SCALED-UP PROJECT CONCEPT IN KATHMANDU

JUNE 2024

This project has received funding from the European Union Horizon 2020 research and innovation Programme under grant agreement no. 875041

PROJECT PARTNERS

ABOUT

This paper has been prepared for the project SOLUTIONSplus. The project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement no. 875041

TITLE

Solutionsplus Scale-Up Concept Note: Kathmandu

FINANCIAL PARTNERS

Solutionsplus

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LAYOUT

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PICTURES

All the pictures are provided by the SOL+ partners

June, 2024

JUNE 2024

PURPOSE	The scaled-up projects concept for Kathmandu support activities, such as monitoring the prototypes' operation to verify their technical and financial viability, informing commercial banks about potential targeted loan schemes, and undertaking awareness campaigns targeting potential investors and operators
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LIST OF ABBREVIATIONS

CAGR	Compound annual growth rate
CER	Cost effectiveness ratio
DoTM	Department of Transport Management
EA	Evolutionary algorithm (in the context of metaheuristics)
eMOB	e-mobility calculator (of UNEP)
EV	Electric vehicle
FMC	Future Mobility Calculator
GHG	Greenhouse gas
GWO	Grey wolf optimiser (in the context of metaheuristics)
IBRD	International Bank for Reconstruction and Development
IRR	Internal rate of return
ITS	Information Technology Services
KPI	Key performance indicator
NOx	Nitrogen oxides
PM	Particulate matter
PT	Public transport
SA	Simulated annealing (in the context of metaheuristics)
SDG	Sustainable development goal (in the context of the UN)
UNEP	United Nations Environment Programme
WtW	Well-to-wheel (in relation to emissions)

1 BACKGROUND

With growing urbanisation and income, the demand for private vehicles in Kathmandu increases fast also straining the available public transport services in the city. Adverse effects are observed in several directions, including congestion, air pollution, GHG emissions, and service quality attributes such as frequency of service, safety, and comfort.

The Kathmandu demonstration action of the project aims to contribute in creating an ecosystem of electric mobility in the valley to enhance public transport. It includes the following components:

- **Converted bus.** An old diesel mini-bus is converted to an e-bus, mainly through replacing the drive system (motor, transmission, and rear axle) with imported components, while assembly will take place locally
- **Remodelled Safa Tempo for passengers.** Safa tempos are electric 3Ws built in late 1990s for passenger transport. Remodelling will include the replacement of the old lead acid battery set with a 23 kWh Li-ion battery, and the upgrading of the passenger cabin to make riding more comfortable.
- **Remodelled Safa Tempo for cargo.** A remodelled Safa tempo demonstrates the possibility of expanding the vehicle's utility to freight transport while replacing a conventional ICE pick-up truck.
- **New e3W design for passengers.** The passenger version of a mini-Safa Tempo aims to provide services to the secondary and tertiary routes of the city as a last mile connectivity.
- **New e3W design for cargo.** The cargo version of a mini-Safa Tempo aims to provide services for businesses at inner city.
- **Converted e4W design for waste collection.** The waste collection version of the e3w proved financially infeasible and was replaced by a converted 4W pick-up truck especially adjusted for the intended operation for the municipal waste collection.
- **Converted pick-up truck.** Aims to replace the widely used ICE pick-up truck with an electric vehicle.
- **New e-shuttle van design.** A closed-type van for 6 passengers suitable for transporting tourists to the Bhaktapur historical sites.

Based on the assessment of the above-mentioned vehicles, a scaled-up concept is developed in terms of monitoring the prototypes' operation to verify their technical and financial viability and inform commercial banks about potential targeted loan schemes, and undertaking awareness campaigns targeting potential investors and operators. The scaled-up project assessment is also a part of impact assessment (under SOLUTIONSplus deliverable D1.6).

2 SCALED-UP PROJECT ASSESSMENT

2.1. BASELINE SCENARIO

The baseline scenario describes the situation in the project area as it would have developed in the absence of the investigated project and is used as the basis against which the impacts of the studied intervention are assessed. More specifically, the performance of the scaled-up project in relation to CO2, NOx and PM2.5 emissions is assessed against the cumulative volume of the respective emissions in the Kathmandu valley over the period 2024-2030. This section aims at estimating these emission volumes.

Initially, the eMOB calculator was selected for this purpose. However, due to its current beta state and consequent limited functionality, it cannot be used as planned. Instead, the Future Mobility Calculator (FMC) has been chosen for its established reliability and comprehensive features. FMC, an Excel-based tool developed by the World Resources Institute and Siemens in collaboration with the Coalition for Urban Transitions,[1] is primarily designed to aid cities in planning for the electrification of urban transportation systems. It concentrates on the adoption of EVs and the necessary infrastructure for urban mobility. The tool projects scenarios for EV adoption in 2030 and 2050, while primarily detailing the potential emissions (CO2, NOx, PM2.5) over the entire time horizon, alongside outlining the required infrastructure and its associated costs.

As seen in Figure 1, FMC is structured into three primary modules: data input (including initial data input – used for default values, city mobility and charging), calculations (covering mobility, charging and emissions), and results. The tool's interface is transparent, allowing users to integrate their own data for customisation.

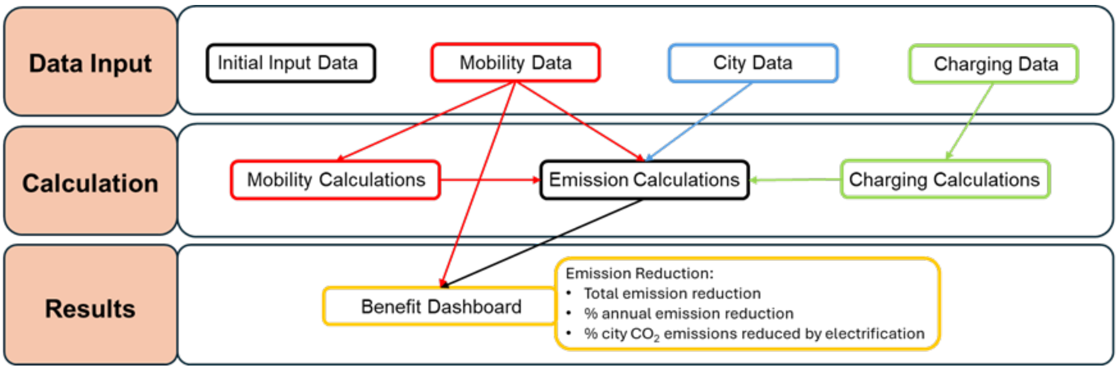


Figure 1 FMC components and functionality

Vehicle stock and emission factors

Among the administrative districts for which vehicle registration data is published, the Bagmati Province is the closest one to the Kathmandu valley. The vehicle types that are relevant for this analysis are minibuses (the appropriate term for the converted bus), microbuses (corresponding to the shuttle van), 3-wheelers (for the demo vehicles of 3W), and pick-up trucks (for the remaining demo vehicles). The total number of vehicles for 2022, as shown in Table 1, reflect the official statistics for the selected vehicle types. The 174 electric microbuses is an estimate of DoTM for the entire country (assuming that all of them are registered in the Bagmati Province). In relation to 3Ws, local press[2] stimates about 1,000 non-diesel vehicles, out of which about 700 are Safa Tempos.

