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Economic and environmental viability assessment of NASA's turboelectric distribution propulsion

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ABSTRACT

The concept of turboelectric-distributed propulsion (TeDP) has become integral to engineering because of its ability to generate electricity. However, social science compels careful evaluations of TeDP's environmental and economic impacts—out of caution, such elements must be taken up before TeDP is put into practice. Responding to this call, this research investigates TeDP's economic and environmental viability with a case study of the National Aeronautics and Space Administration's (NASA) proposal for a TeDP aircraft, N3-X, using technical aspects and real data integration. The economic assessment measures NASA's N3-X economic added value for aviation manufacturing, operations, and investors as well as net present value, internal rate of return, and payback period. Meanwhile, the environmental assessment looks at carbon monoxide and dioxide and oxides of nitrogen. The economic and environmental evaluation results establish the viability of TeDP.

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1. Introduction

Aviation sustainability is considered a desirable achievement for major environmental organisations, and governments intend to bring in legislation to that end. One of the global aviation goals projected by the International Civil Aviation Organisation (ICAO) is the Sustainable Aviation Fuels (SAF) 2050 Vision (ICAO, 2019). This vision envisages emission reduction by targeting technologies, standards, and operational improvement. ICAO and the Advisory Council for Aeronautics Research in Europe (ACARE) adopted an action plan for emission reduction of up to 90% by 2050 (Muller et al., 2010). Constant increases in air traffic have produced several motley environmental challenges for aviation research and development. While carbon monoxide and dioxide (CO and CO_2) and nitrogen oxide (NOx) emissions are an integral part of organisational and governmental activities, the world is increasingly focusing on quickly reducing carbon emissions to address environmental threats. Such emission reduction demands a high level and velocity of technological change over the next decade; this will require a complete shift in aircraft designing, modelling, and integration.

The turboelectric system is one of the processing technologies to electrify the legacy propulsion system. This technology should enter into service (meaning it should be merchandised) by 2030. The concept of turboelectric-distributed propulsion (TeDP) is quickly emerging as an alternative for future transportation. It uniquely offers a gas turbine engine that generates electric power for motors and propulsions (Alrashed et al., 2020; Schiltgen et al., 2016; Steiner et al., 2012). According to Nalianda and Singh, turboelectric transmission uses electric generators to transform a turbine's mechanical energy into electric energy (Armstrong and Blackwelder, 2020; Nalianda and Singh, 2014). Turboelectric transmission has several advantages: (1) it can facilitate the adaptation of high-speed turning turbines to slow wheels to manage a sophisticated gearbox; (2) it can provide large vehicles, such as aircraft, trains and ships, with the necessary amount of electricity; (3) it can provide electricity to a radar system, communication equipment, and computers; and (4) TeDP produces emissions at a lower node (Flynn et al., 2017). As green energy, TeDP offers an alternative to decrease the environmental and economic losses currently plaguing aero, ground, and marine transportation.

Therefore, a wide-ranging investigation of TeDP's economic and environmental costs and benefits will surely accelerate its use

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in the field. This study takes on this task by conducting economic and environmental assessments of NASA's N3-X, a TeDP aircraft. This study covers a gap in economic and environmental viability assessment for real-life use of TeDP in commercial aviation. To reveal the importance of the economic and environmental aspects of the aviation sector, Section 2 provides an overview of the aviation impact on the global economy and emission. Section 3 presents the methods used in this study for both economic and environmental assessments. It includes a practical case study of NASA N3-X. The qualitative TeDP results gained from the assessment are reviewed and discussed in Sections 4 and 5. The last section summarises the finding of this study and illustrates the limitations, which may be considered as promising TeDP areas of research on future financial trends.

2. Environmental economics overview

The relationship between the environment and economics creates positive impacts that lead to forming economic models to be used in environmental economic studies. Such economic models distinguish the maximum visible use of power resources based on emission limitations (Smith, 2015). Economic analysis is motivated by the cost-effective properties of each component in the power system concerning environmental aspects. An analysis of the two sectors evaluates the benefits gained from the system to the environment from the additional positive costs (Emodi et al., 2019; Smith, 2015). To maintain the quality of the environment, alternative economic solutions need to be considered to overcome the cost engineering outcome challenges.

