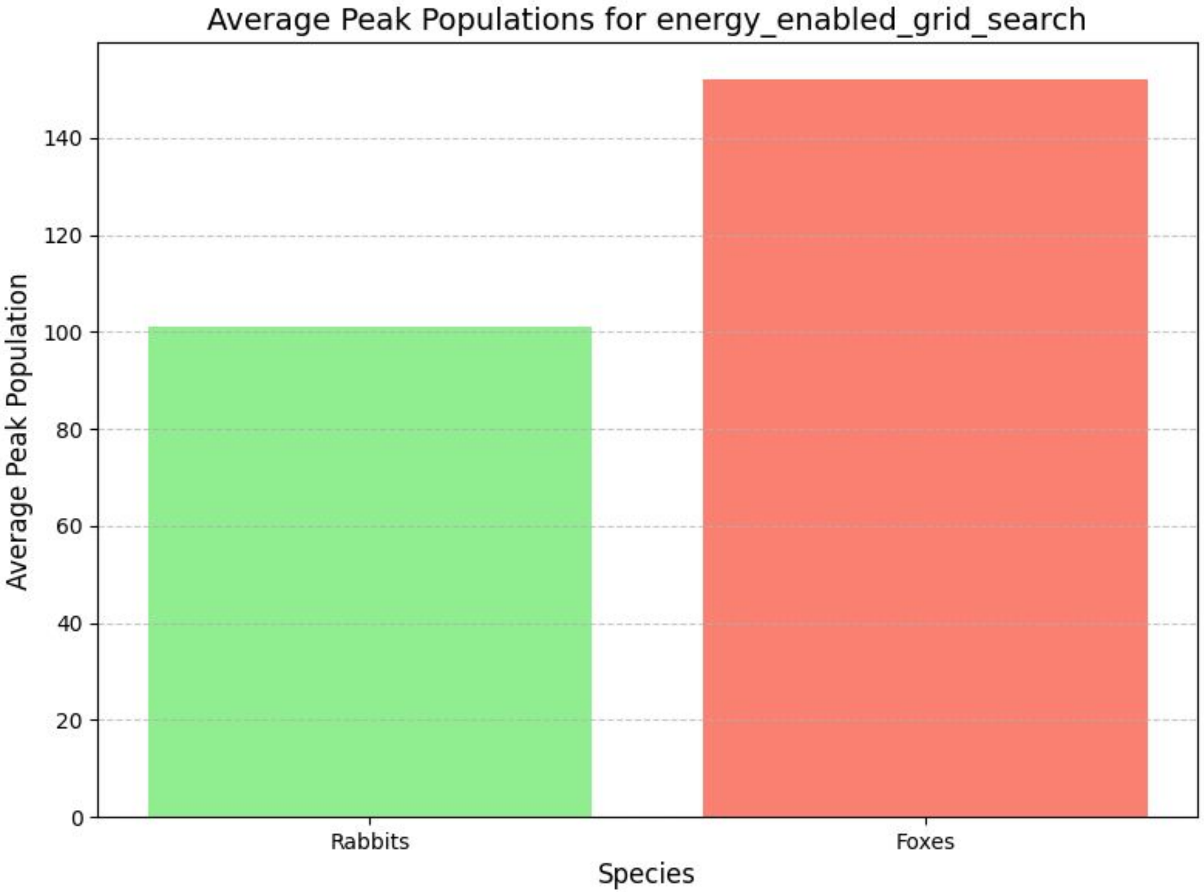
Results

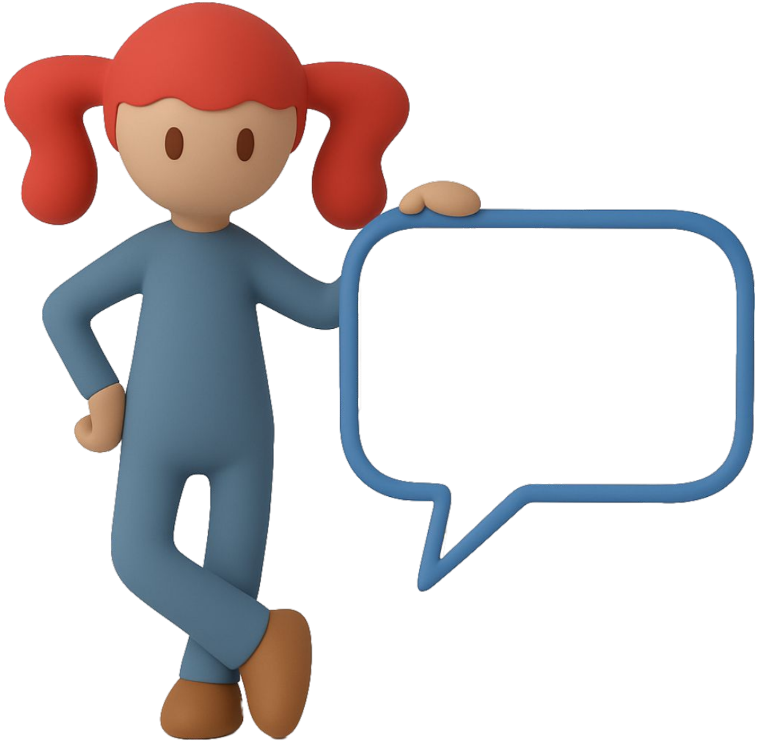
Energy enabled


Averaged Fox Energy Over Time for energy_enabled_grid_search
Average Fox Energy (Averaged Across Runs)
Average Energy
100
90
80
70
60
50
0
50
100
150
200
Time (Simulation Ticks)


Averaged Population Dynamics Over Time for energy_enabled_grid_search
Average Rabbits (Prey)
Average Foxes (Predator)
Average Population Count
Time (Simulation Ticks)
0
20
40
60
80
100
120
140
160
0
50
100
150
200