1 https://urbantransitions.global/en/publication/future-mobility-calculator-an-electric-mobility-infrastructure-tool/

2 https://kathmandupost.com/valley/2020/08/01/tempo-drivers-are-driven-to-despair-as-not-many-are-using-these-three-wheelers-over-covid-19-fears

Table 1. Relevant vehicle stock

Vehicle types		Vehicle stock (Bagmati Province)			Annual mileage (km/year)				Lifespan (years)	Fuel efficiency (km/lt)	Emission factors (gr/km)		
		2022	2030	2050	Km/trip	Trips/day	Days/year	Mileage (km/year)			CO2 (WtW)	NOx	PM2.5
Mini buses	Diesel	9.284	11.618	18.545	32	4	326	41.728	20	4,5	678,04	9,02	2,34
	Electric	0	179	2.927	32	4	326	41.728	20		0,00	0,00	0,00
	Total	9.284	11.797	21.472									
Micro buses	Diesel	5.262	4.588	3.376	10	10	320	32.000	20	6,2	471,46	2,21	0,76
	Electric	174	1.037	2.752	10	10	320	32.000	20		0,00	0,00	0,00
	Total	5.436	5.625	6.127									
3-wheelers	Diesel	4.195	4.063	3.750	13	9	330	38.610	20	12,5	156,22	1,47	1,20
	Gas	300	0	0	13	9	330	38.610	20	20,2	81,78	0,04	0,13
	Electric	700	0	0	13	9	330	38.610	30		0,00	0,00	0,00
	Total	5.195	4.063	3.750									
Pick-up trucks	Diesel	39.429	57.635	60.936	20	3,5	330	23.100	20	12,0	250,00	1,15	1,58
	Electric	0	620	10.145	20	3,5	330	23.100	20		0,00	0,00	0,00
	Total	39.429	58.255	71.082									

The total number of minibuses for 2030 and 2050 is calculated based on the 2022 fleet and the compound annual growth rate (CAGR) estimated using the available official statistics for the period 2018-2022 (3.04%). Against the very ambitious SDG targets for the shares of EVs in PT (50% by 2030), it was assumed that 179 minibuses will be electric by 2030 (30 initial vehicles growing at 25% annually), the number reaching 2,927 by 2050 (at a CAGR of 15%).

A CARG of 0.43%, estimated over the 2018-2022 period, is applied to the 2022 microbus fleet to reach the 2030/2050 projections. The electric microbuses are assumed to grow by 25% per year until 2030 and 5% thereafter.

According to the 2018-2022 statistics, the 3-wheeler fleet (no distinction between passenger and cargo use) is shrinking by 0,40% per year. This trend is kept unchanged for the 2030/2050 projections. As per Bagmati Province's periodic Plan for 2019-2023, the gas 3Ws will be banned by 2028. Safa Tempos will also be retired once their 30-year license expires by 2030.

The 2018-2022 data indicate a CARG of 6.96%. A more moderate 5% growth rate has been assumed for the period until 2030, followed by an 1% rate for the 2030-2050 period. Similarly to the minibuses, 620 pick-up trucks are expected to be electric by 2030 (130 initial vehicles growing at 25% annually), the number reaching 10,145 by 2050 (at a CAGR of 15%).

The lifespan of all vehicles is assumed to be 20 years, apart from Safa Tempos, for which a special license extension to 30 years has been officially issued. The mileage, fuel efficiency and emission factors of Table 1 are in line with the figures used for the respective financial assessments carried out in detail impact assessment (under SOLUTIONSplus deliverable D1.6).

Based on these inputs, the baseline scenario CO2 (WtW), NOx and PM2.5 emissions, as computed by FMC, are depicted in Figure 2 below. The savings in emissions escalate over time with the expansion of the electric fleet, highlighting its positive impact. However, a steady increase in emissions, even until 2050, is observed due to the continuous growth in the number of ICE vehicles. Although the growth rate of ICE vehicles declines over time as they are gradually replaced by EVs, there is still an increase in their numbers. This means that the growth rates for EVs assumed in the input data need to be revised if emissions are to be stabilised and reduced well before 2050. A 25% annual growth rate for EVs has been assumed for the period until 2030. Considering the realities in the country, a higher rate for these early years appears excessively optimistic. On the contrary, the

CARG used for the 2030-2050 period should be revised upwards. Given, however, that the assessment period of the present analysis ends with 2030, any adjustments in the EV sales afterwards will have no effect on the analysis results. The cumulative emissions of the baseline scenario for the period 2024-2030 that enters the assessment of the scaled-up scenario appear in Table 7.

