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ENERGY

Electric Log Truck Feasibility in the Nisqually Community Forest

NORTHWEST NATURAL
RESOURCE GROUP
LEADERS IN ECOLOGICAL FORESTRY

NISQUALLY
COMMUNITY FOREST

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Executive Summary

Major automotive manufacturers have begun producing heavy duty (class 8) electric vehicles configured for a variety of industries. Trucks configured for log hauling (from here referred to as electric log trucks, or ELTs) are emerging in international markets such as Australia[1], Canada[2] and Sweden[3] but as of 2025 have not yet been deployed in the United States.

The Pacific Northwest may be particularly suited to ELTs because of the regional topography; timber is typically harvested from higher elevation forests but processing facilities and ports occur near sea level. ELTs can capture gravitational potential energy via regenerative braking as they travel downhill, so the standard log hauling cycle in which unloaded trucks drive uphill to harvest sites and loaded ones drive back down to delivery sites offers a unique opportunity. Along its route, a loaded truck with regenerative braking could recharge its batteries using braking force, extending the truck's range and potentially reducing its overall reliance on external energy supplies. Since fuel cost is one of the highest costs associated with forest operations[4], understanding the capabilities and potential cost savings associated with ELTs is critical for the advancement of these systems. Washington State may also be well suited to ELTs because of the low cost of electricity[5] and relative abundance of public and private charging stations[6], compared to many other regions in the USA.

This report presents the first commercial feasibility study of an ELT in the Pacific Northwest using in-situ data, developed in partnership with and prepared for the Northwest Natural Resource Group (NNRG). The study examined the feasibility and applicability of deploying an ELT in Washington's Nisqually Community Forest (NCF), with particular attention to the effects of regenerative braking on energy availability. The objective of this report is to show the overall energy cost to haul timber from two mainline roads in the community forest to three local timber processing facilities and map the energy costs and vehicle range associated with harvesting from sites throughout the forest.

Using Mauka Energy Inc.'s electric vehicle routing and mapping technologies[7], the round-trip energy consumption costs were calculated for four theoretical heavy duty logging truck configurations based on Kenworth's T880E, including four battery engine configurations (with different numbers of battery packs, also known as "strings") and a T880 diesel engine configuration. The costs were calculated to the furthest point of termination of two roads, the Ashford and Scott Turner Road, and their branch roads. The transportation cost of delivery was also mapped to harvest landings using heat mapping and Isoline / Isotherm mapping.

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[1] Bradbrook and Adamo, "Electric Vehicle Logging Truck Launches for Green Triangle Trial in South Australia."

[2] *Electric Log Truck "Topsy" - Government Recognition*.

[3] Rönnqvist et al., "The World's First Battery Electric Timber Truck."

[4] Noreland, "Semi-Empirical Model for Timber Truck Speed Profile and Fuel Consumption."

[5] U.S. Energy Information Administration, "Monthly Electric Power Industry Report."

[6] U.S. Department of Energy, "EV Charging Station Numbers by State."

[7] Hamilton, Hybrid and electric vehicle energy routing tool.

The key results from these analyses indicate that:

1. Energy cost savings from regenerative braking reduce the gross average energy cost of transportation by 34% with an average range extension of 51% amongst all routes (Table 1)

Table 1: Average Energy Recovery and Cost Results amongst

Forest Road	Scott Turner Road			Ashford Road		
Mill Location	Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
Average Gross Energy Cost (kWh)	391	509	398	273	388	384
Average Net Energy Cost (kWh)	263	377	244	162	273	249
Energy recovered (%)	33%	26%	39%	41%	30%	35%
Range Extension	49%	35%	63%	69%	42%	54%

2. When considering the number of trips that a T880E configured for log hauling can perform in a day before recharging, the best option amongst the four EV vehicles analyzed was the 4-string battery pack configuration because it allowed at least 2 round trips to almost every mill if the driver can take advantage of opportunistic charging. In the absence of opportunistic charging, a 5-string configuration (i.e., 5 battery packs) would be needed to ensure that a minimum of 2 round-trips are possible with a full charge. While the 5-string configuration can meet the same needs, it has a higher tare weight which reduces the overall operational payload and can cause additional wear and tear on the vehicle and roads.

Table 2: T880E Battery capacity relative to delivery costs using opportunistic charging

T880E Battery Pack String	**Battery Capacity** (kWh) + 75 kWh Charge	**Net Delivery Cost (kWh)**					
		Scott Turner Road			Ashford Rd		
		Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
2 string	**325**	🟨 249	🟥 359	🟨 230	🟩 151	🟨 259	🟨 235
3 string	**450**	🟨 263	🟨 377	🟨 244	🟩 162	🟨 273	🟨 249
4 string	**575**	🟩 276	🟨 394	🟩 258	🟦 172	🟩 287	🟩 263
5 string	**700**	🟩 290	🟨 412	🟩 272	🟦 182	🟩 301	🟩 277
🟥 No Trips		🟨 1 Trip		🟩 2 Trips		🟦 3+ Trips	

3. The electricity cost to deliver a load of timber products using a T880E is estimated to be $18.85 when averaged across all assessed routes at the Industrial electricity rate. In contrast, the net average fuel cost to deliver timber using the conventional diesel T880 is $86.50. The commercial electricity rate is an estimate based on the statewide rate which is highly sensitive to the utility area where (and when) the vehicle charged. The diesel rate is the monthly average paid by a logging contractor working for the NNRG.

We recommend future in-situ testing and validation of these results, using Mauka's rolldown tool[8] and the National Laboratory of the Rockies (NLR) speed and torque heavy duty vocation vehicle heatmapping methodologies[9] to determine air, rolling resistance and the deployed vehicle's engine profile. The NLR's Total Cost of Ownership (T3CO) tool[10] could be incorporated with results from this feasibility study to calculate the total cost of owning any assessed vehicle configuration over its lifetime. The results of this report should also be developed into a peer reviewed publication.

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[8] Hamilton et al., "Identifying Rolling Resistance and Air Resistance Simultaneously for an Electric Truck."

[9] Zhang et al., "Development of In-Use Engine Speed/Torque Heat Maps across Multiple Heavy-Duty Commercial Vehicle Vocations."

[10] Lustbader et al., *T3CO (Transportation Technology Total Cost of Ownership) Open Source [SWR-21-54]*.

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Introduction

Overview

When electric vehicles descend grades, they can harness gravitational potential energy that is typically lost in diesel engines and use it to recharge their batteries via regenerative braking. This potential for energy recovery offers a mechanism to increase energy efficiency and vehicle range, and previous work[11,12] has indicated that there are significant opportunities for efficiency gains and emission reductions using electric trucks in forest operations if regenerative braking is accounted for.

This study evaluated the battery recharge potential of heavy-haul forestry routes within the Nisqually Community Forest (NCF) and en route to three nearby mills (Figure 1). The analysis is based on a segmented evaluation of road pitch, distance, and surface type, which are used to estimate the regenerative energy potential of electric logging trucks under loaded and unloaded conditions. To support this analysis, Mauka improved its energy estimation model for electric log truck operations in variable mountainous and forested environments by accounting for curves on forest roads and limited sight lines. Field surveys collecting high accuracy road data were conducted along the two main haul routes from NCF harvest units to the three processing mills.

The Nisqually Community Forest grew out of the Nisqually Indian Tribe's role in recent decades as the lead entity for salmon recovery in the Nisqually watershed. The tribe and nonprofit partners worked to establish the Nisqually Community Forest in the early 2010s. Currently, 2,880 acres of forestland are held by the nonprofit, and another 2,620 acres are owned in fee by the tribe, all managed jointly as the Nisqually Community Forest.

Objectives

The primary objective of this analysis was to calculate, model, and map the net energy cost to haul timber from harvest units along two mainline roads in the community forest to three timber processing facilities in the local region. The other objectives were to calculate the gross energy cost and regenerative braking energy gain, graph these results relative to distance and elevation, and compare these results to a conventional diesel vehicle configuration. The results demonstrate how an electrified log transport system in the NCF would affect energy usage and regenerate energy compared to conventional vehicles.

Scientific Basis

Established principles of vehicle dynamics and transportation energy modeling can be applied to heavy-duty vehicles operating in forested terrain[13]. The energy required to haul timber is governed by vehicle mass, road grade, distance, rolling resistance, aerodynamic drag, and powertrain efficiency. Unlike conventional diesel trucks, electric log trucks can recover a portion of the energy expended during uphill

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[11] Hamilton et al., "Forestry Electric Vehicle Energy Routing and Mapping GIS Tool."

[12] Hamilton et al., "Developing Forestry EV Energy Cost Mapping."

[13] Noreland, "Semi-Empirical Model for Timber Truck Speed Profile and Fuel Consumption."

travel through regenerative braking, which captures a portion of the gravitational potential energy when descending with a load, reducing net energy consumption and operating cost[14].

The modeling approach used in this study evaluates energy use on a segment-by-segment basis along forest haul roads, accounting for changes in elevation, curvature, surface conditions, and operating speed under loaded and unloaded conditions. High-resolution elevation data (Figure 2) and in-situ road observations are integrated within a geographic information system (GIS) to estimate gross energy demand, regenerative energy recovery, and net transportation energy cost across the road network and harvest landings.

Comparisons with conventional diesel trucks are conducted using energy-equivalent fuel conversion factors and efficiency assumptions consistent with U.S. Department of Energy guidance[15]. Together, these scientifically established methods provide a robust and defensible basis for evaluating the theoretical technical feasibility and relative operating cost advantages of electric log trucks in the NCF and similar forestry environments. The next step in developing these modeling technologies would be to compare this theoretical analysis against the actual field performance of a deployed ELT, in order to arrive at a proof of concept and fine tune the modeling approach for use elsewhere.

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[14] Hellmund, "Regenerative Braking of Electric Vehicles."

[15] U.S. Department of Energy, "DOE Diesel Fuel Properties Dataset"; Lustbader et al., *T3CO (Transportation Technology Total Cost of Ownership) Open Source [SWR-21-54]*.