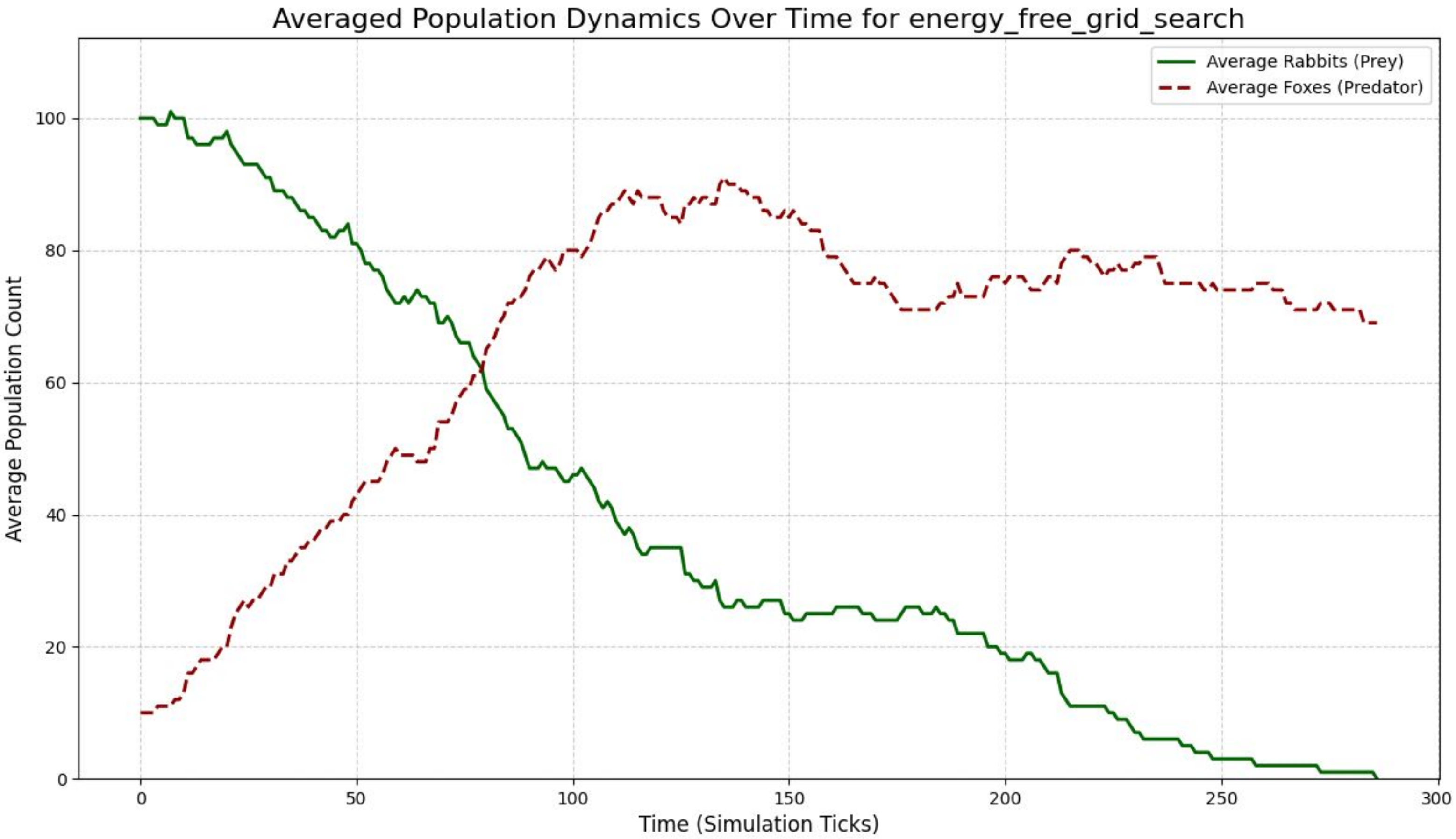

Average Time to Extinction for energy_enabled_grid_search
Average Extinction Tick
0
25
50
75
100
125
150
175
200
Rabbits
Species