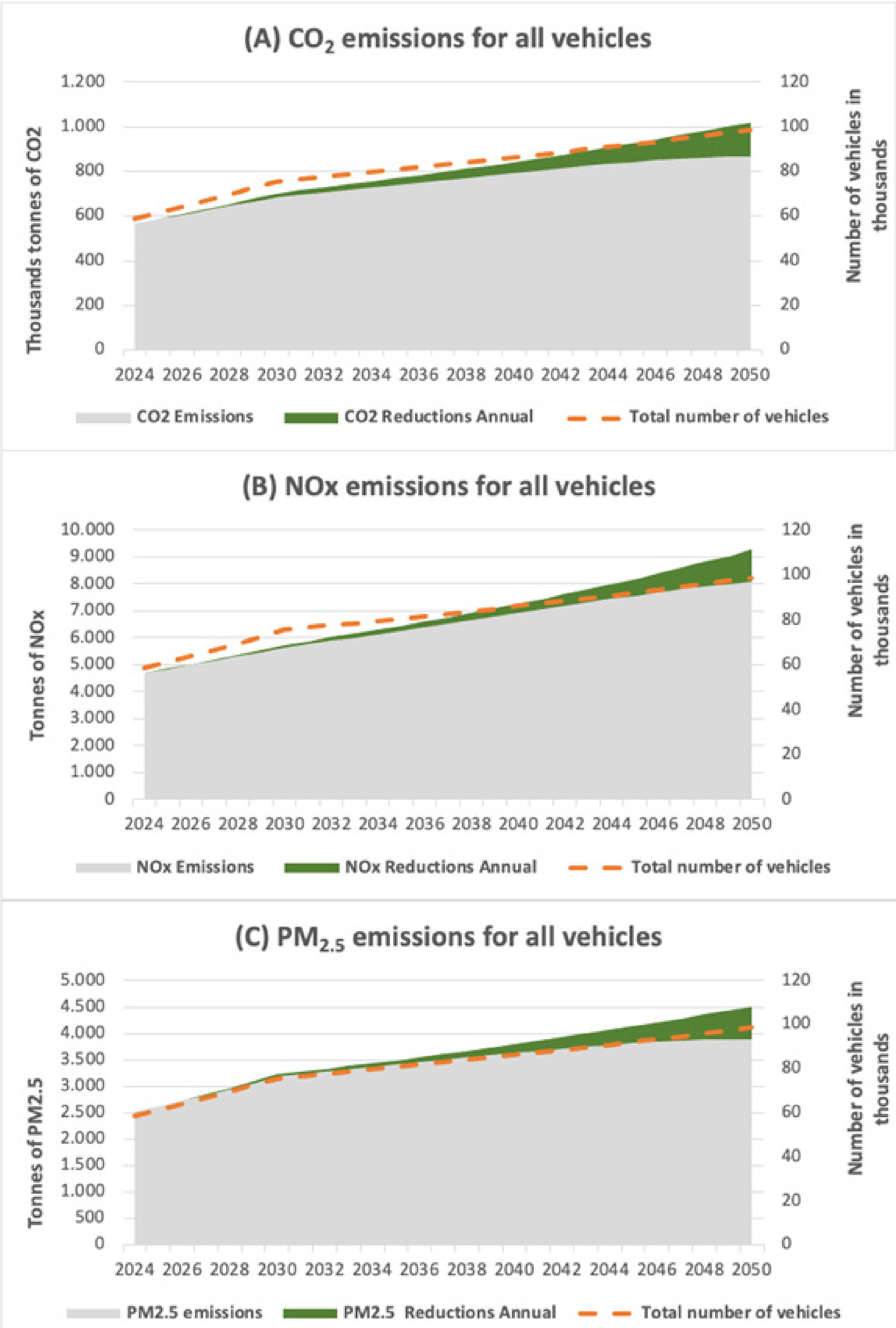
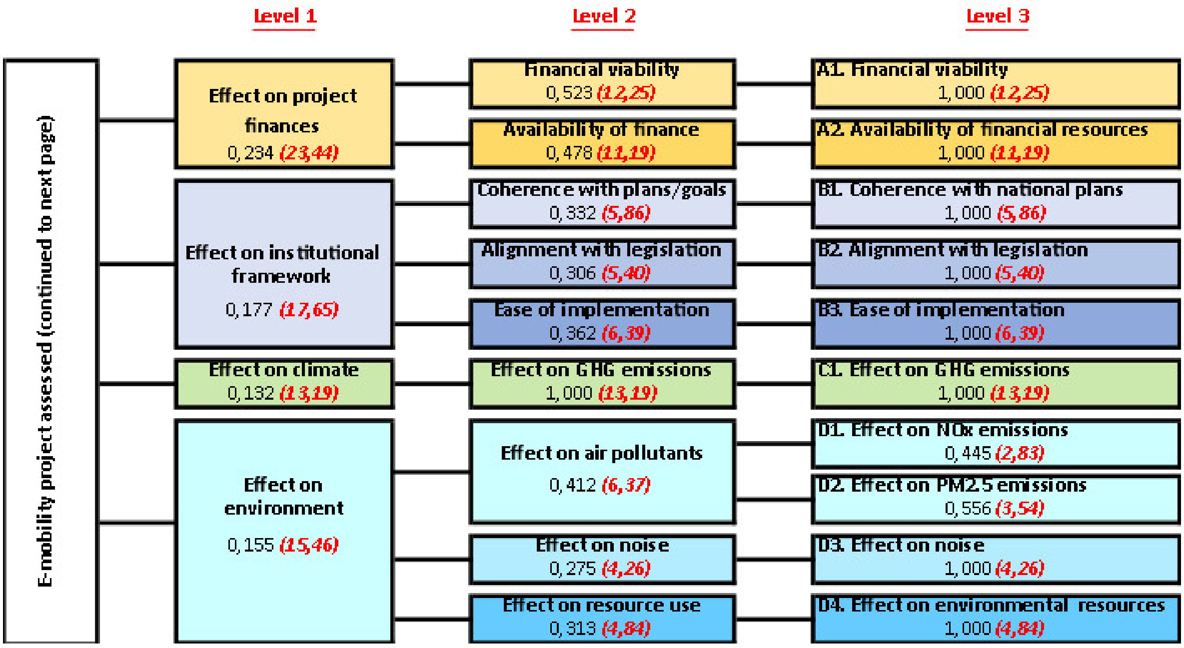


Figure 2. Baseline scenario emissions

2.2. KPIS FOR ASSESSING THE SCALED-UP PROJECT

All KPIs of Figure 3 enter the assessment of the scaled-up project. The indicators concerning the effect of the project on the wider economy should, thus, be added to those of Table 2. These additional indicators relate to the effect on budget, external trade, and employment. Unfortunately, the efforts made by the city team to gather data on the budget of relevant institutions (municipalities of the Kathmandu valley) available for the procurement of vehicles, proved fruitless and the corresponding KPI had to be dropped from the analysis. Lack of data also lead to abandoning the KPI on the effect on 'other imports,' restricting external trade consideration to merely fossil fuel imports. When viewed in isolation, however, this indicator exhibits a great deal of overlap with the effect on GHG emissions, which is not allowed by the MECE (mutually exclusive and collectively exhaustive) principle of KPI trees. As such, both indicators on external trade were finally excluded, and the wider economy effects were reduced to impacts on employment through job creation and technical skill requirements, which are presented in the following headings.