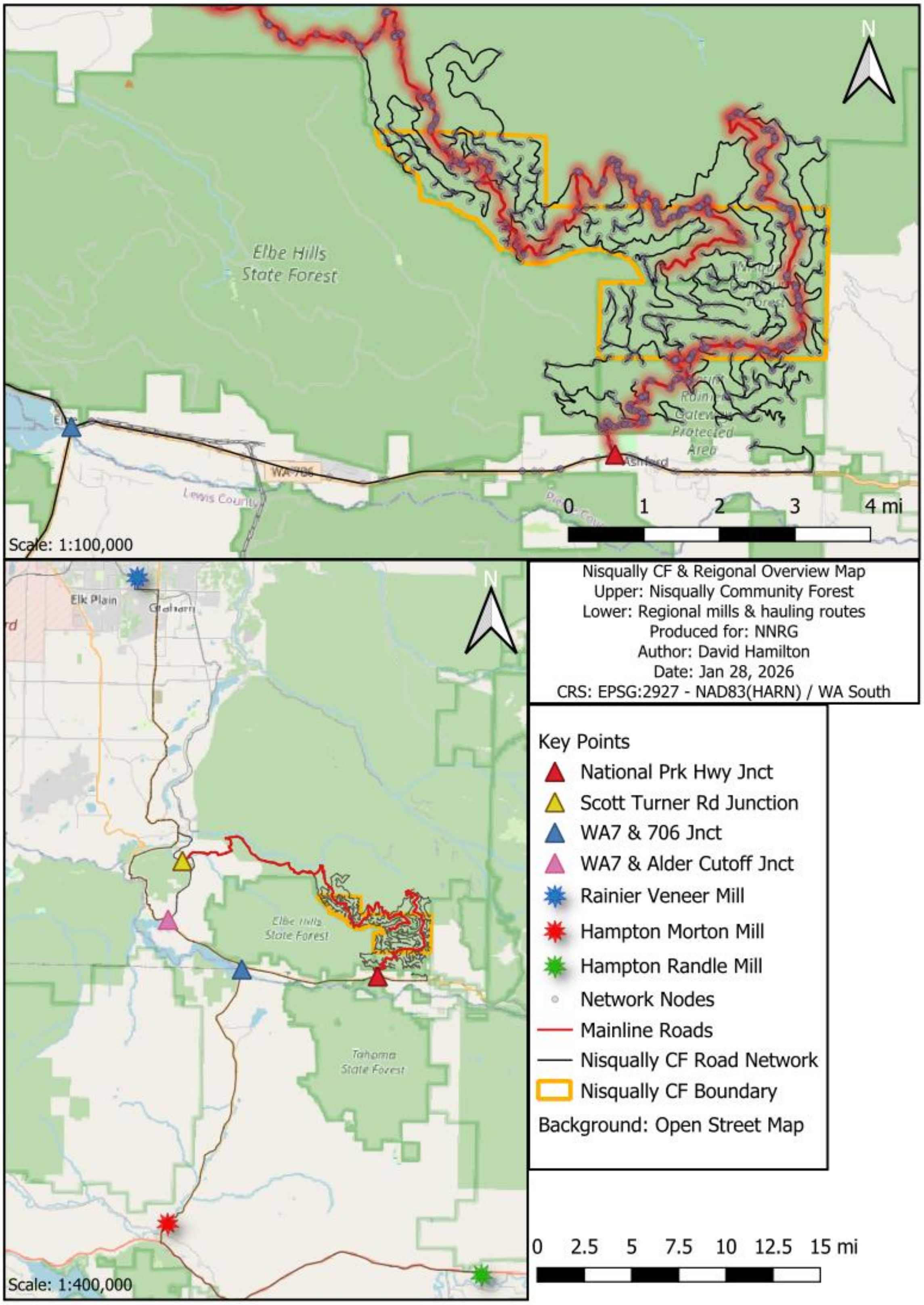

Figure 1: Overview map of the Nisqually Community Forest region

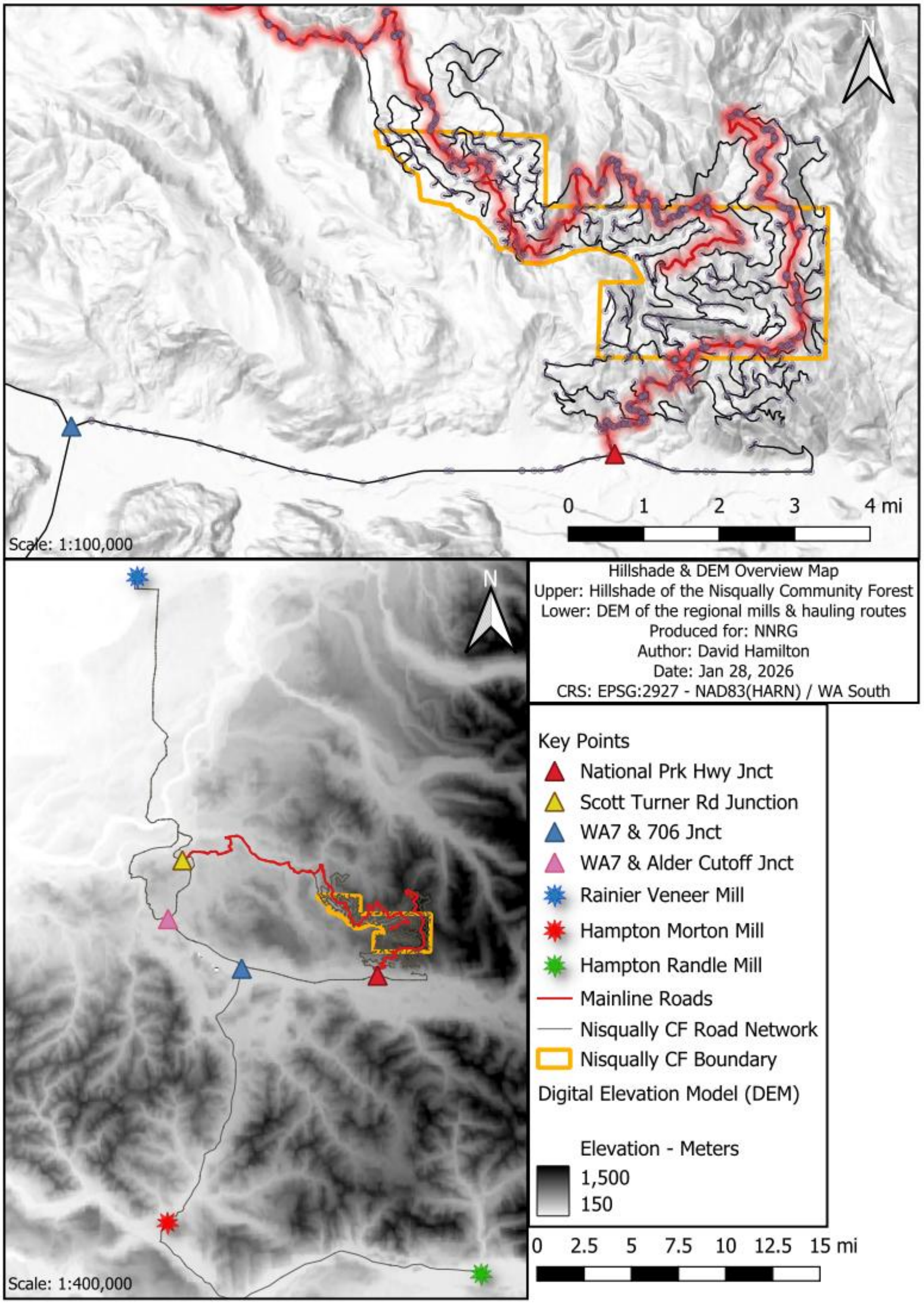

Figure 2: Hill shade map of the Nisqually Community Forest and DEM of the region

Methodology

Field Data Collection

NNRG provided existing remote sensing datasets that included 110 miles of road networks within the NCF. Mauka also developed geospatial data for 94 miles of road networks outside the NCF. In order to prepare the databases for use in the development of the electric vehicle energy modeling system, Mauka Energy ground-truthed the provided geospatial and elevation data along key forest haul routes and added data relevant to driving behavior.

The surveys were conducted on October 29 and 30, 2025, in collaboration with NNRG. Field conditions included moderate autumn weather and active forestry operations, requiring coordination with local forest managers to ensure safety and minimize operational disruptions.

Mauka Energy staff utilized high-precision GPS and digital mapping equipment to survey approximately 12 miles of the Scott Turner Mainline / 3000 Road and 9 miles of the Ashford / 4500 Roads, both of which serve as the primary hauling routes for timber operations in the NCF. Geospatial data points were recorded at features on the road that could cause changes in the vehicle's speed, with particular attention to curves, sight barriers, and slowing or stopping points that influence vehicle power demand and regeneration opportunities.

Network Development & Analysis

Road Network

The relevant road networks within the NCF were digitized to three hauling destinations: Hampton Morton sawmill, Hampton Randle sawmill and Rainier Veneer mill. Initial GIS data for the forest was provided to Mauka by the NNRG, combined with Washington State geospatial road data[16], and validated during fieldwork.

Through this digitization and validation process, the road networks were broken into a series of line segments (referred to as *edges)* which were connected at intersections and points along the road (referred to as *nodes)*. The nodes were placed wherever characteristics of the road changed, such as points where the road surface changed, alternative routing options were available, or the driving speed changed due to a curve. The network model used in this analysis assumed reduced speeds at curves and visual barriers in the landscape. Nodes were also placed at every forest harvest landing planned for the next 5 years.

The final network includes a total of 1264 nodes. The key node locations used in this analysis are described in Table 3. A high accuracy LiDAR-derived digital elevation model[17] was overlaid to determine the precise elevation of each node along the road networks, shown in Figure 3. Further metadata on the nodes, edges and route lengths can be found in Appendix A, Tables A1 – A3.

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[16] Washington State Department, "WA State Road Spatial Data Archive."

[17] Washington State Department of Natural Resources, "Washington DNR LIDAR DEM Dataset."

Table 3: Key Node Locations

Name	Node ID	Description / Location
Hampton Morton	1081	Hampton Lumber Morton Sawmill 302 WA-7, Morton, WA 98356
Hampton Randle	1088	Hampton Lumber Randle Sawmill 10166 US-12, Randle, WA 98377
Rainier Veneer	575	Rainier Fiber Veneer Mill 8220 Eustis Hunt Rd, Graham, WA 98338
Junction	1076	This is the Junction of Highways 706 & 7, located across from the Nisqually River Bridge 54312 182 Ave Ct E, Elbe, WA 98330
Ashford Start	195	Ashford Road, known to loggers as the "45 Road," begins at Highway 706 adjacent to Ashford County Park 29801 WA-706, Ashford, WA 98304
Ashford End	1031	The furthest point of termination of the Ashford Road and its branch roads
Scott T Start	570	Scott Turner Road East begins at the junction with Alder Cutoff Road East
Scott T End	282	The furthest point of termination of the Scott Turner Road and its branch roads

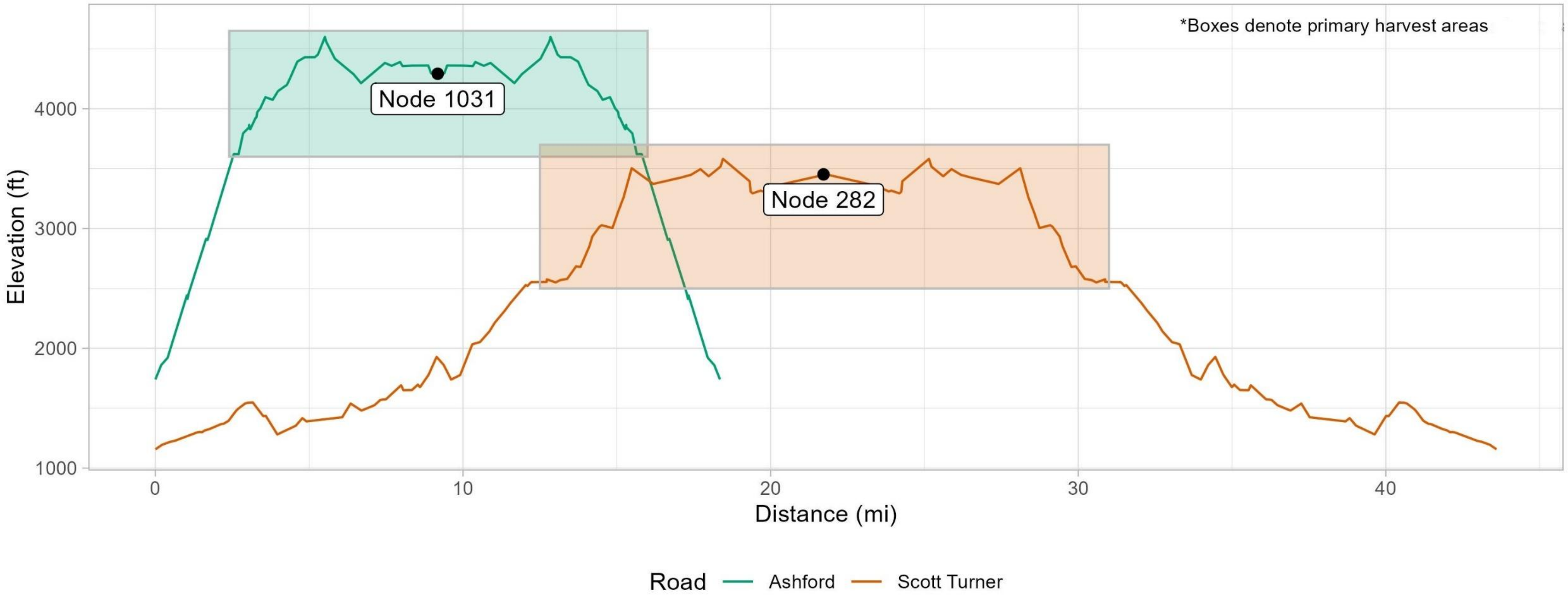

Figure 3: Round trip road elevation profiles for the Ashford and Scott Turner Roads between their start nodes (195 & 528) to end nodes (1031 & 282).

Vehicle Configurations

The vehicle configurations used in this analysis consisted of four theoretical Kenworth T880E EV logging truck configurations[18] with varying numbers of battery packs, or “strings,” and a conventional T880 diesel engine configuration[19] (Table 4). The tare weight of each vehicle was based on a theoretical T880 configured to haul timber; the components that make up each vehicle’s tare weight and their references can be found in Appendix A, Tables A4 - A5. For each mill, the load of each truck was set as the average load delivered by the NNRG to that mill as part of their forest operations. The frontal area was based on existing log truck frontal area and accounts for the changing shape of these vehicles as they receive a load of timber; these values have been used in previous EV logging truck energy analysis and mapping technologies[20].

Engine efficiency rates were developed by the U.S. National Renewable Energy Lab and can be found in their Native Vehicle Model Assumptions dataset for their Total Cost of Ownership tool[21]. For the battery electric configuration, we used the dataset’s Class 8 day cab mid-roof BEV 2025 vehicle and the motor efficiency from this dataset was taken by analyzing efficiency across its entire operating range of speed (RPM) and torque. To remain conservative and represent the rugged conditions of forest operations, the low-end efficiency value of approximately 0.83 was utilized rather than the peak value of 0.92. Efficiency rates do not consider losses from the grid to the battery.

For the diesel configuration, we used the Class 8 day cab mid-roof diesel 2025 vehicle. Diesel engine efficiency is also taken from the Native Vehicle Model Assumptions dataset. We used the upper-end efficiency value from the map, corresponding to a peak engine efficiency of approximately 0.45. This is the best-case scenario for a diesel engine, and we would expect that a diesel truck would perform worse than this analysis suggests given the harsher conditions found in forest hauling relative to typical class 8 highway hauling.

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[18] Kenworth, “T880E Spec Sheet.”

[19] Kenworth, “T880 Diesel Spec Sheet.”

[20] Hamilton et al., “Forestry Electric Vehicle Energy Routing and Mapping GIS Tool.”

[21] Lustbader et al., *T3CO (Transportation Technology Total Cost of Ownership) Open Source [SWR-21-54]*.

Table 4: T880 Vehicle Configurations

#	Name	Weight (lbs)	Tare (lbs)	Load (lbs)	Total Efficiency	Regen Efficiency	Area (m^2)	Motor/Engine Efficiency	Powertrain Efficiency
1	T880E 2 string Unloaded	26678	26678	0	71%	70%	4.65	83%	85%
2	Veneer T880E 2 string Loaded	84093	26678	57415	71%	70%	7.43	83%	85%
3	Morton T880E 2 string Loaded	81170	26678	54492	71%	70%	7.43	83%	85%
4	Randle T880E 2 string Loaded	83804	26678	57126	71%	70%	7.43	83%	85%
5	T880E 3 string Unloaded	29608	29608	0	71%	70%	4.65	83%	85%
6	Veneer T880E 3 string Loaded	87023	29608	57415	71%	70%	7.43	83%	85%
7	Morton T880E 3 string Loaded	84100	29608	54492	71%	70%	7.43	83%	85%
8	Randle T880E 3 string Loaded	86734	29608	57126	71%	70%	7.43	83%	85%
9	T880E 4 string Unloaded	32536	32536	0	71%	70%	4.65	83%	85%
10	Veneer T880E 4 string Loaded	89951	32536	57415	71%	70%	7.43	83%	85%
11	Morton T880E 4 string Loaded	87027	32536	54492	71%	70%	7.43	83%	85%
12	Randle T880E 4 string Loaded	89662	32536	57126	71%	70%	7.43	83%	85%
13	T880E 5 string Unloaded	35466	35466	0	71%	70%	4.65	83%	85%
14	Veneer T880E 5 string Loaded	92881	35466	57415	71%	70%	7.43	83%	85%
15	Morton T880E 5 string Loaded	89957	35466	54492	71%	70%	7.43	83%	85%
16	Randle T880E 5 string Loaded	92592	35466	57126	71%	70%	7.43	83%	85%
17	T880 Diesel Unloaded	25455	25455	0	36%	0%	4.65	45%	80%
18	Veneer T880 Diesel	82869	25455	57415	36%	0%	7.43	45%	80%
19	Morton T880 Diesel	79946	25455	54492	36%	0%	7.43	45%	80%
20	Randle T880 Diesel	82581	25455	57126	36%	0%	7.43	45%	80%

A conservative weight estimate was established using a primary-source invoice for a T680E[22] that provided itemized net weight changes for the diesel-to-electric transition. Since the PACCAR ePowertrain variant (debuting Spring/Summer 2025) lacked similar sources, particularly those pertaining to weight changes, this study utilized the Meritor-based specifications as a high-fidelity proxy. By applying these documented deltas to a standard T880 chassis and incorporating the mass of heavy-duty vocational reinforcements, the model ensures a 'worst-case' weight scenario, accounting for the higher mass inherent in early-production e-axle architectures. While industry reports regarding the gen 3 vary, most do not state weight savings beyond 1500lbs. This lack of sources for the T880E also extends to the vehicle efficiencies which are based on existing estimates for heavy duty EV and ICE efficiencies[23]. Other efficiency factors such as the loss of energy due to tire slip would also be accounted for in the powertrain efficiency estimate.

The T880E string configuration battery capacities, which are important for understanding the number of trips a vehicle can make before recharging, can be found in Table 5. Since operators prefer to have remaining charge in their vehicles[24] and energy is often drawn for auxiliary systems like heating and communication, the manufacturer has listed the battery capacity at 12% below the actual battery capacity.

Table 5: T880E Battery String Configuration Options[25]

Battery String Configuration	Capacity (kWh)	Estimated Range (miles)
2	250	100
3	375	150
4	500	200
5	625	250

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[22] Kenworth of Jacksonville, “Kenworth T680 Build Order Vehicle Summary.”

[23] Kenworth, “T880: STANDARD SPECIFICATIONS.”

[24] Philipsen et al., “Running on Empty – Users’ Charging Behavior of Electric Vehicles versus Traditional Refueling.”