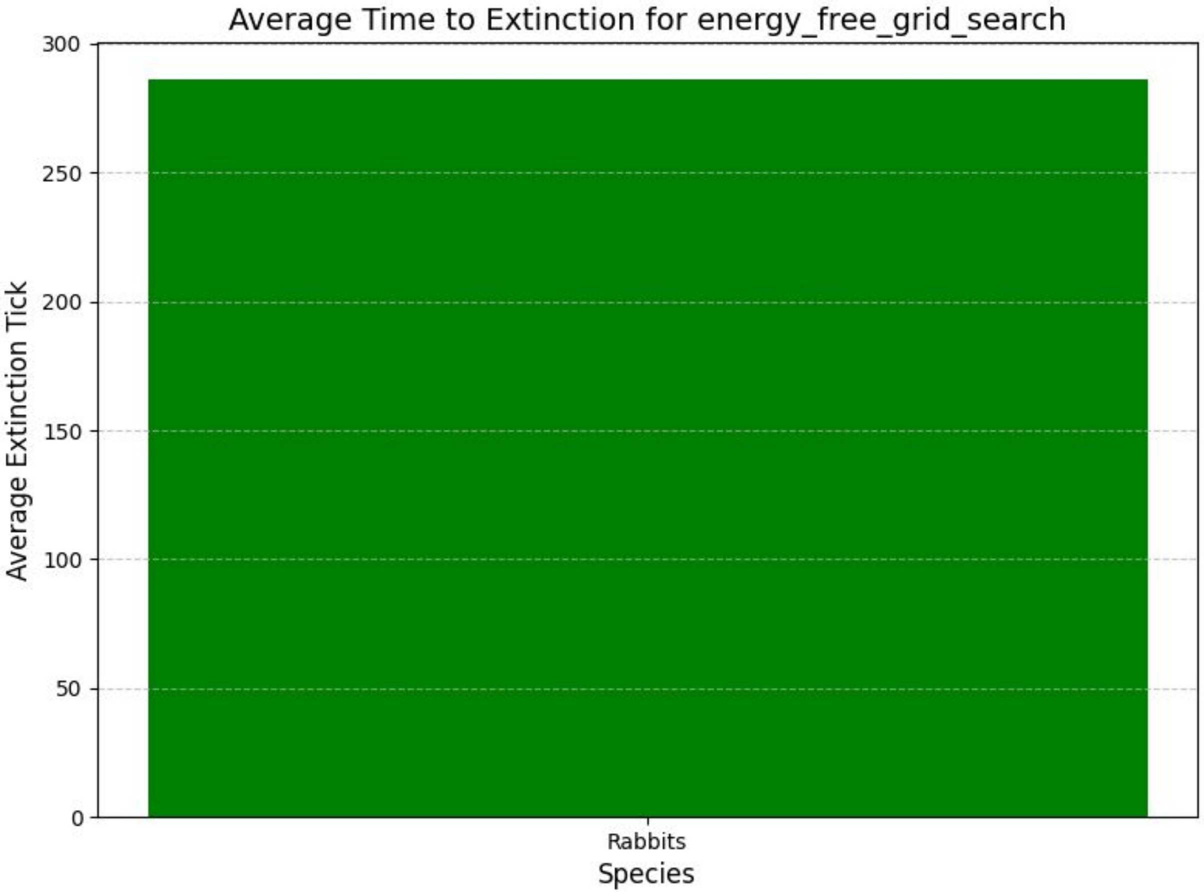

Average Peak Populations for energy_enabled_grid_search
Average Peak Population
0
20
40
60
80
100
120
140
Rabbits
Foxes
Species