Several methods and case studies are used in environmental economic analysis. These research studies customise a specific area of investigation to overcome the optimum alternative solution. For example, a method is developed to evaluate the cost–benefit relationship in prognostics and health management for commercial aircraft. This analysis methodology estimates the economic feasibility by eliminating degradation in legacy aircraft (Leão et al., 2008). Another research discusses the benefit of using electrical power in airport ground taxing and its relation to financial impact. The analysis shows that proper ground operation benefits from the electric power added with the correlation of economic challenges (Hospodka, 2014).

The sensitivity of environmental economic analysis is considered in the regulations and legislation for future emission reduction plans. Therefore, this study implements a method to assess the turboelectric propulsion system within the framework of environmental economic analysis.

3. Methods of assessment

There are two models used to assess the TeDP system: (1) an economic model and (2) an environmental model. These two models have been universally employed within the hybrid propulsion system, especially for turboelectric use.

3.1. Economic assessment

Strategic management and lean studies provide an economic model built on the business model canvas. This method can illustrate an entity's economic constitution and valuation. Accordingly, this study uses the economic canvas model to evaluate the financial costs and benefits of TeDP along with any technologies that may be integrated into it in the future, such as batteries. The reason for this further integration is to make the canvas model useable and flexible well into the future.

The economic canvas model involves the following four types of costs, which are central to conducting economic analyses and projecting prospective revenues:

- *Capital cost* a one-time cost to get a business off the group; capital cost varies by propulsion model
- *Annual cost:* a period cost that must be accounted for each year; annual cost varies in line with economic factors and by propulsion model.
- *Emission cost:* the cost of tax and penalties charged against emissions.
- *Investment cost:* additional costs necessary to keep the business running. In other words, it is the total costs needed to establish and operate the project.

Table 1 illustrates the economic canvas model and its diverse finance parameters.

3.1.1. Net present value

Net present value (NPV) is an essential tool that falls under the umbrella of capital budgeting. In finance, NPV is applied to a series of future cash flows. It has the capacity to discount future cash flows to analyse an item's actual worth in the present; thus, it idealises the concept of time value of money (TVM). NPV identifies the present worth of an entity's anticipated future cash flows (Grant, 2003). A high NPV is desirable—it draws investment to the business, promising a good return. The selection criteria of NPV is clear: if the NPV is positive and higher than the initial investment outlay of the business, then it should be accepted; otherwise, it should be rejected (Nwogugu, 2017). Accordingly, NPV is one of the most powerful and widely used tools used in capital budgeting; economic and organisational decisions are often made based explicitly on NPV because the measure gives a strong sense of a project's feasibility. Moreover, as already noted, NPV indicates an expected cash return, which is one of the main concerns involved in establishing business and reducing investor risk (Hopkinson, 2017). To be sure, the insights of NPV are applicable to TeDP. Based on the application of NPV, the installation of TeDP should be considered only if the NPV is higher than the initial outlay. The formula for the NPV is as follows (Beaves, 1993):

$$NPV = \sum_{t=0}^{n} \frac{x_t}{(1+R)^t}$$

where

- x_t : future net cash flows,
- R : average periodic rate to invest, and
- t,n : time period.

3.1.2. Internal rate of return

Apart from NPV, there is another significant method under the ambit of capital budgeting: the internal rate of return (IRR). It is generally the point at which a project's NPV equals zero. Moreover, it is an accessible and highly effective capital budgeting method to evaluate the project's ability to match investor confidence. While investment returns are always significant for a company to pursue, and can help a company to visualise its growth and plan accordingly (Lin, 1976), IRR is unable to convey a sense of monetary return to the management. Therefore, IRR is not as vital as NPV (Lin, 1976). The selection criteria of IRR are simple: if the computed IRR is higher than the discount rate, the project should be accepted. For example, if the discount rate of the project is 12% and the IRR is 20%, then the project should be accepted; otherwise, it should be rejected. This can be applied to any project, including that of this study. A management that applies the integrity of TeDP should emphasise increasing the cash flow accordingly in order to realise growth. It should focus

Table 1
TeDP economic canvas model.