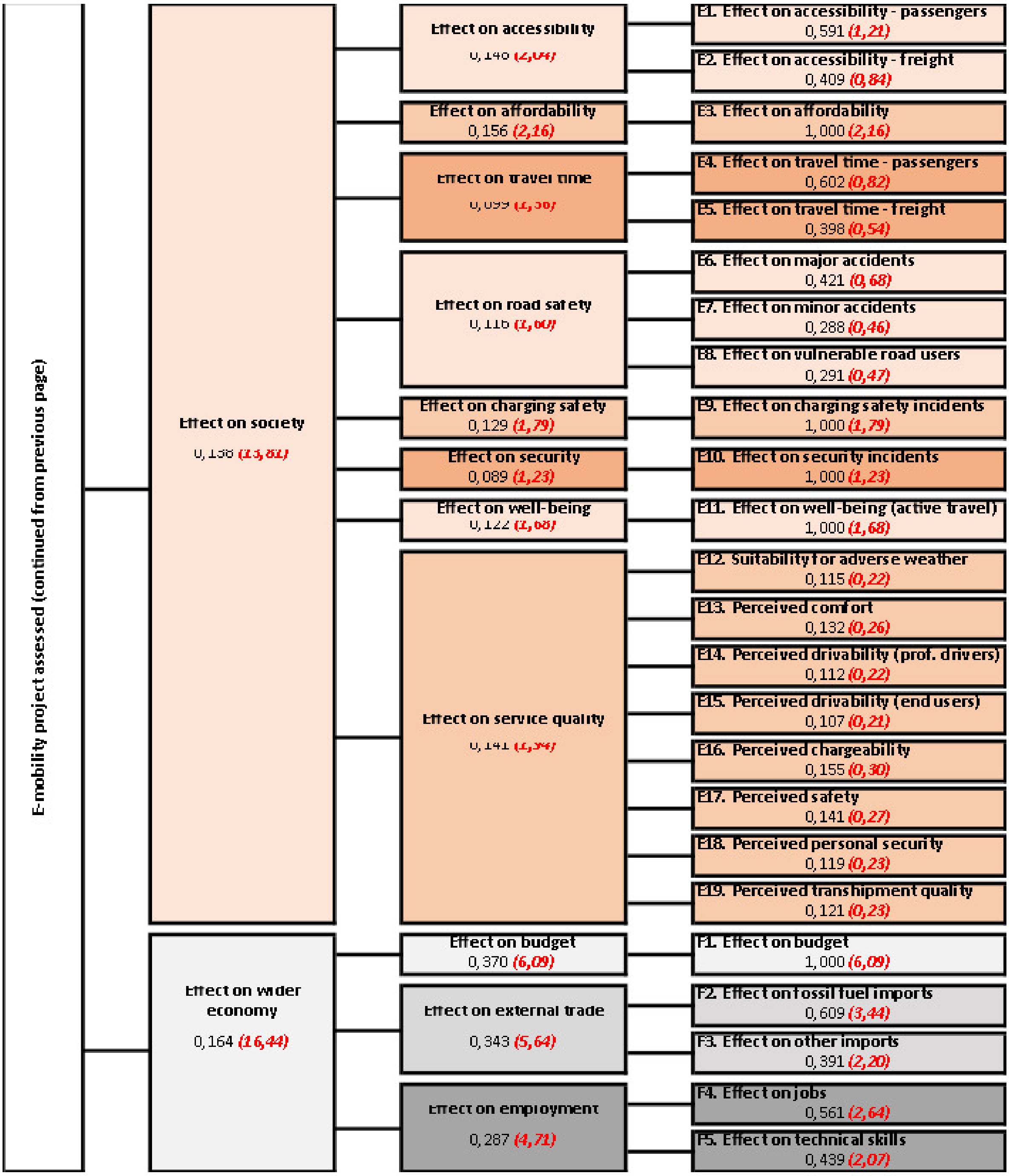


Figure 3. Attribute weights indicated by the Kathmandu stakeholders

Table 2. Applicable KPIs and corresponding report sections

			Converted bus	Remodeled Safa Tempo (passengers)	Remodeled Safa Tempo (cargo)	New e3W design (passengers)	New e3W design (cargo)	New e4W design (waste)	Converted truck	Shuttle van
Ex ante assessment	A1	Financial viability	3.4.1	3.5.1	3.6.1	3.7.1	3.8.1	3.9.1	3.10.1	3.11.1
	A2	Availability of financial resources	3.3.1	3.3.1	3.3.1	3.3.1	3.3.1	3.3.1	3.3.1	3.3.1
	B1	Coherence with national plans/goals	3.3.2	3.3.2	3.3.2	3.3.2	3.3.2	3.3.2	3.3.2	3.3.2
	B2	Alignment with legislation	3.3.3	3.3.3	3.3.3	3.3.3	3.3.3	3.3.3	3.3.3	3.3.3
	B3	Ease of implementation	3.3.4	3.3.4	3.3.4	3.3.4	3.3.4	3.3.4	3.3.4	3.3.4
	C1	Effect on GHG emissions	3.4.2	3.5.2	3.6.2	3.7.2	3.8.2	3.9.2	3.10.2	3.11.2
	D1	Effect on NOx emissions	3.4.2	3.5.2	3.6.2	3.7.2	3.8.2	3.9.2	3.10.2	3.11.2
	D2	Effect on PM emissions	3.4.2	3.5.2	3.6.2	3.7.2	3.8.2	3.9.2	3.10.2	3.11.2
Ex post assessment	D3	Effect on noise	3.4.2	3.5.2	3.6.2	3.7.2	3.8.2	3.9.2	3.10.2	3.11.2
	D4	Effect on environmental resources	3.3.5	3.3.5	3.3.5	3.3.5	3.3.5	3.3.5	3.3.5	3.3.5
	E1	Effect on accessibility - passengers	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E2	Effect on accessibility - freight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E3	Effect on affordability	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E4	Effect on travel time - passengers	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E5	Effect on travel time - freight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E6	Effect on major accidents	3.3.6	3.3.6	3.3.6	3.3.6	3.3.6	3.3.6	3.3.6	3.3.6
	E7	Effect on minor accidents	3.3.7	3.3.7	3.3.7	3.3.7	3.3.7	3.3.7	3.3.7	3.3.7
	E8	Effect on accidents involving VRUs	3.3.8	3.3.8	3.3.8	3.3.8	3.3.8	3.3.8	3.3.8	3.3.8
	E9	Effect on charging safety	3.3.9	3.3.9	3.3.9	3.3.9	3.3.9	3.3.9	3.3.9	3.3.9
	E10	Effect on security	3.3.10	3.3.10	3.3.10	3.3.10	3.3.10	3.3.10	3.3.10	3.3.10
	E11	Effect on well-being (active travel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E12	Suitability for adverse weather	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E13	Perceived comfort	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E14	Perceived drivability (prof. drivers)	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E15	Perceived drivability (end users)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	E16	Perceived chargeability	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E17	Perceived safety	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E18	Perceived personal security	3.4.3	3.5.3	3.6.3	3.7.3	3.8.3	3.9.3	3.10.3	3.11.3
	E19	Perceived transhipment quality	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