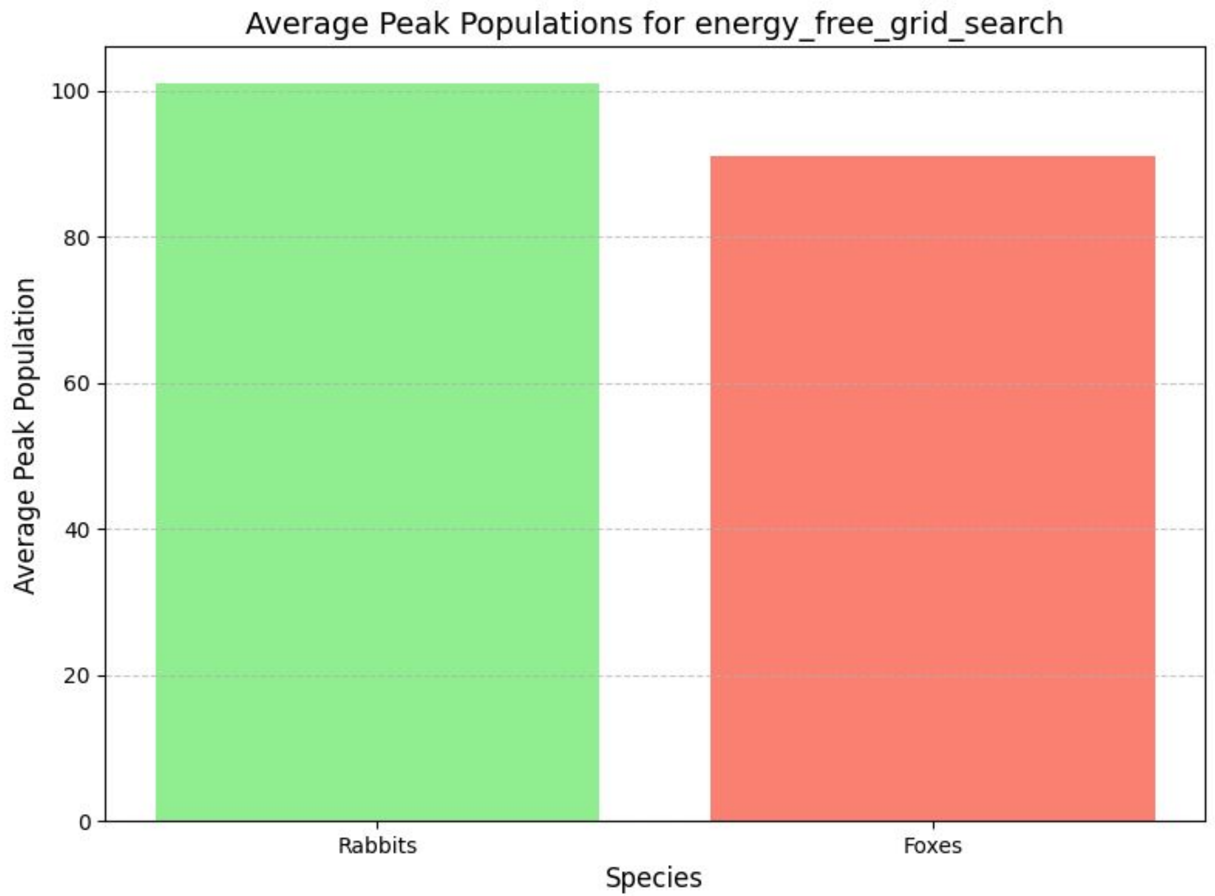


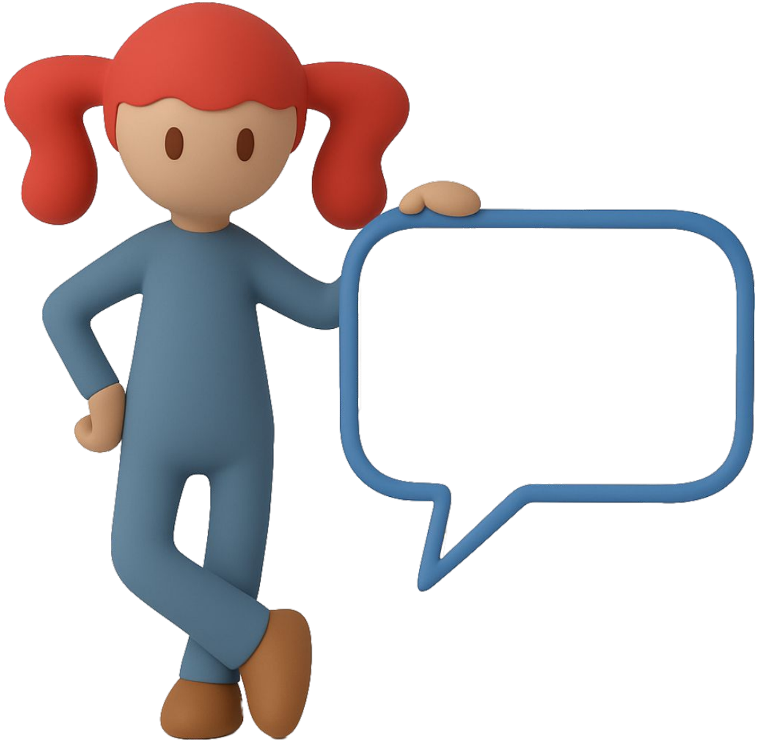
Results

Energy free


Averaged Population Dynamics Over Time for energy_free_grid_search
Average Rabbits (Prey)
Average Foxes (Predator)
Average Population Count
Time (Simulation Ticks)
0
20
40
60
80
100
0
50
100
150
200
250
300