[25] Kenworth, “T880E Spec Sheet.”

Results

Round-trip Energy Use and Cost Tables

Round-trip Energy Use - kWh

Tables 6 and 7 show total round-trip energy cost and regeneration for each T880E vehicle configuration. Table 6 summarizes the energy use of trips using the Scott Turner Road, beginning with the truck's departure from the mill, unloaded, and ending with its arrival back at the mill with a payload collected at the end of the road. Table 7 similarly summarizes the energy cost travelling on the Ashford Road. The costs of transportation using a diesel vehicle and a calculation in terms of MPG can be found in Appendix B.

Table 6: Round Trip Energy Use and Recovery results (kWh) for the Scott Turner Road for alternative battery configurations.

	Hampton Morton			Hampton Randle			Rainier Veneer		
Truck	Gross	Regen	**Net**	Gross	Regen	**Net**	Gross	Regen	**Net**
2 string	371	123	**249**	485	126	**359**	377	147	**230**
3 string	391	129	**263**	509	132	**377**	398	154	**244**
4 string	411	135	**276**	533	138	**394**	419	161	**258**
5 string	431	141	**290**	557	145	**412**	441	169	**272**

Table 7: Round Trip Energy Use and Recovery results (kWh) for the Ashford Road for alternative battery configurations.

	Hampton Morton			Hampton Randle			Rainier Veneer		
Truck	Gross	Regen	**Net**	Gross	Regen	**Net**	Gross	Regen	**Net**
2 string	258	106	**151**	369	110	**259**	345	110	**235**
3 string	273	111	**162**	388	114	**273**	393	144	**249**
4 string	288	116	**172**	406	119	**287**	414	151	**263**
5 string	303	121	**182**	425	124	**301**	435	158	**277**

Battery Capacity & Opportunistic Charging

The key factor limiting the daily operational range of each truck is battery capacity, which is based on the marginal range and weight of each added string of batteries. Table 8 shows the T880E configurations' battery capacities and the energy required for each delivery route.

Table 8: T880E Battery capacity relative to delivery energy requirement

	Battery Capacity (kWh)	**Net Delivery Cost (kWh)**					
		Scott Turner Road			Ashford Rd		
		Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
2 string	**250**	🟨 249	🟥 359	🟨 230	🟨 151	🟥 259	🟨 235
3 string	**375**	🟨 263	🟥 377	🟨 244	🟩 162	🟨 273	🟨 249
4 string	**500**	🟨 276	🟨 394	🟨 258	🟩 172	🟨 287	🟨 263
5 string	**625**	🟩 290	🟨 412	🟩 272	🟦 182	🟩 301	🟩 277
🟥 No Trips		🟨 1 Trip		🟩 2 Trips		🟦 3+ Trips	

It would be optimal for operators to be able to deliver at least 2 loads of timber before stopping to fully recharge, but the presence of a DC fast charger at the delivery point, allowing operators the chance to partially charge their vehicle during the delivery, could also extend the vehicle's utility. At 350kW standard, that would add an estimated 75 kWh before or after the timber on the truck is scaled and unloaded. Table 9 shows the battery capacity with the additional 75 kWh opportunistic charge and delivery cost to each mill for the T880E configurations used in this analysis with optimal routes, where the truck can complete two round trips per day, highlighted in green, single trips in yellow, and inoperable routes in red. Based on these results, the 4-string vehicle should meet most operational needs for log deliveries from NCF.

Table 9: T880E Battery capacity relative to delivery costs using opportunistic charging

T880E Battery Pack String	**Battery Capacity** (kWh) + 75 kWh Charge	**Net Delivery Cost (kWh)**					
		Scott Turner Road			Ashford Rd		
		Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
2 string	**325**	🟨 249	🟥 359	🟨 230	🟩 151	🟨 259	🟨 235
3 string	**450**	🟨 263	🟨 377	🟨 244	🟩 162	🟨 273	🟨 249
4 string	**575**	🟩 276	🟨 394	🟩 258	🟦 172	🟩 287	🟩 263
5 string	**700**	🟩 290	🟨 412	🟩 272	🟦 182	🟩 301	🟩 277
🟥 No Trips		🟨 1 Trip		🟩 2 Trips		🟦 3+ Trips	

Round Trip Energy Cost in Dollars

Tables 10 and 11 convert the energy cost in terms of kWh into their US dollar value. The energy and fuel prices used in the analysis are based on U.S. Energy Information Administration monthly energy cost report for October 2025[26] and the diesel cost is the monthly average fuel rate that logging contractors working for the NNRG paid in October 2025, which were $0.072 per kWh for industrial energy costs and $4.39 per gallon of diesel fuel[27]. The energy cost assumes that the NNRG can partner with local mill owners and receive the statewide average industrial electricity rate, which is lower than the standard rates typically paid by existing EV owners. For a detailed breakdown and example of the diesel vehicle cost conversion, refer to Appendix B.

Table 10: Round Trip Industrial Energy Use and Recovery results in $ USD for the Scott Turner Road

	Hampton Morton			Hampton Randle			Rainier Veneer		
Truck	Gross	Regen	**Net**	Gross	Regen	**Net**	Gross	Regen	**Net**
2 string	26.11	8.62	17.49	34.13	8.87	25.26	26.49	10.31	16.17
3 string	27.51	9.05	18.46	35.80	9.30	26.50	27.98	10.83	17.16
4 string	28.92	9.49	19.43	37.46	9.73	27.73	29.48	11.34	18.14
5 string	30.33	9.92	20.40	39.13	10.17	28.96	30.98	11.86	19.12
Diesel	86.80	-	86.80	110.55	-	110.55	88.67	-	88.67

Table 11: Round Trip Industrial Energy Use and Recovery results in $ USD for the Ashford Road

	Hampton Morton			Hampton Randle			Rainier Veneer		
Truck	Gross	Regen	**Net**	Gross	Regen	**Net**	Gross	Regen	**Net**
2 string	18.13	7.48	10.65	25.94	7.70	18.24	24.22	7.70	16.52
3 string	19.19	7.82	11.36	27.26	8.05	19.21	27.66	10.15	17.51
4string	20.24	8.17	12.08	28.57	8.39	20.18	29.12	10.61	18.51
5 string	21.30	8.51	12.79	29.89	8.73	21.16	30.57	11.08	19.50
Diesel	60.84	-	60.84	84.59	-	84.59	87.52	-	87.52

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[26] U.S. Energy Information Administration, “Monthly Electric Power Industry Report.”

[27] Chase Beyer, “Average Diesel Cost for Loggers Working for the NNRG.”

Energy Use and Cost Summary

Table 12 summarizes the key energy costs and savings of the results presented in Tables 6 – 11. The energy recovered on route reduced the overall energy used by an average of 34%, leading to an average range extension of 51% amongst all routes. The average net energy cost amongst all three T880E configurations from the two roads to each mill was 261 kWh. The most energy, 377 kWh, was needed to deliver to the Hampton Randle mill via the Scott Turner Road, and the least, 162 kWh, was needed to deliver to the Hampton Morton mill via the Ashford Road.

Table 12: Key Energy Recovery and Cost Results using $0.072 per kWh for industrial energy rate costs, $0.129 for transportation energy rate costs and $4.39 per gallon of diesel. Electricity costs do not include grid-to-battery energy overhead or charging infrastructure costs.

Forest Road	Scott Turner Road			Ashford Road		
Mill Location	Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
Average Gross EV Energy Use (kWh)	391	509	398	273	388	384
Average Net Energy Use (kWh)	263	377	244	162	273	249
Energy recovered (%)	33%	26%	39%	41%	30%	35%
Range Extension	49%	35%	63%	69%	42%	54%
Average Net T880 EV Fuel Cost (USD) - Industrial	$ 18.95	$ 27.11	$ 17.65	$ 11.72	$ 19.70	$ 18.01
Average Net T880 EV Fuel Cost (USD) - Transportation	$ 34.74	$ 49.71	$ 32.35	$ 21.49	$ 36.12	$ 33.93
T880 Net Diesel Fuel Cost (USD)	$ 86.80	$ 110.55	$ 88.67	$ 60.84	$ 84.59	$ 87.52
Est. Fuel Savings Industrial EV rate over Diesel per Trip (USD)	$ 67.86	$ 83.44	$ 71.03	$ 49.12	$ 64.90	$ 69.52
Est. Fuel Savings Industrial EV rate over Diesel per Trip (%)	78%	75%	80%	81%	77%	79%
Est. Fuel Savings Transportation EV rate over Diesel per Trip (USD)	$ 52.07	$ 60.84	$ 56.32	$ 39.36	$ 48.48	$ 53.59
Est. Fuel Savings Transportation EV rate over Diesel per Trip (%)	60%	55%	64%	65%	57%	61%

Energy Use and Cost Comparison Graphs

A series of figures summarizing gross energy demand, regenerative energy recovery, and net energy consumption as functions of distance, elevation, and vehicle speed are presented below (Figures 4 – 7). Figures 4 and 6 illustrate continuous changes in elevation, speed, and cumulative energy use along each round-trip route, while Figures 5 and 7 aggregate energy values into 5 mile intervals to highlight localized regenerative braking gains, particularly along sustained downhill segments of the routes. Figures 4 and 5 depict round-trip results for deliveries to the Morton Sawmill via the Scott Turner Road and Figures 6 and 7 are via the Ashford Road. Links to the datasets used to generate these results can be found in Appendix C. Similar figures are available in Appendix D for the other routes analyzed.

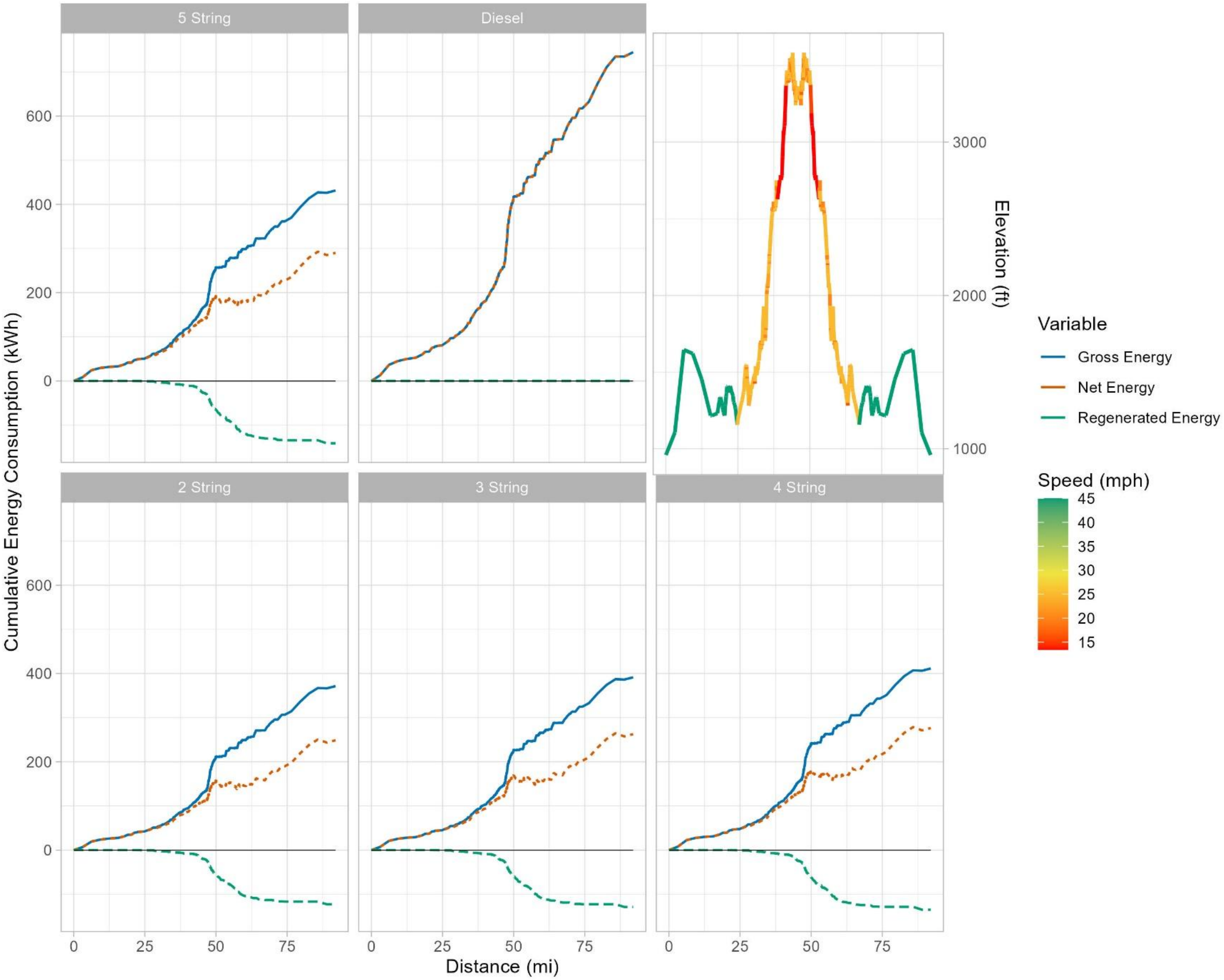

Figure 4: Round trip elevation, speed and energy cost (kWh) line graphs for the Scott Turner Road from the Morton Sawmill for every vehicle configuration

Figure 5: Round trip elevation, speed and energy cost (kWh) bar charts at 5mi intervals for the Scott Turner Road from the Morton Sawmill for every vehicle configuration