2.2.1. Effect on jobs

Experiences in both Nepal and other countries suggest a significant effect on job creation associated with EV manufacturing. Following the successful implementation of the Global Resources Institute electric vehicle programme in Kathmandu during 1993-1996, five different manufacturers produced a total of 706 Safa Tempos during 1996-2011, an average of 47 a year. In China, the previous 10-year plan aimed at creating 1.2 million jobs engaged in producing 1.67 million new EVs annually during the decade 2010–2020. Three experts affiliated with car manufacturing and sales provided their views on the potential impact of EV manufacturing on job creation. To consider the effect of economies of scale, the interviewees were asked to consider the manufacturing of 35 units of each type of vehicle in the period 2023-2030. The responses received are summarised in Table 40, where also the net effect per unit of manufactured vehicle is presented.

2.2.2. Effect on technical skills

As stated in Vol.1 (Appendix B6.3 under SOLUTIONSplus deliverable D1.6), this KPI is defined based on the net positions of technically skilled employees required for the manufacturing and maintenance of EVs. The specialties of concern are: (i) EV technicians, (ii) EV design engineers, and (iii) IT analysts or other Industry 4.0 experts. These positions are transformed into EV technician equivalent ones, through the corresponding mean salaries earned in Nepal, as provided in: https://www.paylab.com/salary-report?lang=en. Table 3 summarises the salary information (in US$) obtained through this link on 23/1/2024 and calculates the corresponding conversion factors.

Table 3. Conversion factors for calculating the EV technician equivalent positions (as of 23/1/2024)

	10% earn less than	10% earn more than	Mean value	Conversion factor
Auto electrician	US$ 140	US$ 294	US$ 217.00	1:1
Auto design engineer	US$ 119	US$ 394	US$ 256.50	1:1.18
IT analyst	US$ 161	US$ 548	US$ 354.50	1:1.63

The same experts interviewed for job creation were asked to provide their estimates for the net positions of technically skilled employees that would be generated by the manufacturing and maintenance of 35 units of each vehicle type. Their responses are presented in Table 5. The last two columns of the table transform the net positions of all three specialties into EV technician equivalent ones for the set of 35 vehicles, as well as for a single unit.

Table 4. Effect on job creation

F.4 Effect on jobs

Demo component	Old solution	New jobs	Job losses	Net effect on jobs	Net effect on jobs
		(per 35 new vehicles) [1]			(per new vehicle)
Converted bus	Diesel bus	81,00	58,67	22,33	0,6381
Remodelled e3W pax	Existing Safa Tempo (pax)	34,00	20,00	14,00	0,4000
Remodelled e3W cargo	Petrol-driven pick-up truck	34,00	20,00	14,00	0,4000
New e3W design pax	Existing Safa Tempo (pax)	34,00	10,67	23,33	0,6667
New e3W design cargo	Petrol-driven pick-up truck	34,00	10,67	23,33	0,6667
Converted e4W waste	Petrol-driven 3-wheeler	34,00	10,67	23,33	0,6667
Converted truck	Petrol-driven pick-up truck	67,67	46,67	21,00	0,6000
New e-shuttle van	Open-type e-shuttle van	35,00	10,67	24,33	0,6952

Notes
[1] The interviewees were asked to provide their estimates for a batch of 35 vehicles of each type.

Table 5. Effect on technical skills

F.5 Effect on technical skills

Demo component	Old solution	EV technicians			EV design engineers			IT analysts & other experts			EV technician equivalent [1]	
		New jobs	Job losses	Net add.	New jobs	Job losses	Net add.	New jobs	Job losses	Net add.	Net (35 veh.) [2]	Net/unit
Converted bus	Diesel bus	12,67	3,00	9,67	5,00	0,00	5,00	4,33	0,00	4,33	22,63	0,6466
Remodelled e3W pax	Existing Safa Tempo (pax)	7,00	2,33	4,67	4,00	0,00	4,00	4,00	0,00	4,00	15,91	0,4545
Remodelled e3W cargo	Petrol-driven pick-up truck	7,00	2,33	4,67	4,00	0,00	4,00	4,00	0,00	4,00	15,91	0,4545
New e3W design pax	Existing Safa Tempo (pax)	11,00	2,67	8,33	7,67	0,00	7,67	6,00	0,00	6,00	27,16	0,7760
New e3W design cargo	Petrol-driven pick-up truck	11,00	2,67	8,33	7,67	0,00	7,67	5,67	0,00	5,67	26,62	0,7605
Converted e4W waste	Petrol-driven 3-wheeler	11,00	2,67	8,33	7,67	0,00	7,67	5,67	0,00	5,67	26,62	0,7605
Converted truck	Petrol-driven pick-up truck	15,00	4,00	11,00	5,00	0,00	5,00	5,00	0,00	5,00	25,05	0,7157
New e-shuttle van	Open-type e-shuttle van	13,67	3,00	10,67	7,67	0,00	7,67	5,67	0,00	5,67	28,95	0,8271

Notes
[1] Based on their mean salaries in Nepal (23/1/2024), 1 EV design engineer accounts for 1,18 EV technicians, and 1 IT analyst accounts for 1,63 EV technicians.
[2] The interviewees were asked to provide their estimates for a batch of 35 vehicles of each type.

2.3. SCALED-UP PROJECT DESIGN

The baseline scenario of Section 2.1 and the KPIs on employment of Section 2.2 complete the basic input for designing the scaled-up project. Before presenting some methodological issues concerning the optimisation process itself in the next heading, it is necessary to define the boundaries (scope) of the alternative designs to be assessed.

Firstly, to ensure that the necessary input is available, the scaled-up project should consist of an unspecified (integer) number of units for the eight types of vehicles examined in the Kathmandu demo. Other vehicle types are excluded.