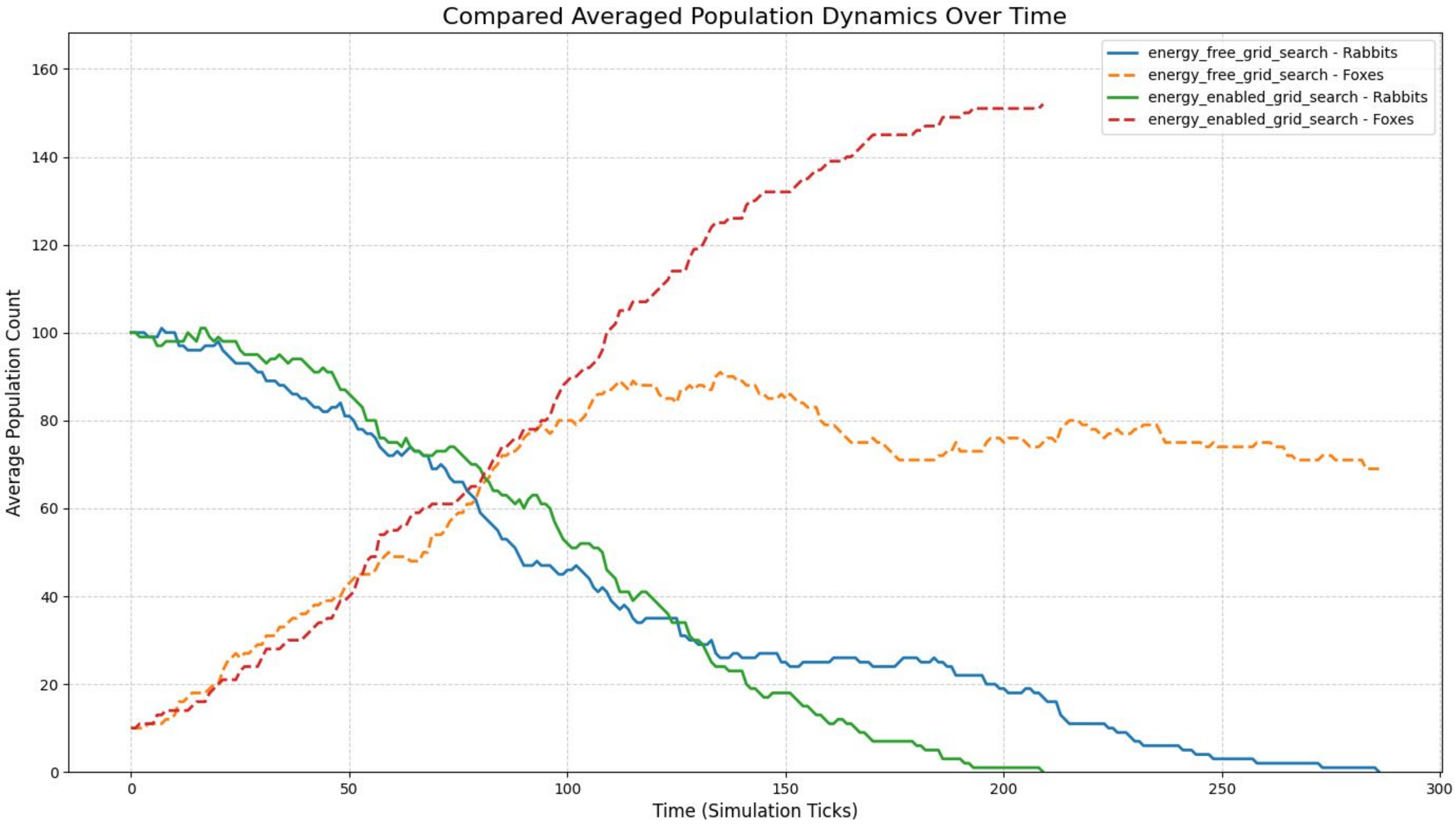

Average Time to Extinction for energy_free_grid_search
Average Extinction Tick
0
50
100
150
200
250
300
Rabbits
Species


Average Peak Populations for energy_free_grid_search
Average Peak Population
0
20
40
60
80
100
Rabbits
Foxes
Species