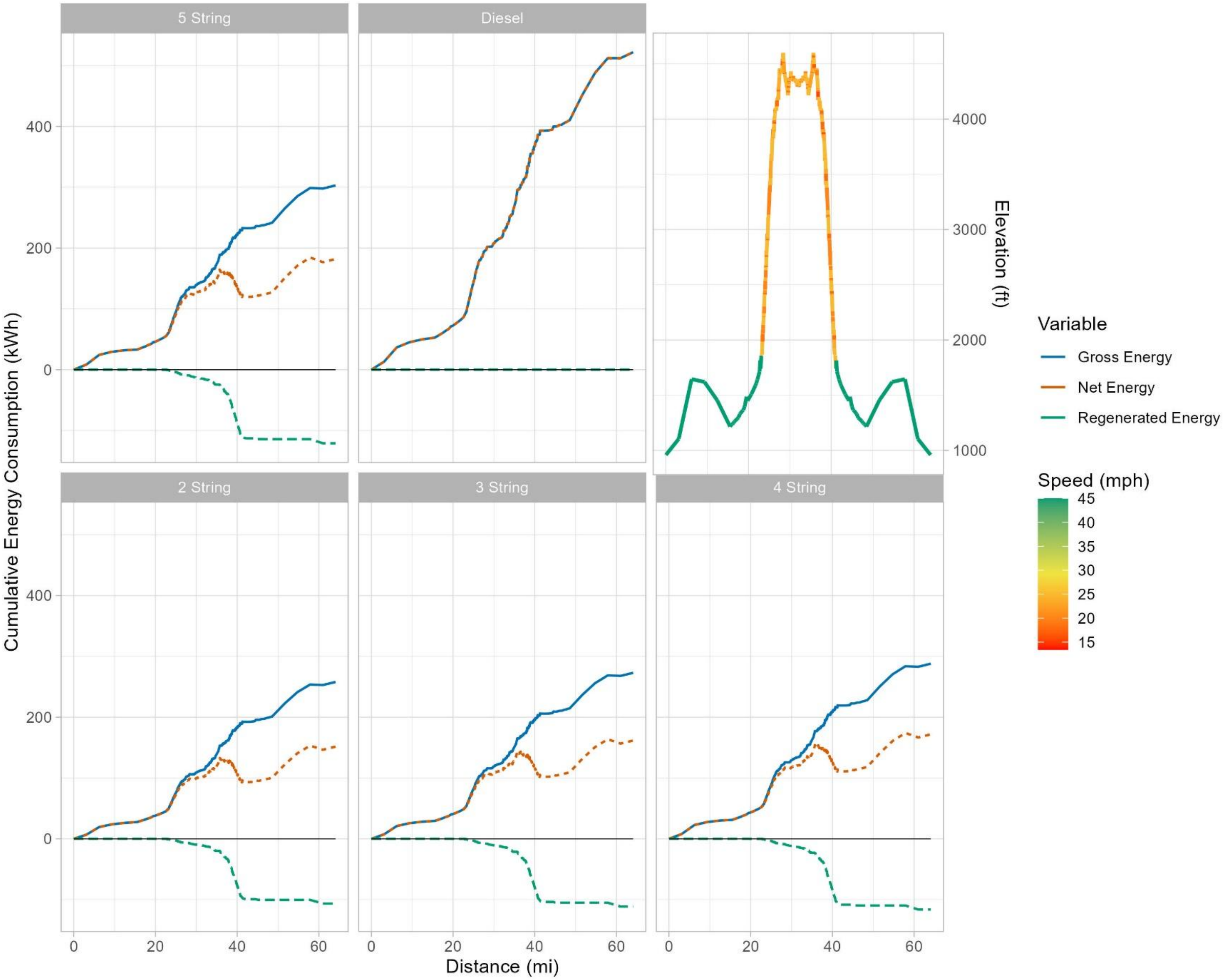

Figure 6: Round trip elevation, speed and energy cost (kWh) line graphs for the Ashford Road from the Morton Sawmill for every vehicle configuration

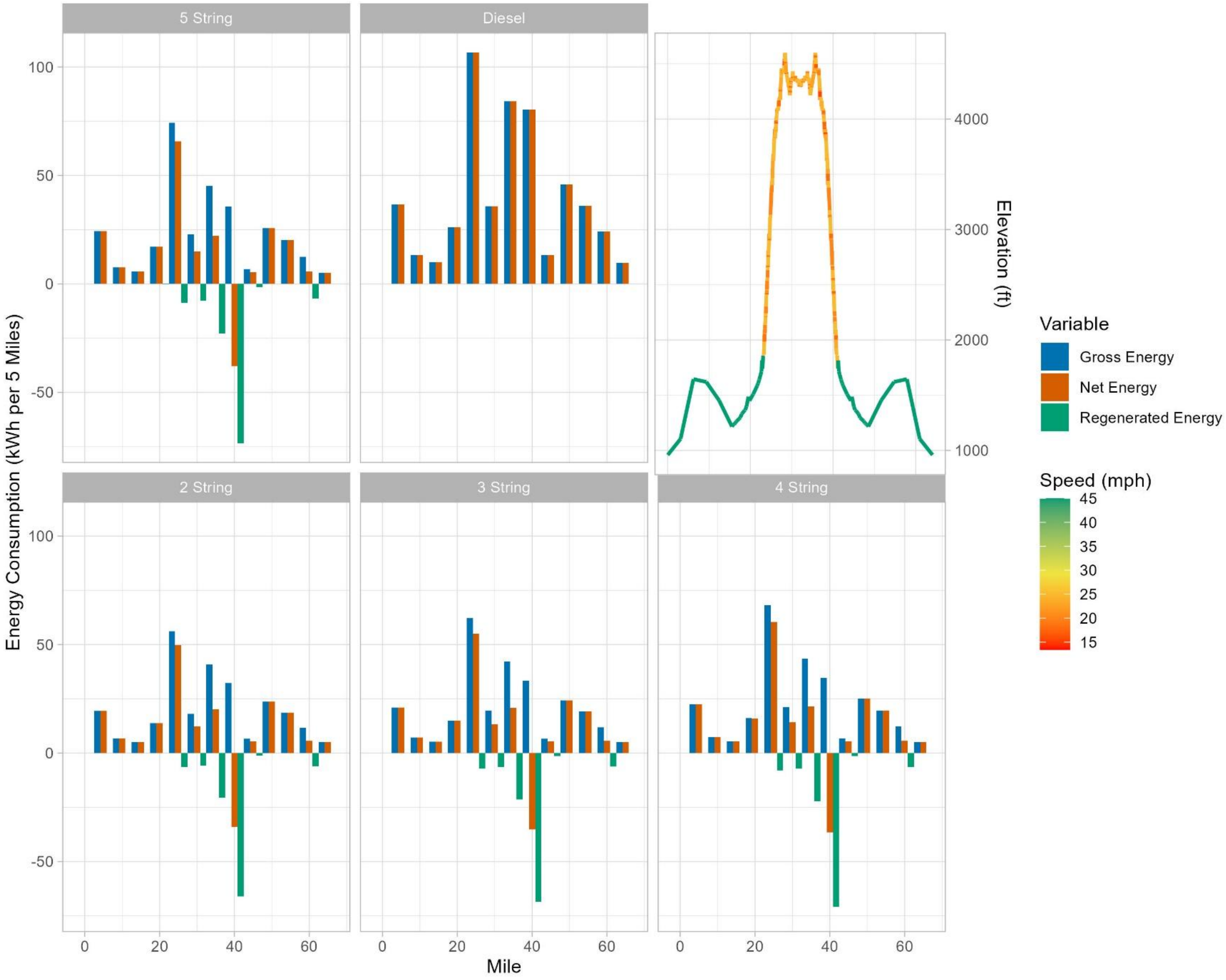

Figure 7: Round trip elevation, speed (kWh) and energy cost bar charts at 5mi intervals for the Ashford Road from the Morton Sawmill for every vehicle configuration

Figure 8 provides a comparative summary of round-trip fuel costs in USD across all vehicle configurations, mills, and roads. The electric vehicles are charging costs using the state average monthly industrial electricity rate for energy cost calculation. The diesel costs are based on the same monthly fuel prices paid by a logging contractor working for the NNRG.

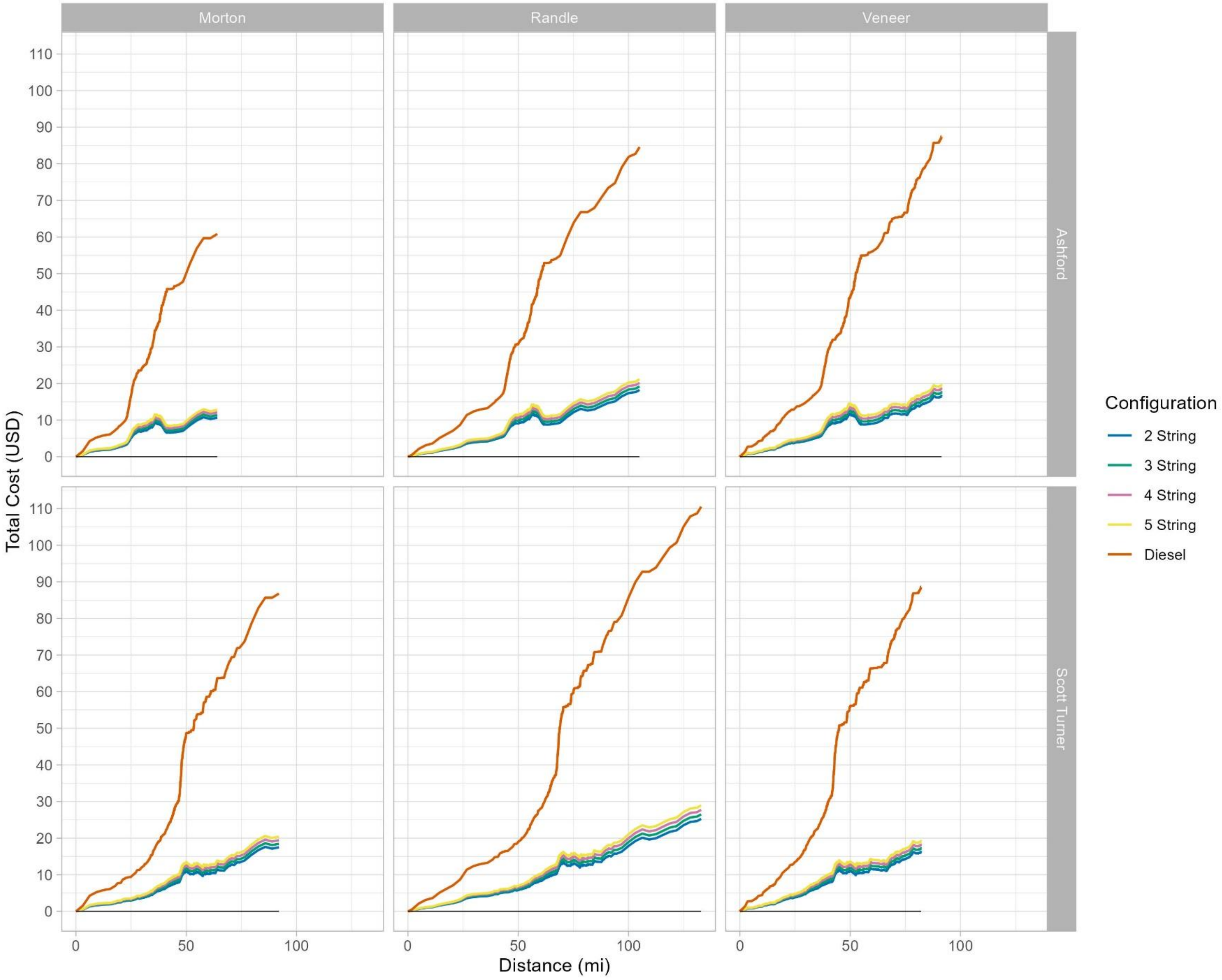

Figure 8: Round trip $ USD cost comparison amongst all vehicles, mills and roads.

Energy Use Mapping

The energy use mapping was performed using Mauka's patented Battery Electric Vehicle Energy Routing tool[28] (BEVER) which performed routing and mapping from every mill to each point on the forest landscape and back. Figure 9-11 shows the results of the round-trip energy cost calculation using the BEVER tool to every location in the forest for the four-string configured vehicle travelling to the Morton, Randle and Veneer Mills. Figures 12 – 14 shows this data using isotherm mapping to harvest landing points and uses a stratified colored scale. The energy requirements have a similar distribution for routes to the Hampton Morton and Hampton Randle mills because they originate from the same highway network; the minor difference is due to the difference in payload weights between the mills.

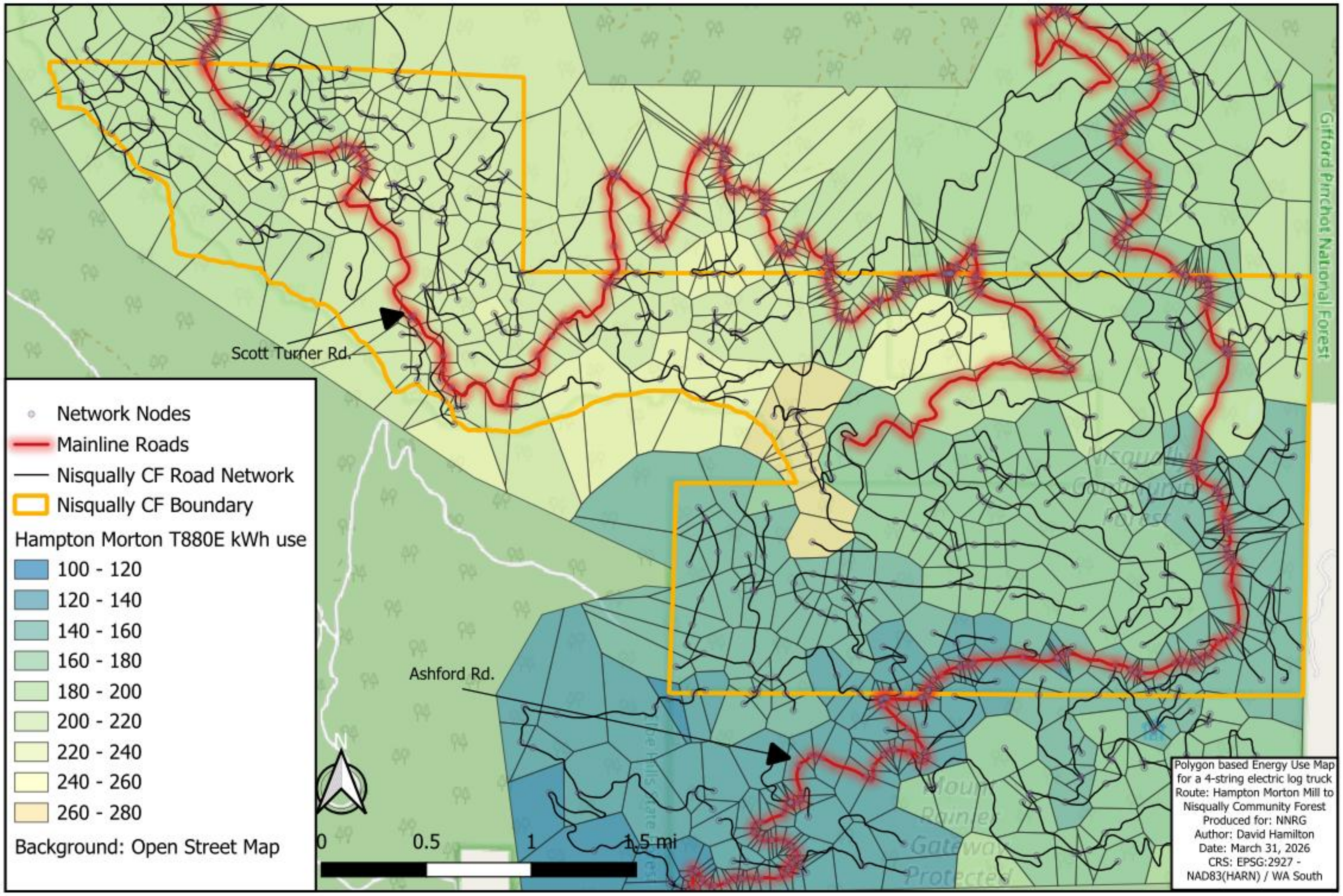

Figure 9: Round trip heat mapped delivery costs to Morton mill in the Nisqually Community Forest for the 4-string vehicle

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[28] Hamilton, Hybrid and electric vehicle energy routing tool.