Secondly, the optimisation process should relate to a specific institution (project owner), who will undertake the necessary investments. A closer look at the eight vehicles of the demo, reveals that five of them (the four e3W components and the converted truck) are vehicles owned and operated by private interests, either investors or operators/drivers. All these vehicles are financially sound with pre-tax IRR values ranging from 30.58% (newly designed e3wheeler – passenger service) to 87.93% (newly designed e3wheeler – cargo service) at constant 2022 prices.[3] Thus, no investments are required by the public sector for these vehicles, other than supporting activities such as monitoring the prototypes' operation to verify their technical and financial viability, informing commercial banks about potential targeted loan schemes, and undertaking awareness campaigns targeting potential investors and operators. The remaining vehicles either fall directly into the public sector sphere as they do not earn revenues (waste collector & shuttle van) or if they do, they are operated by semi-public structures such as the Sajha Yatayat (converted bus). For simplicity purposes, it is assumed that a public entity such as the Lalitpur municipality will be the owner for a scaled-up project consisting of these three types of vehicles.

Thirdly, the project owner has to define the available budget for this activity. A budget line of € 2 million is assumed for this purpose.

Fourthly, the project owner has to define the lower and upper limits of the respective fleets depending on their function. To ensure economies of scale, a lower limit of 10 units has been assumed for all three vehicle types, as long as any of them is selected in the composition of the scaled-up project fleet. Upper limits have been imposed only for the waste collectors and shuttle vans (30 units for each type), as the municipality will probably not need more of these vehicles. The converted buses are left unconstrained from above.

2.3.1. Methodological aspects

As mentioned in Section 2.1.1 (Vol.1), the optimisation objective function is of the following form:

$$\max_{\alpha \epsilon \Omega} V(x) = \sum_{i=1}^{M} w_i \, v_i(x)$$

3. It is worth mentioning that this result is achieved after several assessment iterations optimising the design and operational profile of the vehicles.

where:

x = a 3-dimensional decision vector $[x_1, x_2, x_3]$ indicating the units of each vehicle type that comprise a specific alternative solution

M = the number of KPIs participating in the assessment

V(x) = the overall rating of alternative x

$v_i(x)$ = the score (performance) of alternative x against KPI i $(i = 1, \ldots, M)$

w_i = the weight (relative importance) that the decision makers assign to KPI i

$[0 \leq w_i \leq 1]$ and $\sum_{i=1}^{m} w_i = 1$

Ω = the feasible region

Some of the KPI scores, however, contain metrics such as the share of vehicle type xj in total investment, making the objective function non-linear. Traditional linear solvers cannot be used in such cases requiring the use of a metaheuristic. Metaheuristics are advanced computational algorithms that operate by intelligently exploring the search space through mechanisms that balance exploration (investigating new, unvisited areas) and exploitation (deepening the search around promising areas). This dual approach enables them to efficiently navigate through complex problem landscapes to identify high-quality solutions, often close to the global optimum.

Three different metaheuristics are selected for this particular application: (i) Simulated Annealing (SA), (ii) Evolutionary Algorithm (EA), and (iii) Grey Wolf Optimiser (GWO). Each of these methods, briefly explained below, has its strengths and mechanisms for exploring the solution space and converging towards an optimal or near-optimal solution. All metaheuristics for this application have been executed using the Julia programming language.

Simulated Annealing (SA)

Simulated Annealing is inspired by the annealing process in metallurgy. It is a physical process used to alter the properties of metals: the material is heated to a high temperature and then allowed to cool slowly. The slow cooling process is crucial as it lets the atoms within the material rearrange themselves into a state of minimum energy, leading to a more stable and orderly structure. This process helps in reducing defects, increasing ductility, and relieving internal stresses. The idea of this metaheuristic is to find a low-energy state of a system that corresponds to an optimal or near-optimal solution to a given problem. In the context of optimisation, the 'energy' of the system is analogous to the objective function that needs to be maximised and the 'state' of the system represents a potential solution.

The algorithm starts by initialising the process with a random solution to the problem, which is then iteratively improved upon. At each step, the SA heuristic considers moving from the current solution to a neighbour solution. In our case, a neighbour solution is found by selecting randomly a component (type of vehicles) of the current solution and add to the value component (number of vehicles) a random number between -10 and 10. The decision to move to this new solution is made based on a comparison of the two solutions' objective function values. If the adjacent solution is better, this becomes the new arrangement of the solution, which is then explored in the next iteration. By only accepting the best solutions, the algorithm could lead to a local maximum. So, to avoid this, an acceptance criterion is also defined based on the current temperature of the system. Early in the algorithm, when the temperature is high, there is a higher likelihood of accepting worse solutions, allowing the algorithm to explore the solution space more freely and potentially escape local maxima. As the temperature decreases, the algorithm becomes more conservative, preferring only moves that improve the solution or that represent slight deteriorations, thereby focusing the search on regions of the solution space where a near-optimal solution is likely to be found.

Evolutionary Algorithm (EA)

The Evolutionary Algorithm is based on the principles of Darwinian natural selection and genetic mechanisms observed in biological evolution. Its core concept is to mimic the evolutionary process of natural selection where the fittest individuals are more likely to survive and reproduce. The main biological inspirations are the natural selection (weak species cease to exist through natural selection, whereas strong ones can pass their genes to future generations), genetics and inheritance (biological organisms inherit traits from their parents through genes), and mutations of the children's genes (variation of the genes, represented as random changes, enabling the exploration of the solution space and the possibility of discovering more optimal solutions). These changes may provide additional advantages and may be carried onto the next generation. These mutations often help ensure that the solution does not get stuck on a local extreme point. Over time, fitter solutions will dominate the population until the solution eventually converges on a single optimal solution.

Box 1: Pseudo code of the SA algorithm

Initialise a feasible solution to the problem.
Initialise the temperature of the system.
Initialise the number of iterations.
WHILE the number of iterations is less than the maximum number of iterations,
DO:
Generate a neighbour solution based on the current solution.
IF the neighbour solution is better than the current solution (in terms of KPIs stars) **OR**
IF the acceptance criterion based on the temperature of the system is true, **THEN:**
The neighbour solution becomes the current solution.
END IF
Update the temperature of the system.
Update the number of iterations.
END WHILE

The process starts with the initial population P, consisting of a given number of individuals (feasible solutions). This given number of individuals is a parameter for the algorithm, and must be determined, so that the metaheuristic is as efficient as possible. The creation of the population is done to ensure a diverse gene pool in the different iterations. After this, two individuals are selected to become the parents of the new generation. This is done by giving a probability of being picked to everyone, depending on their score. The better the score, the more likely an individual will be selected. The next step consists of generating two children by crossing over the genes of the parents. To create diversity in the population, a mutation on the genes of the children is carried out. For each child, this is done by selecting randomly one of their components (type of vehicles) and add to the component value (number of vehicles) a random number between -10 and 10. Finally, two individuals from the population are selected to be replaced with the two new children. This is done by giving a probability of being picked to everyone, depending on their score. The worse the score, the more likely an individual will be selected. These steps are repeated until reaching the maximum number of iterations.