Economic canvas - Turboelectric distributed propulsion (TeDP) model			
Capital cost	Annual cost	Emission cost	Economic analysis

• Turbofan
• Turboshaft
• Motorfan
• Generator
• Rectifier
• Cryocooler
• Inverter
• Motor
• Battery
• High-temperature Superconductor
  ◦ Buss
  ◦ Cable
• Cryoflex
	• Inflow
	  ◦ Cargo
	  ◦ Passengers tickets
	• Outflow
	  ◦ Fuel cost
	  ◦ Operating and maintenance cost
	  ◦ Electricity tariff for batteries
		• CO
		• CO_2
		• NO_x
		• Acoustic Noise
			• Payback period
			• Net present value
			• Internal rate of return
			• Profitably index
			• Economic value added

Investment cost		Revenue	
• Manufacturing costs • Electrical equipment and materials • Engineering and supervision • Consulting and contingency • Science and technology • Research and development		• Operation hours • Fuel cost • Maintenance cost • Emission cost	

on the fact that IRR should be higher than the discount/hurdle rate. The formula for IRR is as follows (Belyadi et al., 2017):

$$\sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t} = 0$$

where

- C_t : future cash flow,
- IRR : internal rate of return, and
- t,n : the total period.

3.1.3. Payback period

Payback period (PP) is yet another popular method for capital budgeting. The period in which a project must pay back its initial investment, that is, the period before the initial outlay equals accumulated cash flow, is known as PP. The development and efficiency of NASA's TeDP can be analysed using this tool. Here, it may be helpful to note that this tool is of interest to investors merely because they are likely to buy into companies with low payback periods. Having a low payback period indicates that a business has the tendency and ability to rationalise its operational costs, while a high payback period is often a red flag. On the contrary, PP has nothing to do with the financial competitiveness of a project. As a metric, it only informs investors about the ability of a project to overcome its original cost. Therefore, it should not be used to analyse the financial competitiveness of a project (Dayananda, 2002).

The payback period is usually divided into two parts: undiscounted payback period and discounted payback period. The undiscounted payback period indicates that future cash flows will not be discounted to the present value, and the discount rate will not be used in the same analysis (Fields, 2011). On the contrary, the discounted payback period signifies that future cash flows will be discounted to the present value at a specific discount rate. Contrary to the undiscounted payback period, the latter type is of great use for the management of a business in rationalising its decisions because it gives a complete and thorough idea of the cash flows of a project. The PP formula is as follows:

$$PP = \frac{I_o}{C_a}$$

where

- I_o : the initial investment; and
- C_a : the net annual cash inflow

To find the discounted payback period, the discounted cash flow should be estimated with the expected rate. This means that the annual cash inflow is not constant and can be found using the following formula (French and Gabrielli, 2005; Kruschwitz and Löffler, 2013; Lundholm and O'Keefe, 2001):

$$Discounted\ Cash\ Inflow = \frac{C_a}{(1+r)^t}$$

where

- C_a : net annual cash inflow;
- r : the discount rate; and
- t : the cash inflow period.

3.1.4. Economic added value

Economic added value or economic value added (EVA) is a financial method to estimate the economic profit of a business. It is the value created by the required return of shareholders and is closely linked to the return on capital employed. The economic value added to a project increases with capital employed (Grant, 2003). The formula for EVA includes the return on invested capital (ROIC) and the weighted average cost of capital (WACC). A project with a high EVA is always more effective than one with a lower EVA. This metric is beneficial in comparative work, such as when comparing the effectiveness of two projects (Desai et al., 2006; Fischer, 2001; Trapp, 2011). Moreover, EVA is equally effective for analysing financial competitiveness before and after a merger (if any). This tool is particularly useful for evaluating TeDP because it can yield a sense of the value added by technology's productivity, especially over the long run. The formula for this metric as follows:

$$EVA = NOPAT - (WACC \times Capital\ investment)$$

where

- *NOPAT*: the net operating profits after tax; and
- *WACC* : the weighted average cost of capital.