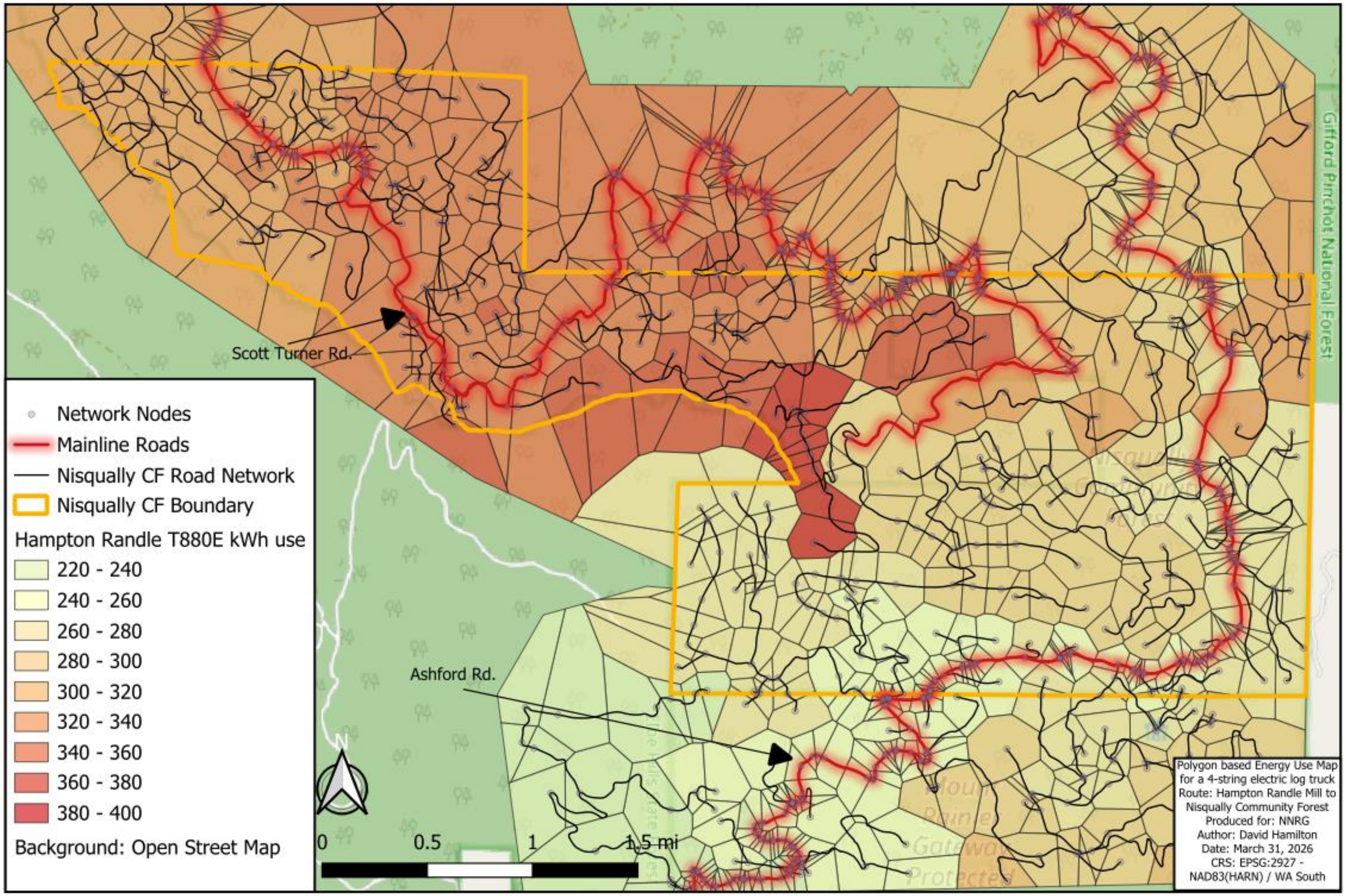

Figure 10: Round trip heat mapped delivery costs to Randle mill in the Nisqually Community Forest for the 4-string vehicle.

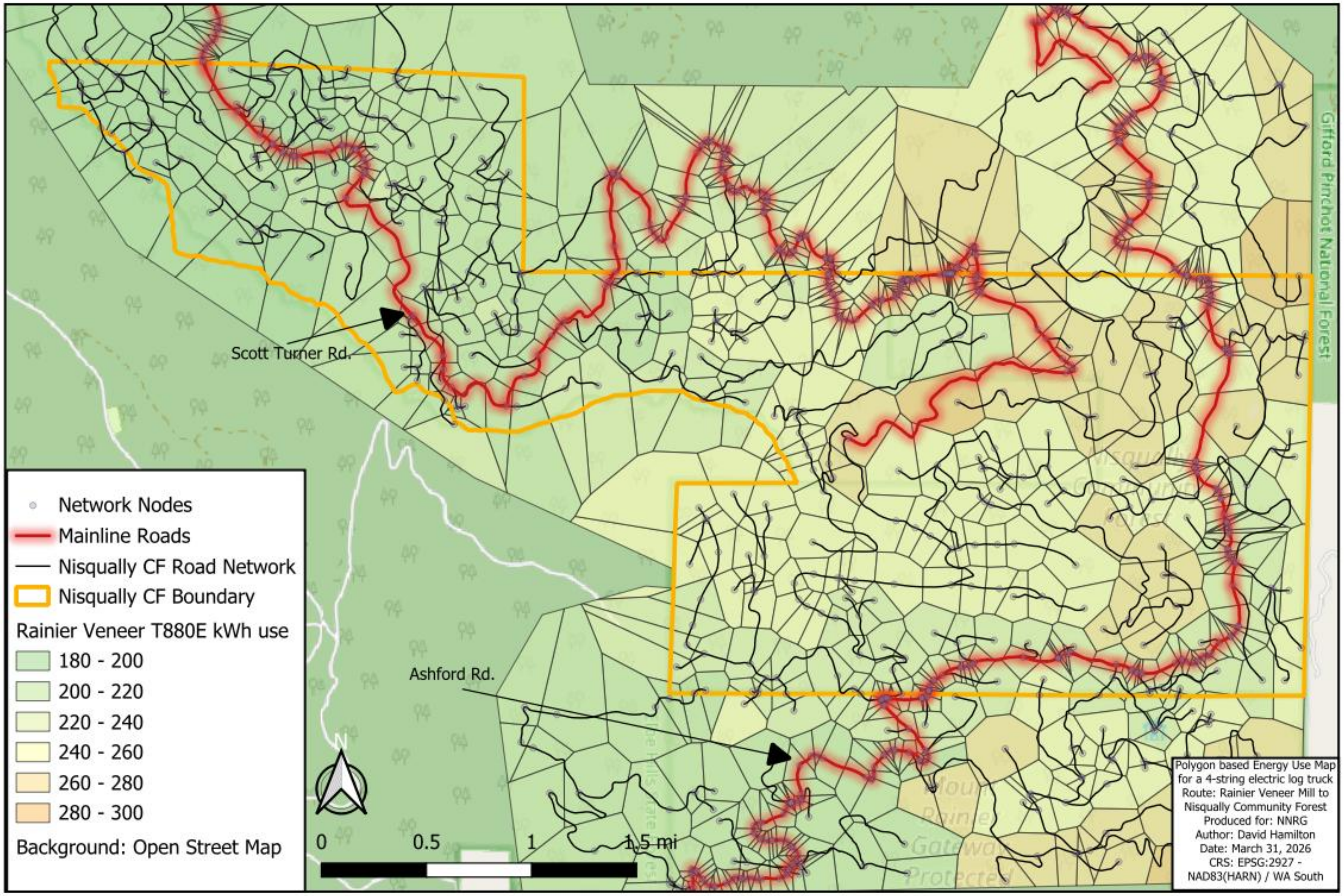

Figure 11: Round trip heat mapped delivery costs to Rainier Veneer mill in the Nisqually Community Forest for the 4-string vehicle

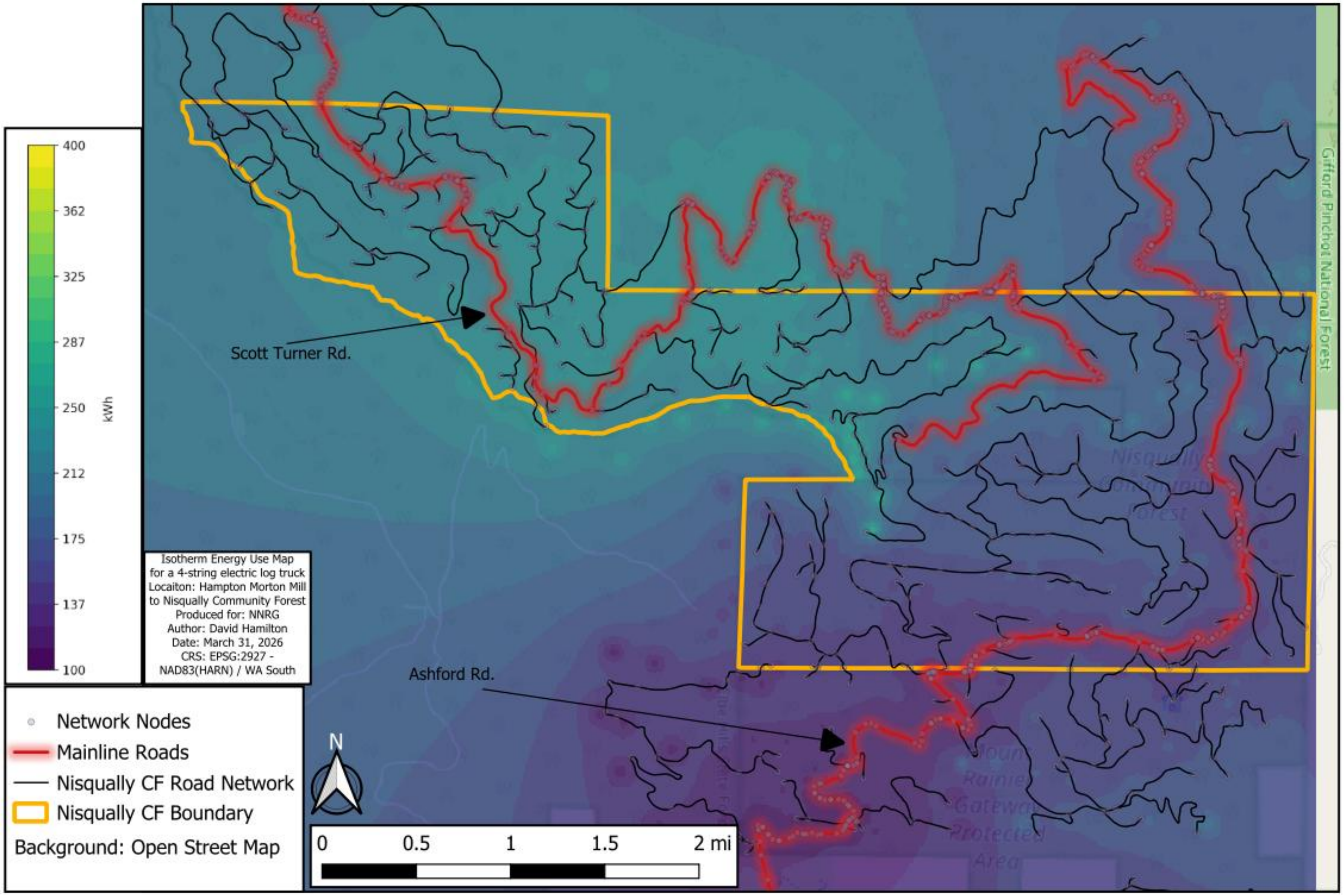

Figure 12: Round trip isotherm mapped delivery costs to Hampton Morton mill in the Nisqually Community Forest for the 4-string vehicle.

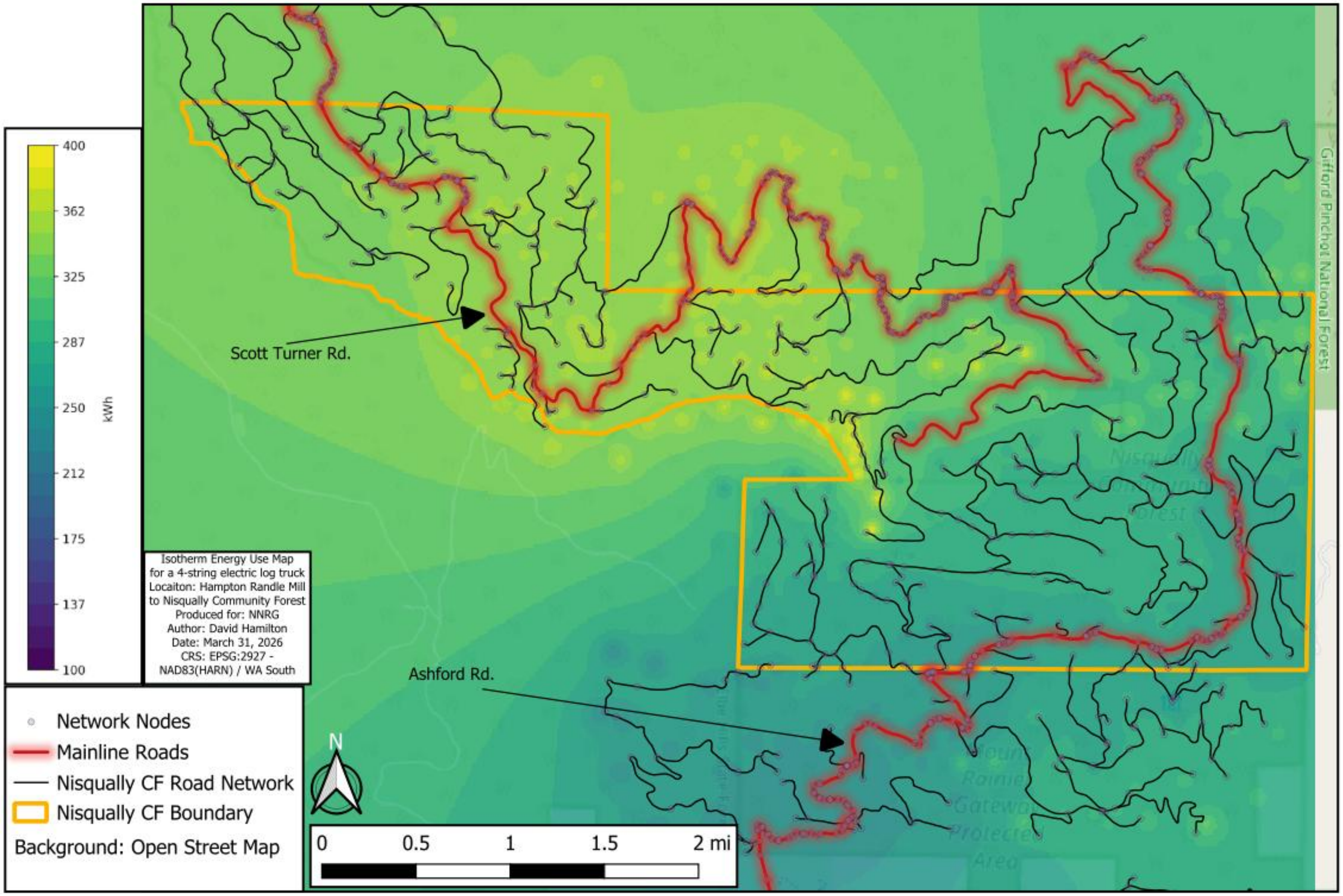

Figure 13: Round trip isotherm mapped delivery costs to Hampton Randle mill in the Nisqually Community Forest for the 4-string vehicle.