Box 2: Pseudo code of the EA

1. Initialise the population with a given number of individuals (feasible solutions).
2. Initialise the number of iterations.
3. **WHILE** the number of iterations is less than the maximum number of iterations, **DO:**
    a. Select randomly two individuals in the population (parents).
    b. Generate two children by crossing over the genes (components) of the parents.
    c. Create a mutation on the genes (components) of the children.
    d. Select randomly two individuals in the population and replace them with the new solutions generated.
    e. Update the number of iterations.
4. **END WHILE**
5. Identify the best individual.

Grey Wolf Optimiser (GWO)

This is an algorithm inspired by the social hierarchy and hunting behaviour of grey wolves in nature. These animals are known for their well-organised social structure and highly cooperative hunting tactics. The social structure of a grey wolf pack is primarily hierarchical, with four levels of rank: Alpha, Beta, Delta, and Omega. The Alpha wolf is the leader of the pack, and it represents the best solution found so far. The Beta wolf is the second in command, and it represents the second-best solution found so far. The Delta wolf is the third in command, and it represents the third-best solution found so far. And finally, the Omega wolves represent the bottom of the hierarchy and tend to follow the orders of the higher-ranked wolves. In the algorithm, Omega wolves follow the Alpha, Beta, and Delta wolves, simulating the exploration of the search space. The hunting strategy of grey wolves is another critical aspect that the GWO algorithm simulates. This strategy typically involves three steps: searching for prey, encircling, and harassing the prey, and finally attacking it. In the algorithm, these steps are mimicked to adjust the positions of potential solutions in the search space, effectively moving towards the optimal solution over iterations.

The process starts by initialising the position of the initial population of wolves, consisting of a given number of individuals (feasible solutions). In the case of the project, the position of the wolves is represented by the number of each type of vehicles. Then, the score of each individual is calculated, so that it is possible to find out who are the Alpha, Beta and Delta wolves. This step represents the search for prey by the group of wolves. After this, the Omega wolves start to encircle the prey. It is done by updating their position, so that they come closer to the higher-ranked wolves. For a given Omega wolf, the position update is calculated by considering its initial position, and the positions of the Alpha, Beta and Delta wolves. This process is repeated until it reaches the maximum number of iterations. At the end of the algorithm, all the wolves get to the same position (same feasible solution), representing the attack against the prey.

Box 3: Pseudo code of the GWO algorithm

1. Initialise the position of the population with a given number of individuals (feasible solutions).
2. Initialise the number of iterations.
3. **WHILE** the number of iterations is less than the maximum number of iterations, **DO:**
   a. Calculate the score of each individual.
   b. Assign the individual with the best score as the Alpha wolf.
   c. Assign the individual with the second-best score as the Beta wolf.
   d. Assign the individual with the third-best score as the Delta wolf.
   e. Update the position of the Omega wolves (remaining of the population) to make it closer to the position of the Alpha, Beta, and Delta wolves.
   f. Update the number of iterations.
4. **END WHILE**

NB: The position of the wolves can be seen as the value of the different components of the solution.

2.3.2. Optimisation results

Table 6 summarises the vehicle-specific input that enters the optimisation model. A total of 23 KPIs (out of the original set of 34) enter the scaled-up assessment. It is worth noting, however, that 7 of them (B1, B3, E6, E7, E8, E10, E18) will not have an effect in the outcome as identical scores are given to all three vehicles.

To evaluate the effectiveness and efficiency of the three metaheuristic algorithms mentioned above, each algorithm is executed 100 times. Each time, the highest scaled-up star rating and the corresponding fleet configuration are reported. The effectiveness of the metaheuristics is assessed based on the frequency with which the highest star rating is achieved out of the 100 repetitions. Efficiency is gauged by computing the average duration required to execute the metaheuristic algorithms.

Table 6. Input for the optimisation model

Code	KPIs participating in the assessment	KPI weight		Converted bus	Waste Collector	E-shuttle van
		Absolute	Normalised	KPI score (or attribute value that needs to be transformed into a star value thru a value function)		
	Required investment (EURO per unit)			46.235	14.465	17.820
A1.	Financial viability	0,122452	0,151963	3	4	5
A2.	Availability of financial resources	0,111906	0,138875	3	2	3
B1.	Coherence with national plans	0,058573	0,072689	5	5	5
B2.	Alignment with legislation	0,054022	0,067041	2	2	3
B3.	Ease of implementation	0,063906	0,079307	3	3	3
C1.	Effect on GHG emissions (tonnes/year/unit)	0,131929	0,163724	-15,14	-3,42	-15,09
D1.	Effect on NOx emissions (kg/year/unit)	0,028315	0,035140	-201,30	-15,61	-70,75
D2.	Effect on PM2.5 emissions (kg/year/unit)	0,035386	0,043915	-52,00	-5,35	-24,19
D3.	Effect on noise	0,042560	0,052817	5	4	3
D4.	Effect on environmental resources	0,048381	0,060041	5	5	1
E6.	Effect on major accidents	0,006757	0,008385	4	4	4
E7.	Effect on minor accidents	0,004625	0,005740	4	4	4
E8.	Effect on vulnerable road users	0,004662	0,005786	3	3	3
E9.	Effect on charging safety incidents	0,017880	0,022189	2	2	3
E10.	Effect on security incidents	0,012324	0,015295	3	3	3
E12.	Suitability for adverse weather	0,002225	0,002761	4	5	5
E13.	Perceived comfort	0,002562	0,003179	4	4	3
E14.	Perceived drivability (prof. drivers)	0,002168	0,002690	4	4	3
E16.	Perceived chargeability	0,003002	0,003725	2	2	3
E17.	Perceived safety	0,002739	0,003400	4	4	3
E18.	Perceived personal security	0,002306	0,002862	4	4	4
F4.	Effect on jobs (net jobs per unit produced)	0,026421	0,032789	0,6381	0,6667	0,6952
F5.	Effect on technical skills (net EV technician equivalent positions per unit produced)	0,020699	0,025688	0,6466	0,7605	0,8271
	Total	0,805799	1,000000			
	Provisional scoring by the Kathmandu city team pending completion of ex post assessment					