3.1.5. Case study: NASA's N3-X

The data for NASA's N3-X were collected and calculated from authentic published sources. The following assumptions anchor our economic assessment of N3-X:

1. Passenger and cargo cost per nautical mile = 0.29 cents (based on KAYAK data KAYAK, 2016, 1 mile = 0.868976 nautical mile, and 1 USD = 0.77 GBP).
2. The N3-X operates with the full load and cargo of 300 passengers, including their luggage (Crabtree et al., 2018). (Ideal passengers and cargo = 300 × 0.29 = 87.0 USD per nautical mile)
3. A 30-year lifetime is the operation block hour assigned to the N3-X until it is retired.
4. The average block hour assumed is 5219.5 h a year (based on Boeing 777-200LR's 14.3 h per day Tinseth, 2011 and 365 days in a calendar year).
5. The N3-X has an average speed of 434.488 nautical miles per hour (500 miles per hour).
6. The distance to fly each year is assumed to be 2,267, 810.116 nautical miles.
7. Crew cost is USD 978 per block hour of operation (Steininger et al., 2011) (USD 5,104,671 per year).
8. The income cash flow is constant for the N3-X's entire 30-year operation life cycle.
9. The net present value of emissions over 30 years = USD 1922M (ICAO, 2013).
10. Hydrogen fuel price is equal to USD 5.843 per nautical mile (IATA Fuel Price Monitor IATA, 2016).
11. Some data have been taken or calculated based on the Boeing 777-200LR, as both aircraft are in the same segment category of aircraft (i.e., 47,890 US gallons = 1140.2380952380952 bbl Fordham, 1970; Steininger et al., 2011).
12. Investment cost for research and development of the material, manufacturing, electrical enhancement and generating, engineering and supervision, consulting and contingency, science and technology is assumed to be 2B USD (Braddorn and Hartley, 2007; Goldberg, 2017; Goldberg et al., 2017).

3.2. Environmental assessment

After the economic assessment, the next important aspect associated with the same analysis is environmental assessment. Fig. 1 illustrates the environmental model for assessing the impact of TeDP. This model examines two types of emissions: acoustic and air pollution. Acoustic emission is evaluated by the level of noise the system is expected to generate. Meanwhile, air pollution is evaluated by the level of harmful gases added to the atmosphere. Three different monoxide gases, listed below, are central to our analysis.

3.2.1. Carbon Monoxide

Carbon monoxide (CM) is a colourless, tasteless, and odourless gas which is slightly lighter than air. This gas is toxic to humanity because it uses haemoglobin as an oxygen carrier. It constitutes one oxygen atom and one carbon atom. This means that one atom of carbon has emerged dominant with oxygen. Carbon monoxide emerges with the intermediate oxidation of a carbon-containing mixture; when there is not enough oxygen to produce carbon dioxide, carbon monoxide is formed (for example, in an enclosed space or when working on a furnace burning internally) (Wang, 2015; Yao, 2011). Some of today's innovative programmes—such as iron purification—still generate carbon monoxide as a side effect. A large amount of CO results during synthesis in the oxidation process.

3.2.2. Carbon Dioxide

Carbon dioxide, denominated as CO_2, is yet another colourless gas with a specific density of around 60%, which is significantly higher than that of dry air. Unlike carbon monoxide, this gas consists of one carbon atom and two oxygen atoms. CO_2 is found naturally on earth and is referred to as a 'trace gas'. Natural sources of carbon dioxide include hot springs, geysers, and carbonate rocks. CO_2 has an excellent capability to dissolve with water and occurs naturally in groundwater, ice caps, and seawater. Moreover, CO_2 can be found in natural gases and petroleum. CO_2 is odourless until concentration, when it develops a mild but sharp odour (Wang, 2015; Yao, 2011). CO_2 is produced by all forms of life that consume oxygen when it provides energy through breathing by treating sugar and lipids. It returns to water through the sputum and to air through the lungs of the local organisms (including humans) that inhale it. CO_2 is produced when natural materials such as hydrogen, natural gas, and petrol are extracted from the ground. Burning wood and other natural materials as well as non-renewable energy resources such as coal, peat, and petroleum gas yields CO_2. To be sure, CO_2 is an adaptable modern material used as inert gas for welding and discharge incinerators, compressed air guns, pressurised gas for oil recovery, synthetic raw materials, and decaffeinated coffee.