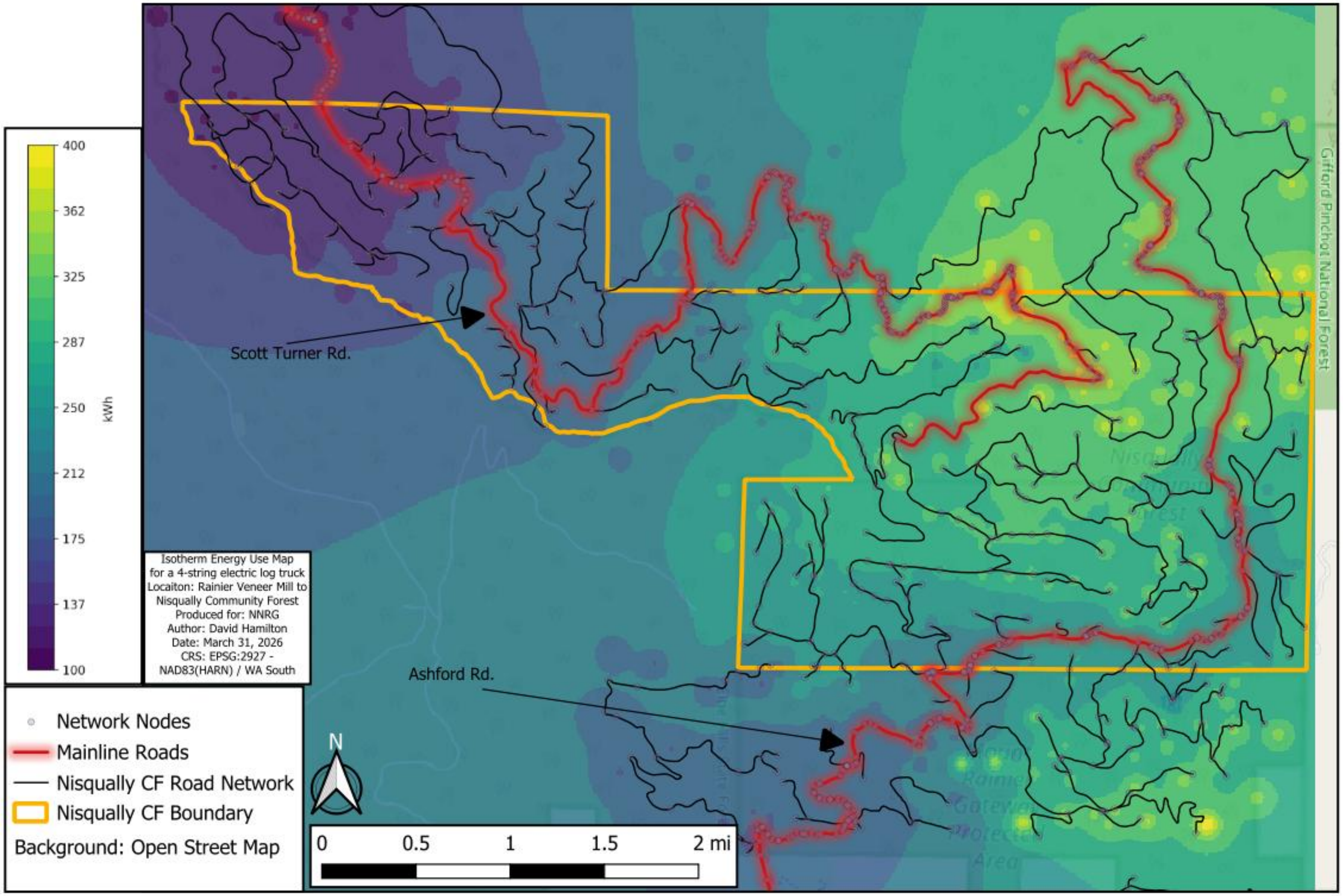

Figure 14: Round trip isotherm mapped delivery costs to Rainier Veneer mill in the Nisqually Community Forest for the 4-string vehicle.

Conclusions and Recommendations

The results show that a T880E can be employed to deliver logs from the Nisqually Community Forest, and that there are several models that can service their needs. Regenerative braking was an important factor that reduced the overall energy used for round trips to the main three mills purchasing NCF timber by an average of 34%, leading to an average range extension of 51% amongst all routes. In all electric vehicles there is a trade-off between battery capacity and weight; the more battery packs (strings) a vehicle has, the heavier it is. In ELTs, this effect is important because they are weight restricted. The optimal configuration is the one that can provide the necessary range with the least possible weight. In this analysis we found that both the 4-string and 5-string configuration would meet the needs for log delivery from NCF, but the 4-string can do so with less weight (Table 13).

Table 13: T880E Battery capacity relative to delivery costs using opportunistic charging

T880E Battery Pack String	**Battery Capacity** (kWh) + 75 kWh Charge	**Net Delivery Cost (kWh)**					
		Scott Turner Road			Ashford Rd		
		Hampton Morton	Hampton Randle	Rainier Veneer	Hampton Morton	Hampton Randle	Rainier Veneer
2 string	**325**	🟨 249	🟥 359	🟨 230	🟩 151	🟨 259	🟨 235
3 string	**450**	🟨 263	🟨 377	🟨 244	🟩 162	🟨 273	🟨 249
4 string	**575**	🟩 276	🟨 394	🟩 258	🟦 172	🟩 287	🟩 263
5 string	**700**	🟩 290	🟨 412	🟩 272	🟦 182	🟩 301	🟩 277
🟥 No Trips		🟨 1 Trip		🟩 2 Trips		🟦 3+ Trips	

The analysis did not consider the cost of installing charging stations. In the best-case scenario, NNRG would work with mill owners to develop charging infrastructure at the mills and receive industrial rates for electricity. The transportation cost of energy could also serve as a conservative estimate of cost when incorporating energy loss due to charging and if the mill charges a surcharge for energy. For example, energy loss could account for 10-20% of the difference and mill surcharges could account for 15-30% of the difference. Given the fluctuations and unknown variables in the energy rate structure, electricity cost could serve as a sensitivity variable for future analysis as it can change based on charging time, charger design, and geographic location.

When comparing the theoretical T880 EV to the diesel configuration, it is also worthwhile to consider the cost of fuel because of the differences in power train efficiency and diesel conversion ratios. Referring to Table 9, the overall average fuel cost (USD) of delivering logs using a T880E is estimated to be $19 per round trip amongst all mills and roads when using electricity at commercial rates; in contrast, the net average fuel cost to use the conventional diesel T880 is $71 per round trip. The average net savings when utilizing the industrial rate for energy is estimated to be $87 per round trip, which represents an average fuel cost savings rate of 78% within a range of 75%-81%. These savings are notable, as fuel is one of the largest components of the cost of owning and operating vehicles.

Recommendations for Future Work

The next natural evolution of this effort is the preparation of a scientific, peer-reviewed publication, which Mauka intends to complete within the next year. The results presented in this report are novel and highly relevant to the fields of heavy-duty electric vehicles and forestry operations. Dedicated funding would expedite publication, allow NNRG to retain ownership of the final work, and ensure that the results are made available as open access. Mauka will also promote these findings through conference presentations whenever possible; for conferences requiring travel beyond two hours from Corvallis, funding would be needed to cover preparation, registration, and travel expenses.

A comprehensive assessment of economic feasibility also requires evaluation of lifetime vehicle costs. The National Laboratory of the Rockies' Transportation Technology T3CO tool is well suited for this purpose[29]. The NLR has also developed methodologies for estimating engine speed and torque profiles using in-situ observations[30]. Applying these methods to a test vehicle would significantly improve model fidelity in forestry applications, as current efficiency assumptions are derived primarily from highway driving or modeled estimates. The NLR has indicated a willingness to support this work under a contracted collaboration if both of the previously mentioned tasks are approved and funded, which would improve the speed and veracity of the work.

Another important factor influencing vehicle performance is rolling resistance, which can be quantified using Mauka's Rolldown Tool.[31] These measurements could be evaluated under varying weather conditions and incorporated into a sensitivity analysis, particularly given the region's frequent precipitation. Rolling resistance values could be measured directly using an electric log truck by integrating into a vehicles electrical system with a combined GPS or estimated using a diesel test vehicle. Additionally, a combination of high accuracy GPS equipment, inertial measurement units, and accelerometers could be employed to study the lateral forces affecting a vehicle as it travels around curves typical to forest road networks.

Finally, Mauka could extend the application of its Forestry Electric Vehicle Energy Routing (FEVER) tool to analyze trips that do not begin and end at the same location. For example, log truck operators often collect a final load after mill closure, drive the vehicle to their residence, and begin the following day by delivering that load. Incorporating these first- and last-trip scenarios would provide a more complete representation of real-world operating conditions and improve estimates of daily energy requirements.

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[29] Lustbader et al., *T3CO (Transportation Technology Total Cost of Ownership) Open Source [SWR-21-54]*.

[30] Zhang et al., "Development of In-Use Engine Speed/Torque Heat Maps across Multiple Heavy-Duty Commercial Vehicle Vocations."

[31] Hamilton et al., "Identifying Rolling Resistance and Air Resistance Simultaneously for an Electric Truck."

Acknowledgments, Funding & Patent

Acknowledgments

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Patents

The BEVER tool, methodology, and subject matter of this paper are protected by United States Patent Number 20250334416 A1. This report serves as a demonstration of the results from implementing and adopting the BEVER Tool.

The FEVER tool, methodology, and subject matter are protected by United States Patent Number 20250020478 A1. The Rolldown tool, methodology, and subject matter are protected by United States Patent Application Number 19/195,576.

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Appendix A: Node and Edge Metadata

Table A1: Node Metadata

Location	Total	Within the NCF	Outside the NCF	Scott Turner Road	Ashford Road
Total number of Nodes	1264	887	377	513	471
Number of harvest Nodes	104	104	0	10	1
Number of terminal nodes (1 connection)	164	160	4	2	2
Number of nodes with 2 connections	914	554	360	473	426
Number of nodes with 3 connections	164	158	6	27	31
Number of nodes with 4 or more	22	15	7	11	12

Table A2: Edge Metadata

Location	Overall	Within the NCF	Outside the NCF	Scott Turner Road	Ashford Road
Total number of edges	1292	908	384	512	470
Total Length	329.95	178.36	151.59	139.36	131.85
Average Length	255.38	196.44	394.77	272.19	280.53
Median Length	102.83	76.28	170.72	75.39	67.32
Average Speed	11.11	8.14	18.11	13.95	14.99
Median Speed	10.3	7.77	20.12	11.18	11.18
Average Rolling Resistance	0.0168	0.018	0.014	0.016	0.0155

Table A3: Round trip routing distances

Mill	Round Trip Ashford (km)	Round Trip Scott Turner (km)
Hampton Morton	103.13	148.08
Hampton Randle	169	213.95
Rainier Veneer	147.1	132.17

Table A4: T880 Vehicle Tare Weight Data Sources and Values

Line #	Vehicle Variable / Component	Data Source Line	Weight (lbs.)	Weight (Kg)
1	Data Sourced from 2020 Data book[32]			
2	(0000810) Standard T880 (diesel)	. 0000810	14844	6733
3	Data Sourced from T680E - Build to order receipt[33]			
4	Meritor eAxle Electric Motor - 400 kW	909591	-1941	-880
5	Electric Vehicle Battery System: Meritor 397 kWh lbs. per kWh: 23.43073048	1900440	9302	4219
6	Meritor MFS14 Plus14.6K 3.5in.	2513031	39	18
7	Front Hub: Iron Hub Pilot 14,600 lbs.	2702500	48	22
8	Single Power Steering Gear: 16K TRW TAS85	2893881	18	8
9	Meritor Tandem eAxle 40k Dual Standard Track	3126130	-1100	-499
10	Frame Rails: 11-5/8 x 3-7/8 x 3/8 in. Steel to	6057600	322	146
11	Full Steel Insert: for 11-5/8 in. Steel Rail to	6144615	944	428
12	Brackets: Iron Front Spring Drive. Included with	6390312	47	21
13	Battery System Interpolation			
14	2 String Battery (250) kWh -> (250kWh*23.4307)	Interpolated from legacy 397 kWh battery pack using kWh-to-lbs. ratio (line 5)	5858	2657
15	3 String Battery (375) kWh -> (375kWh*23.4307)	Interpolated from legacy 397 kWh battery pack using kWh-to-lbs. ratio (line 5)	8787	3985
16	4 String Battery (500) kWh -> (500kWh*23.4307)	Interpolated from legacy 397 kWh battery pack using kWh-to-lbs. ratio (line 5)	11715	5314
17	5 String Battery (625) kWh -> (625kWh*23.4307)	Interpolated from legacy 397 kWh battery pack using kWh-to-lbs. ratio (line 5)	14644	6642
18	Projected 'Stock' T880E Weights			
19	2 String Battery (250) kWh	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 14	19079	8654
20	3 String Battery (375) kWh	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 15	22008	9982
21	4 String Battery (500) kWh	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 16	24936	11311
22	5 String Battery (500) kWh	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 17	27865	12639

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[32] Kenworth, “T880: STANDARD SPECIFICATIONS.”

[33] Kenworth of Jacksonville, “Kenworth T680 Build Order Vehicle Summary.”

Table A5: T880 Vehicle configured for 2025 Whit-Log Trailers with Logging Truck Equipment

Line #	Vehicle Variable / Component	Data Source	Weight (lbs.)	Weight (Kg)
23	2025 Whit-Log Trailers with Truck Equipment	2025 Whit-Log Trailers with Truck Equipment (Includes bunk, headache rack AND tandem trailer)[34]	7600	3447
24	LOGGER 2 String Battery (250)	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 14, 23	26679	**12101**
25	LOGGER 3 String Battery (375)	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 15, 23	29608	**13430**
26	LOGGER 4 String Battery (500)	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 16, 23	32536	**14758**
27	LOGGER 5 String Battery (625)	Sum of lines 2, 4, 6, 7, 8, 9, 10, 11, 12, 17, 23	35465	**16087**
28	Fluids – primary fuel tank	Diesel (150 gal @ 7.1 lb./gal): 1,065 lbs.	1,065	483
29	Fluids - Diesel Exhaust Fluid (DEF) tank	DEF (31 gal @ 9.2 lb./gal): 285 lbs.	285	129
30	Other fluids	(engine, coolant, transmission, diffs, misc.)	300	136
32	TOTAL ADD-ON (full fluids)	Sum of lines 28, 29, 30	1650	748
33	LOGGER 880 DIESEL, Full fluid load	Sum of lines 2, 7, 10, 11, 12, 23, 32	25455	**11546**

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[34] Idaho Truck Sales, "Whit-Log Trailers Spec Sheet."