Table 7. Optimisation results (Scenario A)

	Simulated annealing	Evolutionary algorithm	Grey wolf optimiser
Best star rating found	3.29556	3.29556	3.29556
Best fleet found	[bus, waste, van] [25, 20, 30]	[bus, waste, van] [25, 20, 30]	[bus, waste, van] [25, 20, 30]
Effectiveness: Frequency of occurrence of best star rating	41 /100	7 / 100	95 / 100
Efficiency: Average duration of computing time	0.22 seconds	1.67 seconds	0.09 seconds

The optimisation results appear in Table 7. With an overall rating of 3.29556, a fleet composed of 25 buses, 20 waste collectors and 30 shuttle vans is the best performing solution. All three algorithms have identified the same best performing solution. It is worth noting that due to the utilisation of metaheuristic algorithms, the highest star rating obtained may not represent the optimal solution in theory. Nevertheless, given the project's scale and the constrained budget, it is feasible to enumerate all viable solutions in an Excel spreadsheet and manually calculate the optimal star rating. Through this method, it has been confirmed that the optimal star rating is indeed 3.29556, achieved with a configuration of 25 buses, 20 waste collectors, and 30 shuttle vans.

Table 8. Estimated effect of the scaled-up project on emissions (Scenario A)

Period	Emission type	Baseline scenario (tonnes)	Scaled-up scenario (tonnes)	%
2024	CO_2 (WtW)	568.033,5	911,2	0,16%
	NOx	4.715,6	7,5	0,16%
	$PM_{2.5}$	2.521,7	2,5	0,10%
2024-2030	CO_2 (WtW)	4.380.830,8	6.378,4	0,15%
	NOx	36.216,7	52,6	0,15%
	$PM_{2.5}$	19.887,3	17,7	0,09%
2024-2050	CO_2 (WtW)	20.241.842,9	10.177,4	0,05%
	NOx	175.685,0	80,2	0,05%
	$PM_{2.5}$	92.321,3	27,8	0,03%

The effect of the scaled-up project on emissions is obtained by considering the composition of the scaled-up fleet, the annual emissions abated per unit, and the useful life duration of each vehicle type. Table 8 presents the reduction in the cumulative emissions of the periods 2024-2030 and 2024-2050 resulting from the scaled-up project. It appears that its effect is moderate, amounting to 0.15% for CO2 and NOx emissions and 0.09% for the PM2.5 respectively.

It is possible that Lalitpur municipality might find the investment in 30 shuttle vans excessive, particularly considering that these vehicles earn no revenues and are targeted to tourists, who will likely be willing to pay the fare for a taxi or hotel van to visit the historic sites. In view of this possibility, it was decided to run a second scenario of the scaled-up project, excluding the e-shuttle vans altogether. Under the same budget constraints, the optimal solution now consists of 40 buses and 10 waste collectors (Table 9).

For both scenarios, Tables 7 and 9 illustrate that the Grey Wolf Optimiser emerges as the best metaheuristic in this specific application, outperforming the others in terms of both effectiveness and efficiency.

The metaheuristic algorithms have been run on the same computer. The specifications of this computer are the following:

- **Processor:** AMD Ryzen 5 PRO 5650U with Radeon Graphics 2.30 GHz
- **Installed RAM:** 16,0 GB (14.8 GB usable)
- **Device ID:** EC7911AB-ECFA-43A5-B4F1-1134DCD53EB9
- **Product ID:** 00330-80000-00000-AA322
- **System type:** 64-bit operating system, x64-based processor

Table 9. Optimisation results (Scenario B)

	Simulated annealing	Evolutionary algorithm	Grey wolf optimiser
Best star rating found	3.25346	3.25346	3.25346
Best fleet found	[bus, waste] [40, 10]	[bus, waste] [40, 10]	[bus, waste] [40, 10]
Effectiveness: Frequency of occurrence of best star rating	55/100	97 / 100	100 / 100
Efficiency: Average duration of computing time	0.11 seconds	1.16 seconds	0.08 seconds

2.3.3. Suggested scaled-up project

Following discussions with the stake
holders during a workshop that took place in Kathmandu on 24 April 2024, it was confirmed that Scenario B would be preferable for the Lalitpur municipality. As such, the suggested scaled-up project could look like:

- Conversion of 40 diesel buses — 2.000.000 (= € 50.000 x 40)
- Conversion of 10 mini trucks to waste collectors — 150.000 (= € 15.000 x 10)
- Activities promoting private investments in e3Ws & converted pick-up trucks — 200.000 (lump sum)
- Project management, etc. — 150.000 (lump sum)
- Contingencies — 100.000 (lump sum)

Total (€) — **2.600.000**

The activities supporting investments by the private sector (in the four remodelled and newly designed e3Ws for passenger and cargo use, and the converted pick-up truck) should include:

- Support and monitor the continuous operation of the prototypes for at least six months to verify their technical and financial viability
- Present the financial results to commercial banks (with the intervention of international donors, if needed) to increase their awareness and possibly develop a fast-track loan offering scheme (in all these cases the initial investment is lower than 2 million NPR ≈ € 15.000).
- Undertake an awareness campaign targeting potential investors and operators

In relation to the bus and waste collector fleets, the following activities are suggested:

- Support and monitor the continuous operation of the prototypes for at least six months to verify their technical and financial viability
- Discuss with the relevant authorities the prospect of engaging in developing a fleet of such vehicles. For each one of these vehicles, the production batch cannot be lower than 10 units of each type in an effort to achieve economies of scale
- Identify potential local manufacturers interested in such a contract and verify findings of the performed financial assessment
- Investigate possibility of obtaining support from international donors
- Project management

3 CONCLUSION

Given that all five of the demo vehicles that fall under the private sector (the four e3Ws and the converted pick-up truck) exhibit healthy financial returns, no subsidies are required for their promotion. With regard to these vehicles, therefore, the scaled-up project includes only support activities (monitoring the prototypes' operation to verify their technical and financial viability, informing commercial banks about potential targeted loan schemes, and undertaking awareness campaigns targeting potential investors and operators). An optimisation exercise has been undertaken concerning the remaining three vehicles. For a budget of € 2 million, a fleet of 25 buses, 20 waste collectors and 30 shuttle vans exhibits the best performance in meeting the stakeholder priorities. If the Lalitpur municipality wishes to exclude the shuttle vans, which are targeted to the tourist industry, the optimal fleet becomes 40 buses and 10 waste collectors.

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