3.2.3. Oxides of Nitrogen

Oxides of nitrogen (NO_x) refer to the mixture of gases composed of oxygen and nitrogen. The two main compounds found specifically in these oxides are nitric oxide (NO) and nitrogen dioxide (NO_2). These gases are usually found in the batteries of cars and other vehicles. Both oxygen and nitrogen do not react with each other at a specific ambient temperature of 288.15 K and need more than 1800 K to react (Zheng, 2019). NO_x is very harmful to human health; therefore, proper precautions are necessary when using or producing NO_x. Otherwise, it will create numerous issues and problems for human health. All these environmental aspects should be considered by the management using TeDP because these will impact its efficiency and productivity levels. This study assumes that N3-X is hydrogen-fuelled as proposed by NASA. With this in mind, the economic and environmental assessment was conducted using an input–output method.

4. Viability results

This section represents the results of economic and environmental assessment.

4.1. Results of economic assessment

The turboelectric capital costs estimated for the N3-X—as a case study for a comprehensive turboelectric system—are presented in Table 2. These analysis results are based on the currently (2020) available technologies and standard assumptions.

The results reveal that the motors most significantly affect the capital cost; because the number of electric motors significantly changes the project's economic efficiency, they must be taken into account in developing, manufacturing, and material

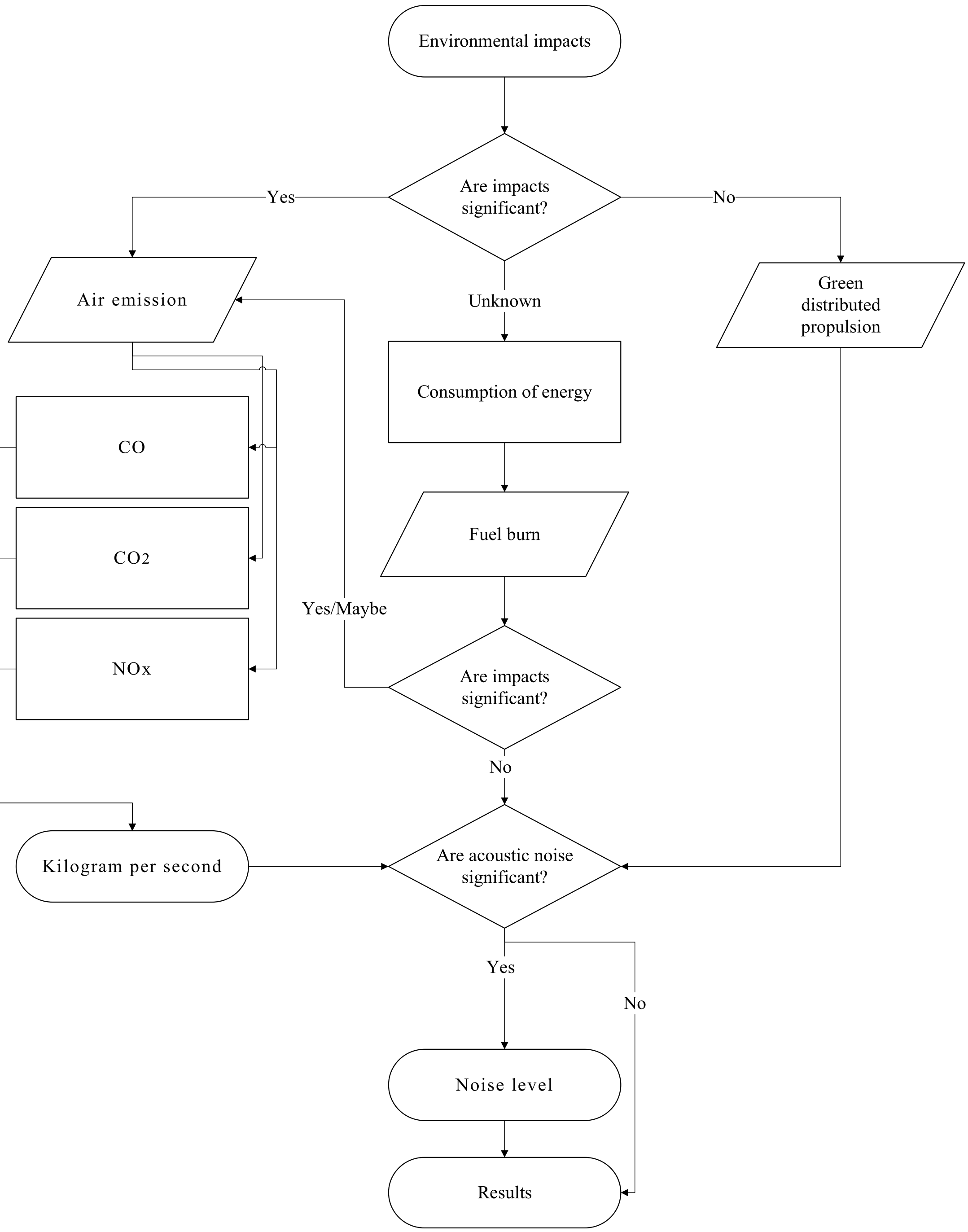

Fig. 1. Environmental model flow chart.