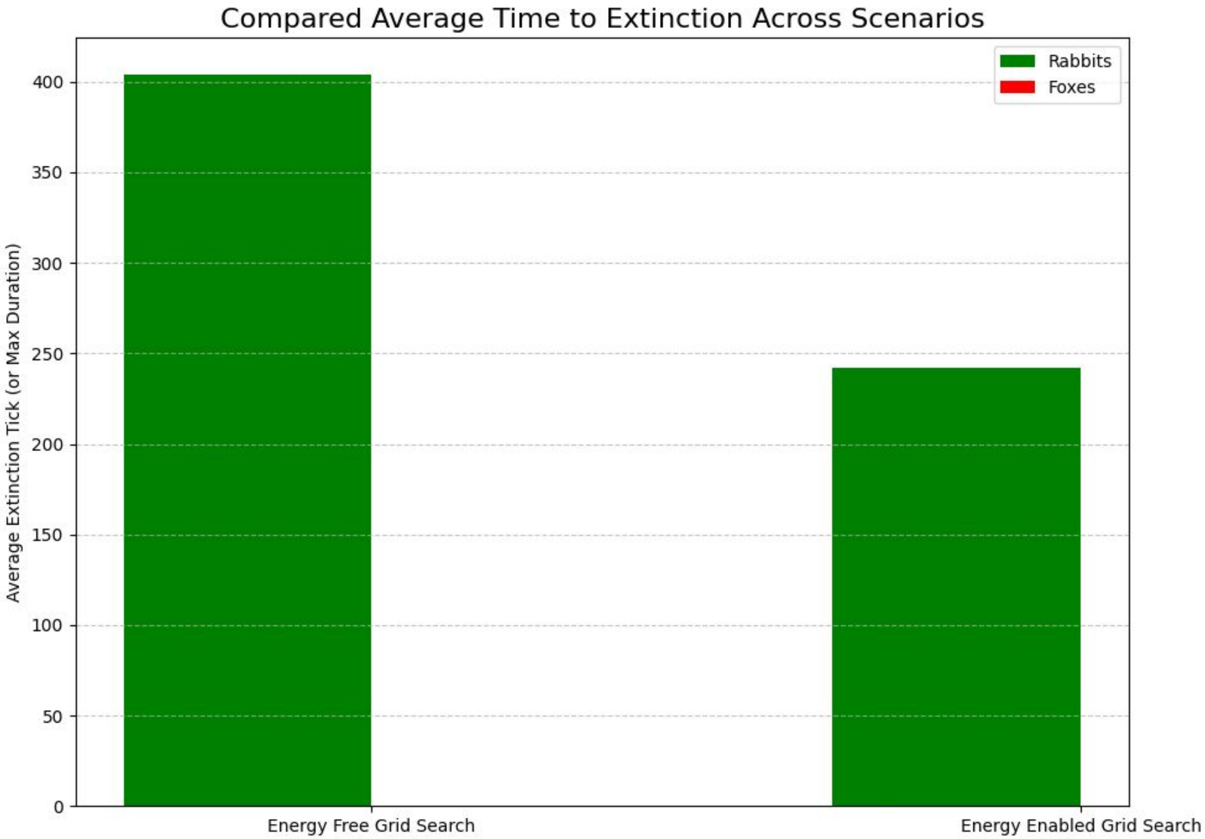


Results

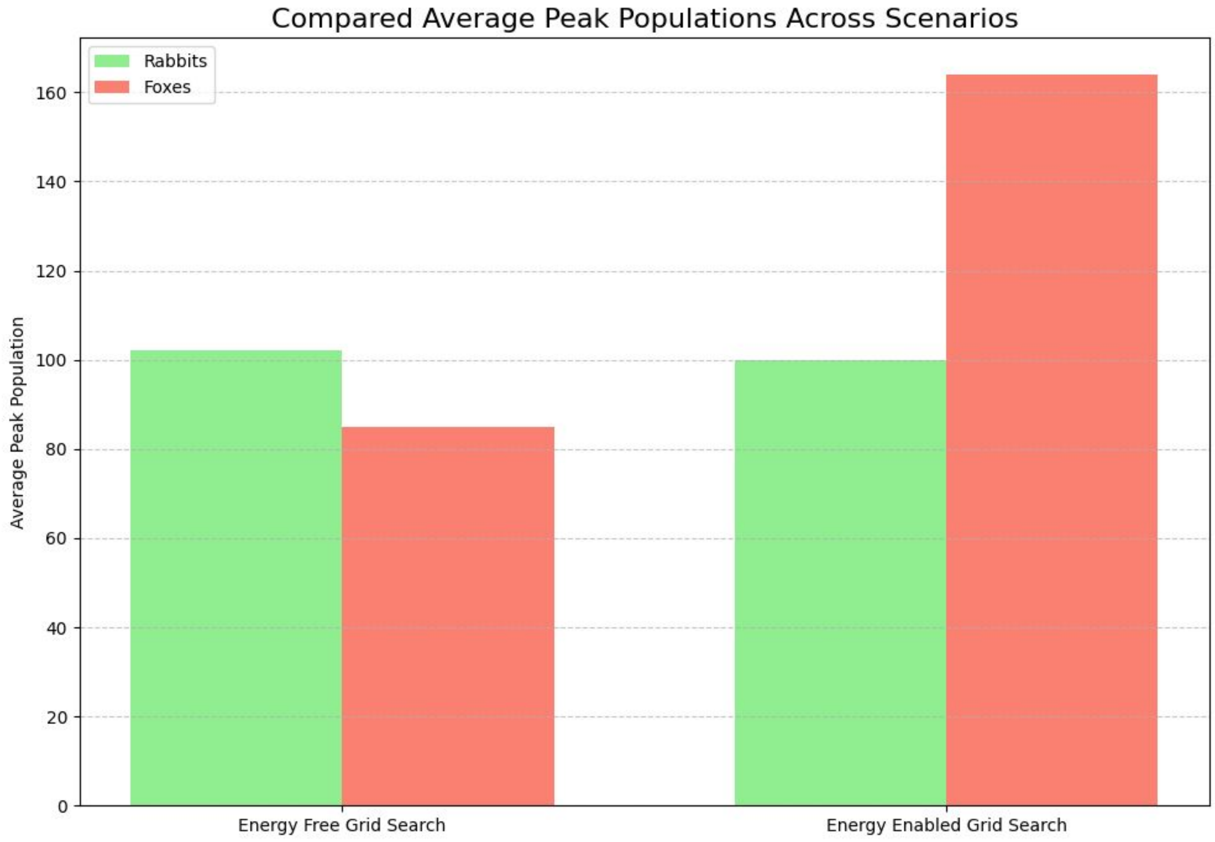
Combined



Compared Averaged Population Dynamics Over Time
energy_free_grid_search - Rabbits
energy_free_grid_search - Foxes
energy_enabled_grid_search - Rabbits
energy_enabled_grid_search - Foxes
Average Population Count
Time (Simulation Ticks)
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300



Compared Average Time to Extinction Across Scenarios
Rabbits
Foxes
Average Extinction Tick (or Max Duration)
0
50
100
150
200
250
300
350
400
Energy Free Grid Search
Energy Enabled Grid Search


Compared Average Peak Populations Across Scenarios
Rabbits
Foxes
Average Peak Population
0
20
40
60
80
100
120
140
160
Energy Free Grid Search
Energy Enabled Grid Search

Conclusions

Introducing an energy-based survival mechanism for predators significantly alters the dynamics of the model.

Compared to the baseline, it leads to:

- Increased fox peak population.
- Unchanged rabbit population.
- Reduced rabbit extinction time.
- Unchanged fox extinction time.
- More volatile population dynamics.

Future work

Extra features that can be added in future:

- Different FOVs for predators and prey
- Movement speed change based on age
- Energy mechanic for prey
- Two agent reproduction
- Group behaviours, such as flocking
- Different space zones, such as grass fields

Thank you

For paying attention