Appendix B: Diesel energy cost results and MPG validation

Table B1: Round Trip Energy Cost and Recovery results (kWh) for the Scott Turner Road for the T880 diesel vehicle configuration.

	Hampton Morton			Hampton Randle			Rainier Veneer		
Road	Gross	Regen	**Net**	Gross	Regen	**Net**	Gross	Regen	**Net**
Scott Turner Road	745	0	**745**	948	0	**948**	761	0	**761**
Ashford Road	522	0	**522**	726	0	**726**	751	0	**751**

Understanding the fuel costs for diesel is more helpful at miles per gallon (mpg) rate and between vehicles is best done by comparing the USD fuel costs. The conversion rate for diesel is set at 37.66 kWh per gallon of diesel, which is the low energy heating value of diesel fuel, as determined by the U.S Department of Energy[35]. The round trip to Randle along the Ashford Road is 64 miles (103 km) with a total estimated energy for that diesel trip is 430 kWh. Using the conversion rate that would require 430 kWh /39.66 kWh per gallon of diesel = 10.84 gallons of diesel. The fuel consumption rate can then be calculated as 64 miles / 10.84 gallon = 5.9 mpg, this is similar to the national Class 8 average of 5.7 mpg and reflects the favorable hauling conditions found in forest operations.

Appendix C: Links to Complete Set of Results & References

1. Routing data, road profiles and graphs we have produced
2. Energy Cost Mapping GIS Files
3. References – NCF T880 Analysis

Appendix D: Complete set of Graphs

The remaining figures summarizing gross energy demand, regenerative energy recovery, and net energy consumption as functions of distance, elevation, and vehicle speed are presented below. These figures summarize the round-trip routes that originate at the Hampton Randle and Rainier Veneer mills.

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[35] U.S. Department of Energy, “DOE Diesel Fuel Properties Dataset.”

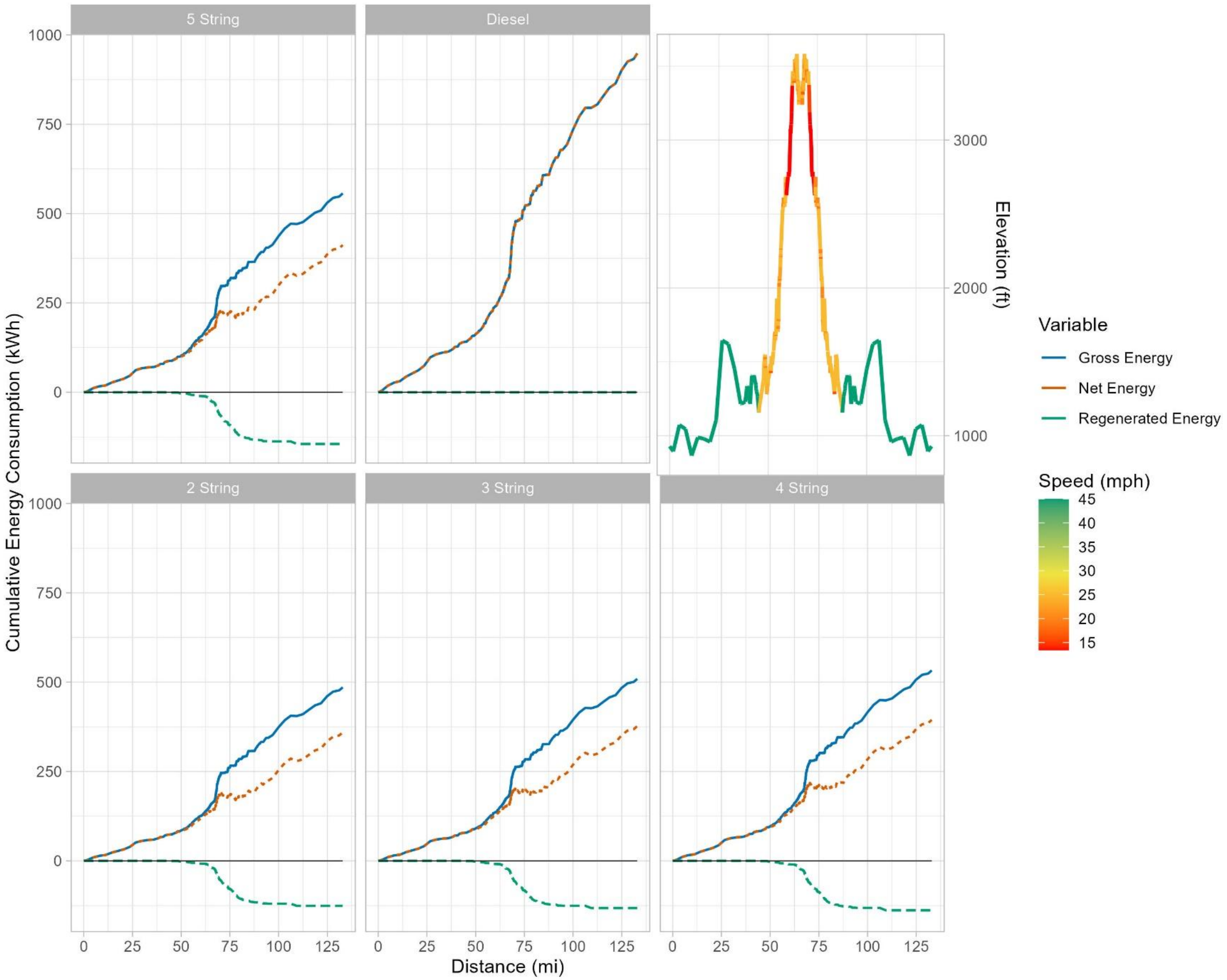

Figure D1: Round trip elevation, speed and energy cost (kWh) line graphs for the Scott Turner Road from the Randle Sawmill for every vehicle configuration

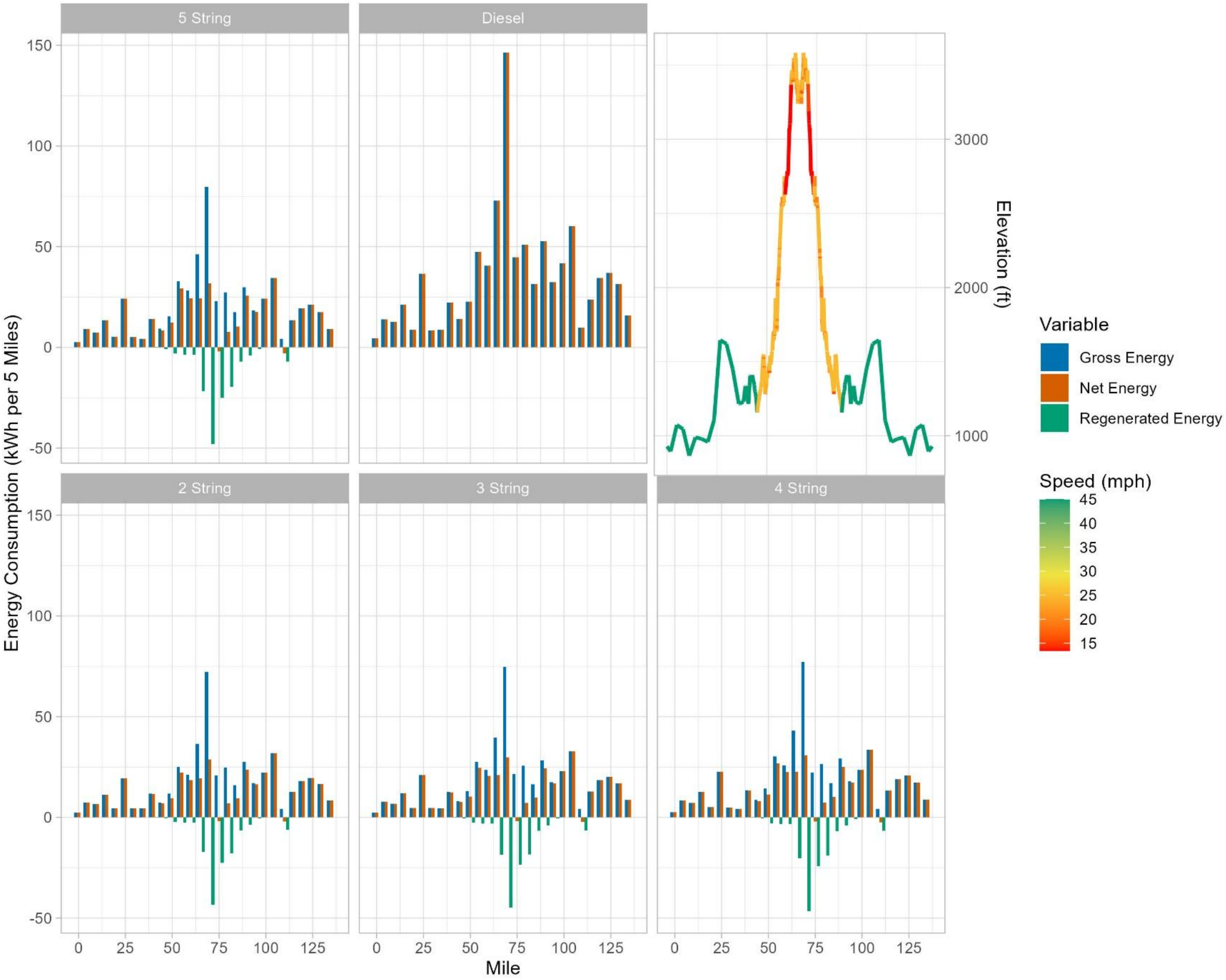

Figure D2: Round trip elevation, speed and energy cost (kWh) bar charts at 5mi intervals for the Scott Turner Road from the Randle Sawmill for every vehicle configuration

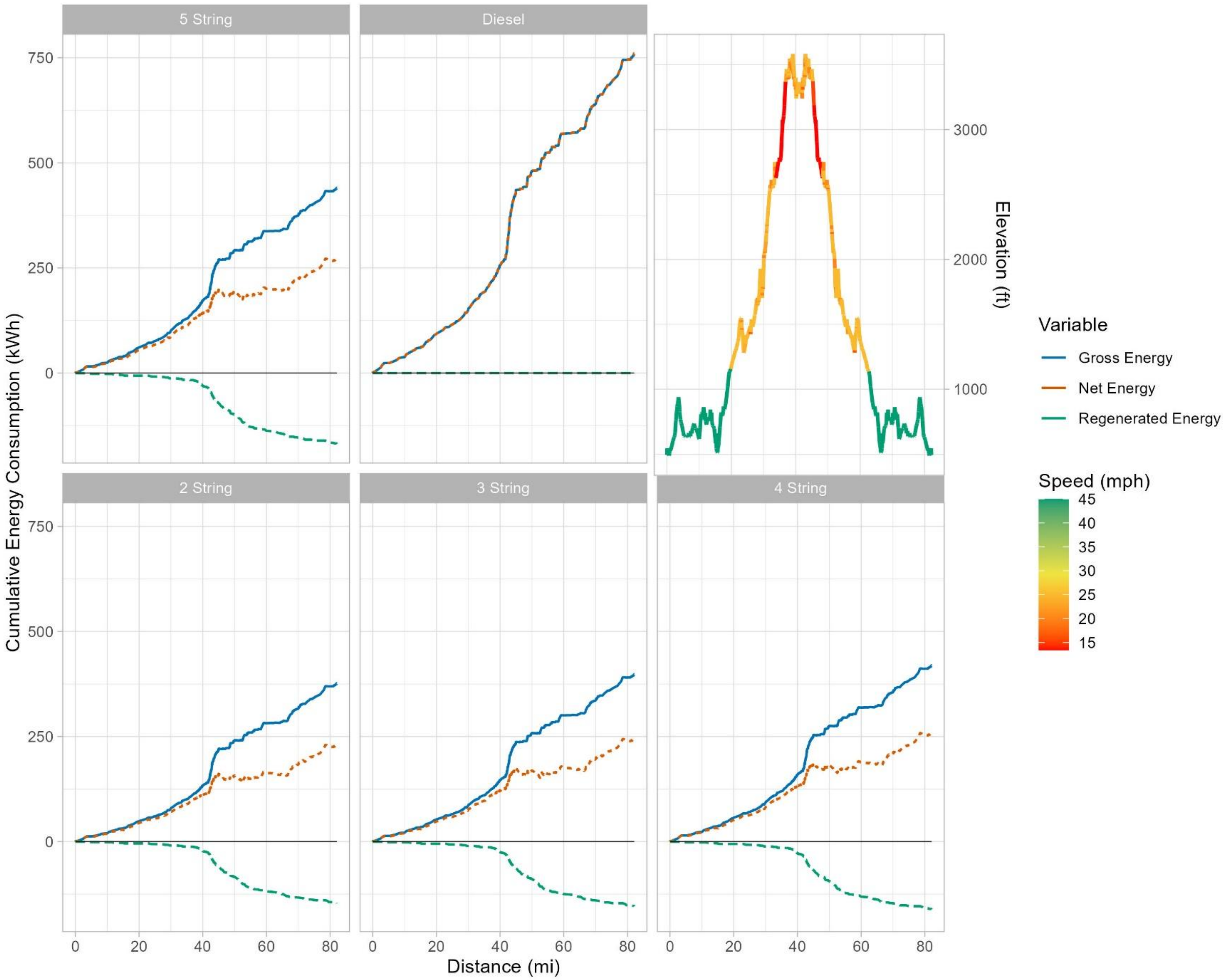

Figure D3: Round trip elevation, speed and energy cost (kWh) line graphs for the Scott Turner Road from the Veneer mill for every vehicle configuration