costs. The second most significant cost is the turboshaft, which can be eliminated by using alternative gas turbine engines and models. However, aside from these two essential costs, the unit side cryocooler is a critical economic challenge. The need for the cryocooler depends on the material used for generators and motors—ultimately, this emerges in a cost chain. Therefore, the cost might be waived if a motor model and generator were employed using nanotechnology materials that could withstand high temperatures and maintain stable system performance. In short, this analysis reveals that the three main costs of a TeDP are airframe, motors, and turbofan engines.

The next part of the economic assessment is a cash flow estimation for TeDP. Based on the economic canvas model, the inflow is calculated for the total volume of passengers and cargo of an N3-X aircraft. An aircraft of this segment can carry 300 passengers and their cargo per trip. The estimation was calculated as a worst-case scenario of income at one trip a day per year over 30 years. The outflow for the same segment estimation was based on real fuel and maintenance costs. Table 3 shows the results of this estimation for TeDP cash flow in USD assuming a 30-year running project.

With the results of cash flow for TeDP in hand, the net present value can be calculated to estimate the amount of profitability that might be realised by investing in TeDP. Fig. 2 conveys the TeDP's future stream and present discounted value. The results indicate a net present value of around 2,686,121,608.0 USD based

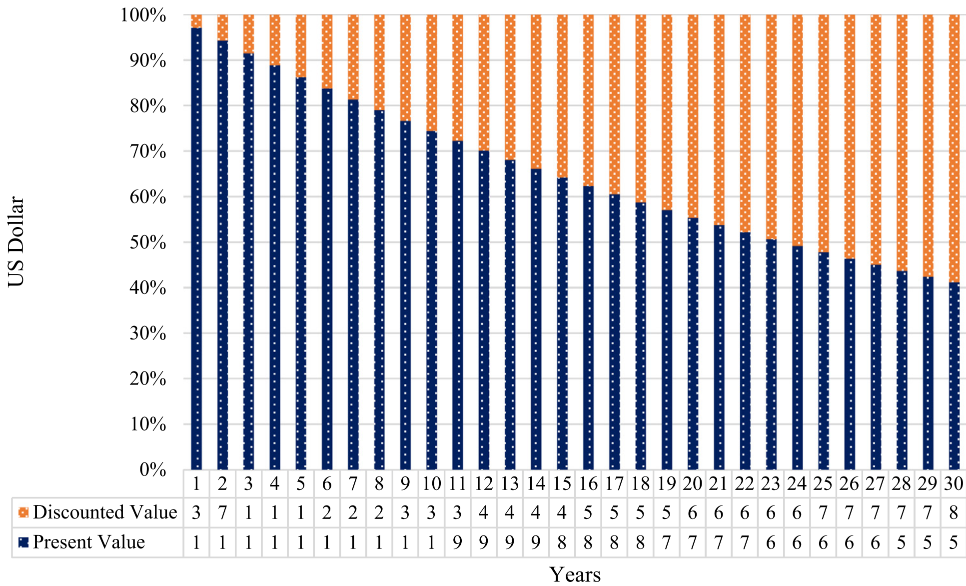

Fig. 2. Net present value chart for NASA N3-X.

Table 2
Estimated capital costs for NASA N3-X (HyperTech, 2020; Partener, 2005; PowerWeb, 2016; Royce, 2008; Rusan and Lazarovich, 2002; Schiferl et al., 2008; Veprik et al., 2012; Yan, 2015).

Turboelectric propulsion capital cost			
Unit	Cost	Number of units	Total
Turboshaft	$ 3,760,000.0/per engine	2	$ 7,520,000.00
Motor	$ 625,000.0/per motor	16	$ 10,000,000.00
Generator	$ 625,000.0/per generator	4	$ 2,500,000.00
Rectifier	$ 1000.0	4	$ 4000.00
Superconductor bus	$ 40.0/m	67.5	$ 2700.00
Cryocooler	$ 2,000,000.0	1	$ 2,000,000.00
Cryoflex	$ 240.0/m	67.5	$ 16,200.00
Total capital cost (TCC)			**$ 22,042,900.00**
Airframe estimation			**$ 320,000,000.00**
Total aircraft cost			**$ 342,042,900.00**
Investment cost			**$ 2,000,000,000.0**
Total			**$ 2,342,042,900.0**

Table 3
NASA N3-X estimated cash flow (Crabtree et al., 2018; Fordham, 1970; IATA, 2016; ICAO, 2013; KAYAK, 2016; Steininger et al., 2011; Tinseth, 2011).

Turboelectric propulsion cash flow			
Inflow ($/nautical mile)		Outflow ($/nautical mile)	
Passengers and cargo	87.0	Fuel Maintenance	−5.843 −18.476
Total	87.0	Total	−24.319
Total income		62.681	
Total in USD			
Income for a year		142,148,605.9	
Income for 30 years		4,264,458,176.0	
Reduction of crew cost		−5,104,671.0 (per year)	
Absolute total in USD			
Income for a year		137,043,934.9	
Income for 30 years		4,111,318,047.0	

Table 4
Net present value for NASA N3-X.

Net present value	
Discount rate	3.0%
Year	**1–30**
Discount factor	0.97-0.41%
Undiscounted cash flow	137,043,934.9
Present value	133,052,364.0-56,460,287.0
Net present value	**2,686,121,608.0**
Discounted value	3,991,571.0–80,583,648.0

Table 5
Internal rate of return (IRR) for NASA N3-X.

		Years 1 to 30		
IRR	3.95%	1 $ −2,342,042,900.0	… $ 137,043,934.9	30 $ 137,043,934.9

on the worst-case profitability, with a 3.0% discount rate. This value gain from the TeDP project situates the investment as acceptable and, to be sure, economically positive.

Table 4 shows the data used in the NPV analysis for the N3-X. It analyses a range of discount factors from 0.97% over the first year through to 0.41% for the last year (i.e., year 30).

The internal rate of return for TeDP was used to evaluate the profitability of potential investments. It was applied to find the correct discounted percentage needed for the project's cash flow to realise an NPV of zero. Table 5 shows the results of NASA N3-X IRR for 30 years, that is, for the aircraft's expected lifetime. The results show that the N3-X has a 3.95% IRR; that is, it has a significantly high potential as a substantial, low-risk investment.

Table 6
Extended internal rate of return (XIRR) for NASA N3-X.

XIRR	4.11%	Years 1 to 30		
		30/06/2019	…	31/12/2047
		$ −2,342,042,900	$ 137,043,934.9	$ 137,043,934.9

Table 7
Payback period for NASA N3-X.

Payback period ($)			
Investment	Year 0	…	Year 30
Cash flows	2,342,042,900	137,043,934.9	137,043,934.9

Table 8
Investment cost for NASA N3-X (Goldberg, 2017; Stuart Harrison, 2015).

Investment cost $/year	
Fuel and maintenance cost	63,466,510.25
Crew cost	5,104,671.0
Operation costs	2,000,000.0
Total	70,571,181.25

For more accuracy and flexibility, the Excel internal rate of return (XIRR) was used for specific dates. Accordingly, the result for 30/06/2019 through 31/12/2047 is approximately 4.11% XIRR. This value is still acceptable for investors and, thus, to keep the project running. Table 6 shows the XIRR results.

Fig. 3 illustrates the IRR chart for the TeDP project; the break-even point between present value and discounted value occurs between years 23 and 24.

To determine the amount of time needed for the cost of investment to be covered, the payback period (PP) method was applied. The IRR and NPV charts show that PP does not need more than 17 years of calculation, and the estimation is based on this assumption. Moreover, the calculated discounted PP with a rate of 3% needs 24.5 years. Table 7 shows the data used for TeDP from year 0 until year 30.