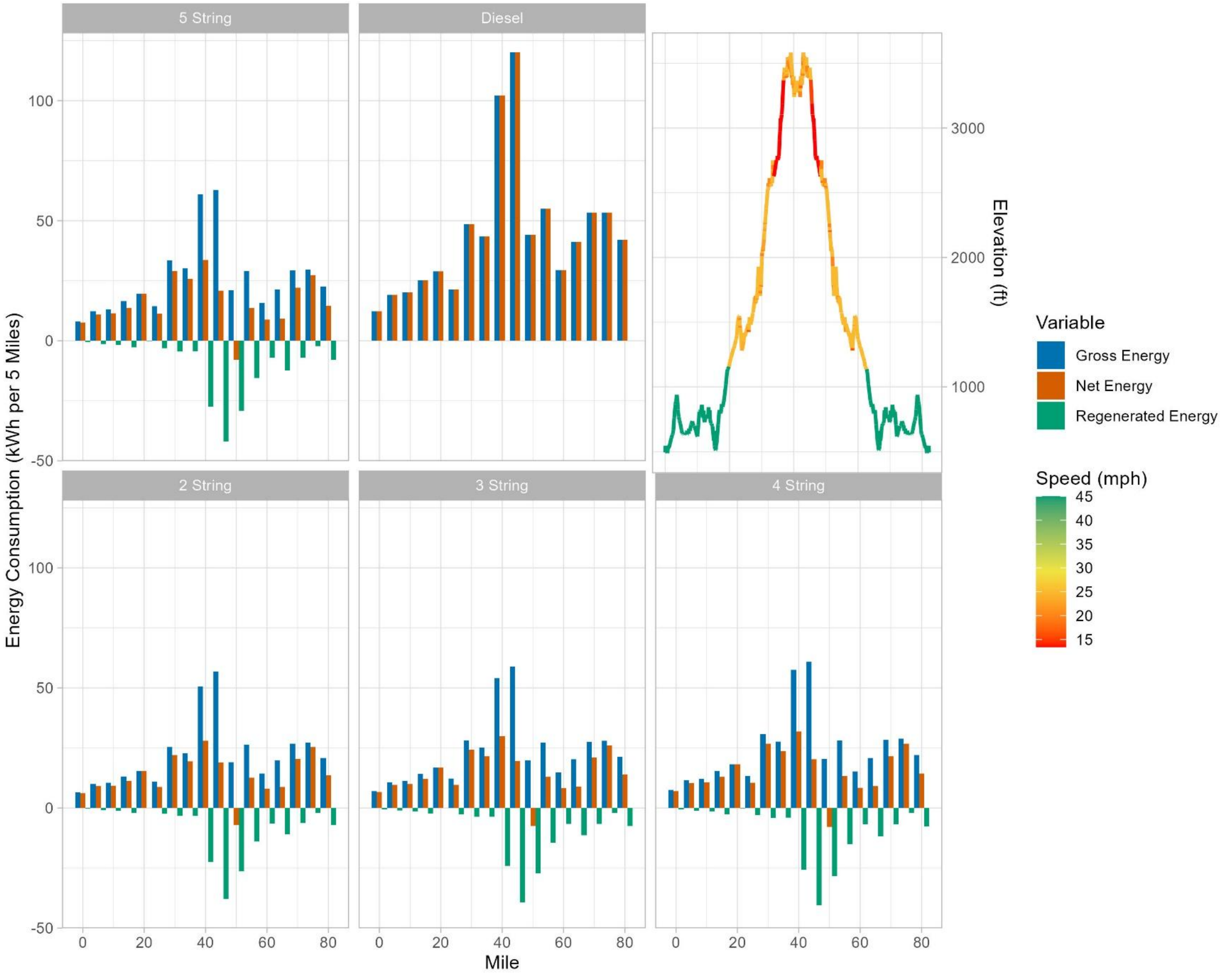

Figure D4: Round trip elevation, speed and energy cost (kWh) bar charts at 5mi intervals for the Scott Turner Road from the Veneer mill for every vehicle configuration

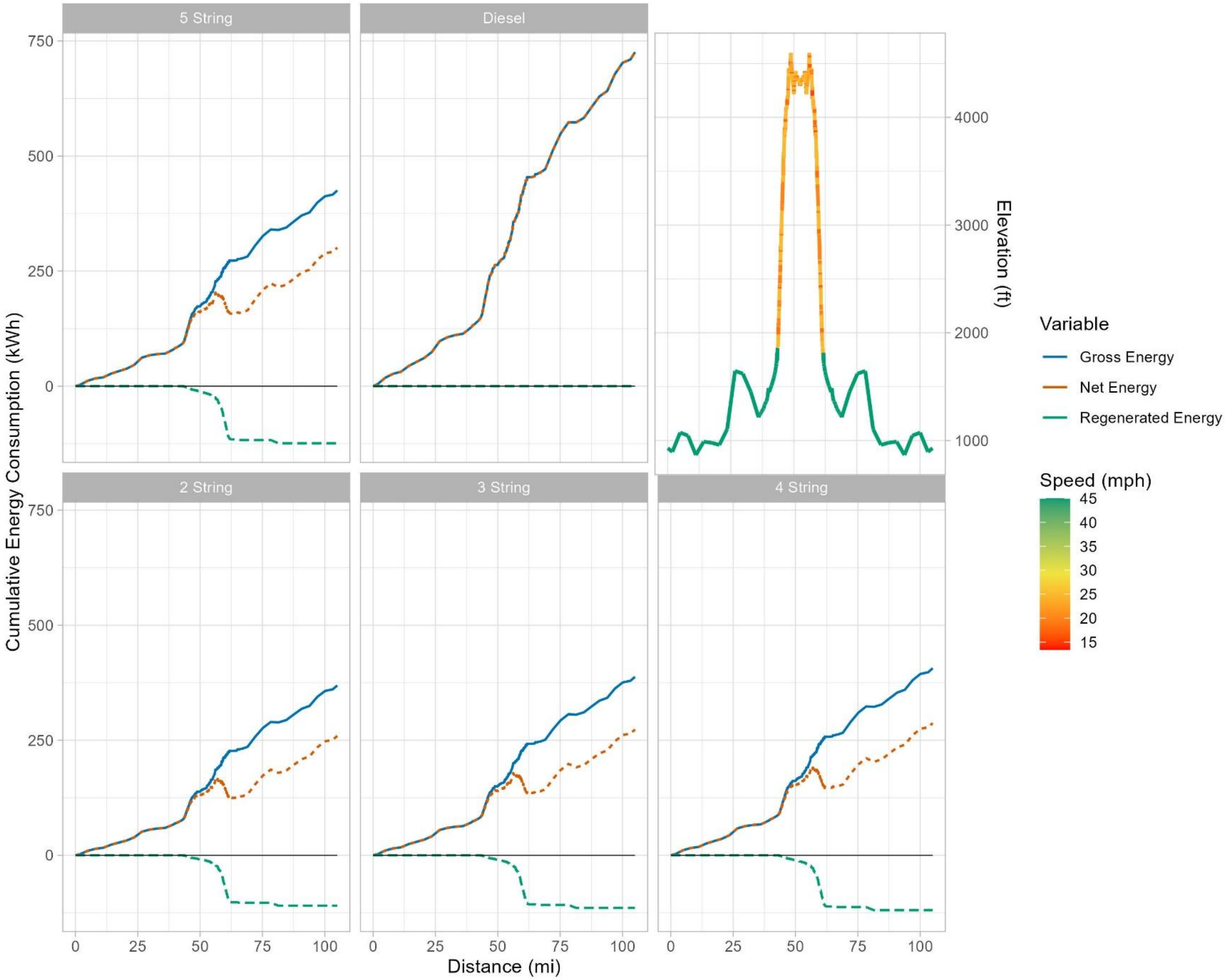

Figure D5: Round trip elevation, speed and energy cost (kWh) line graphs for the Ashford Road from the Randle Sawmill for every vehicle configuration

Figure D6: Round trip elevation, speed and energy cost (kWh) bar charts at 5mi intervals for the Ashford Road from the Randle Sawmill for every vehicle configuration

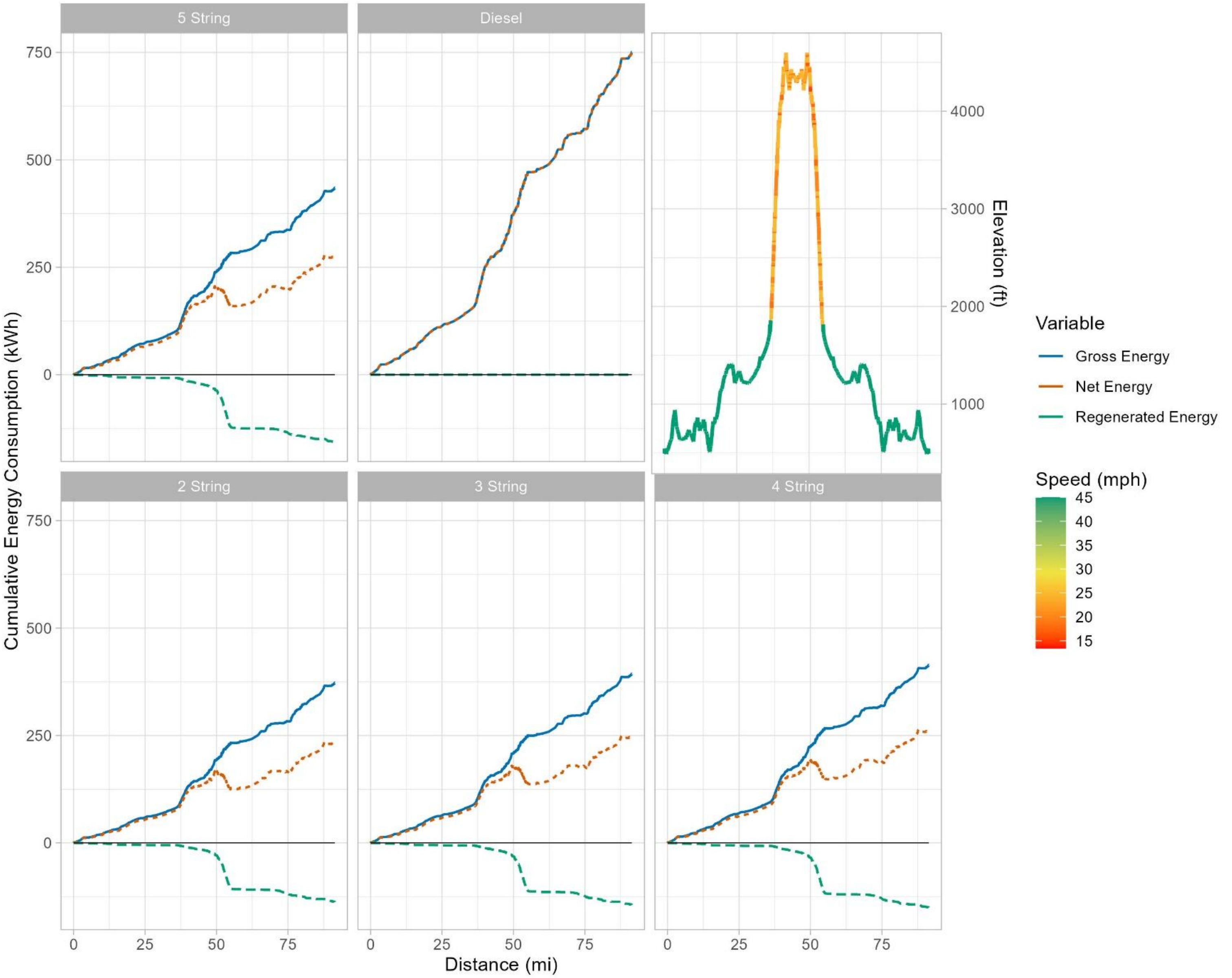

Figure D7: Round trip elevation, speed and energy cost (kWh) line graphs for the Ashford Road from the Rainier Veneer mill for every vehicle configuration

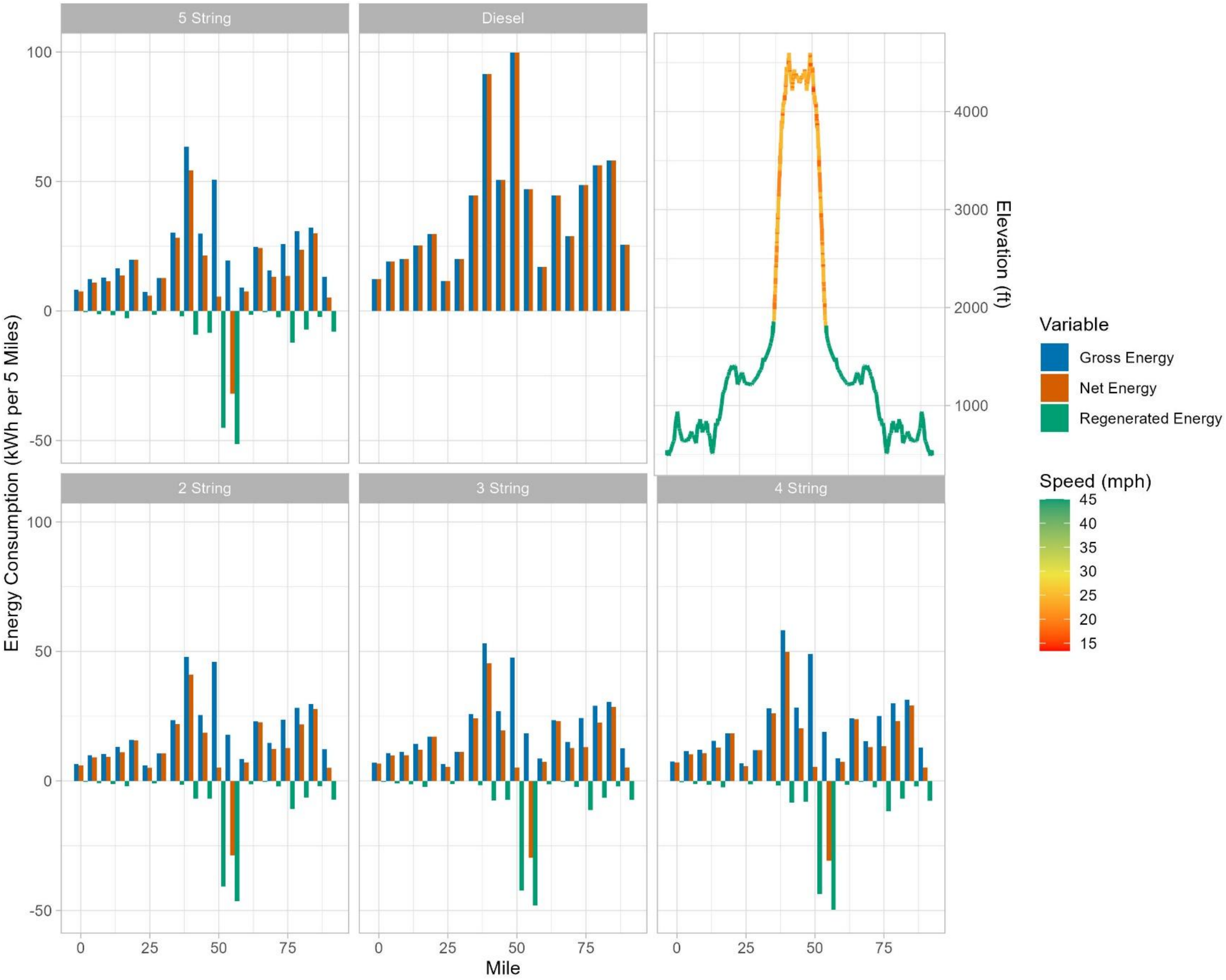

Figure D8: Round trip elevation, speed and energy cost (kWh) bar charts at 5mi intervals for the Ashford Road from the Veneer mill for every vehicle configuration