Fig. 4 presents the chart of PP, which shows the time needed to cover the investment cost in year 17. Figs. 4 and 5 present the charts of undiscounted and discounted PP, respectively.

The exact PP is calculated as follows:

$$PP = (\$2{,}342{,}042{,}900)/(\$137{,}043{,}934.9) = 17\text{ Years}$$
$$= 229\text{ Months}$$

From the calculation, the NASA N3-X TeDP investment needs 229 months to cover the cost. This is acceptable considering that 17 years of the project running life represent 56.6% of the assumed operating life cycle of the project. The final economic assessment of the TeDP project's viability, from a financial performance perspective, is based on the economic added value. This method specifies the economic value that TeDP will contribute. To apply EAV, it is necessary to determine the investment cost per year required to sustain the NASA N3-X project. Table 8 shows the investment cost needed for the project per year; this includes fuel, maintenance, crew, and operation costs.

The following assumptions undergird the EAV calculation:

- The tax rate on tickets as income = 7.5% (Faber and Huigen, 2018),
- WACC of 7%–8% (Goldberg et al., 2017),
- WACC of 7.0% for the first year, with a 0.5% annual increase.

EAV was calculated for three years and, as noted above, the PP was less than this period. Table 9 shows this value and the results taken from the former economic analyses. Net operating profit after tax (NOPAT) was calculated as follows:

$$NOPAT = 137{,}043{,}934.9\ X\ (1 - 0.075) = USD\ 126{,}765{,}639.8$$

4.2. Results of the environmental assessment

Table 10 shows the application of this method to TeDP.

After specifying the output air-polluting gas, the amount of gas generated was determined. Table 11 explores the exact amount of output gases for TeDP fuelled by hydrogen. Moreover, Table 12 estimates the perceived noise emission from the TeDP system.

According to the ICAO, there is no penalty for any range of NOx TeDP emissions over the 30 years of operation. Furthermore, the effective perceived noise from TeDP remains below the level that attracts a noise penalty. As a result of this environmental assessment, TeDP is accepted as environmentally friendly—at least for the 30 years that constitute its lifetime.

5. Sustainability analysis

Over the last decades, academic research has witnessed the integration of the social impact of business with management science. Starting from the 1970s, the social responsibility principle has become a critical factor in economic sustainability (Wood, 1991). Whether social engagement is a real need or a waste of effort is still debated in the financial performance discourse (Griffin and Mahon, 1997). However, governments and organisations leave no room for businesses and economic stakeholders to ignore the public good. Therefore, this study considered social welfare to investigate the sustainability of value added to TeDP.

The framework for sustainability, and particularly for social integration and cooperation, in business analysis has not been limited to one model. This flexibility has provided a wider scope for sustainability analysis. In this analysis, sustainability is defined as the relationship between economic, environmental, and social impacts (Ranganathan, 1998; Wartick and Cochran, 1985). Fig. 6 illustrates the sustainability principle and schematic.

The sustainability analysis model in this study assumes two critical factors of social performance engagement and effect:

- *Social gains*: The benefits to transportation users, providers, and local communities surrounding the business firm.
- *Social pains*: The negative impact on the public and the associated risk.

Table 13 represents the analysed social performance for TeDP with its gains and pains to the society.

Combining the three aspects—economic, environmental, and social—of sustainability analysis shows optimism in the triple bottom line sustainability. Regarding the environmental impact, which is the main point analysed, the technology produces almost zero atmospheric emission. As for social performance, the gains from TeDP are twice as much as the pains, resulting in a positive performance. Likewise, the economic assessment shows an added value of $121M each year. Fig. 7 illustrates the TeDP sustainability triple bottom line.

6. Conclusion

This entire assignment is based on an analysis of the economic and environmental effects of turboelectric-distributed propulsion—zooming, in particular. The analysis reveals that TeDP can be effective in aircraft because of its ability to pass the financial and environmental risk assessments outlined herein. The analysis also reveals that TeDP has certain economic and environmental impacts, each of which should be analysed by the concerned departments and management before application. Ultimately, any investments in this project yield a win–win relationship for both investors and aviation organisations.

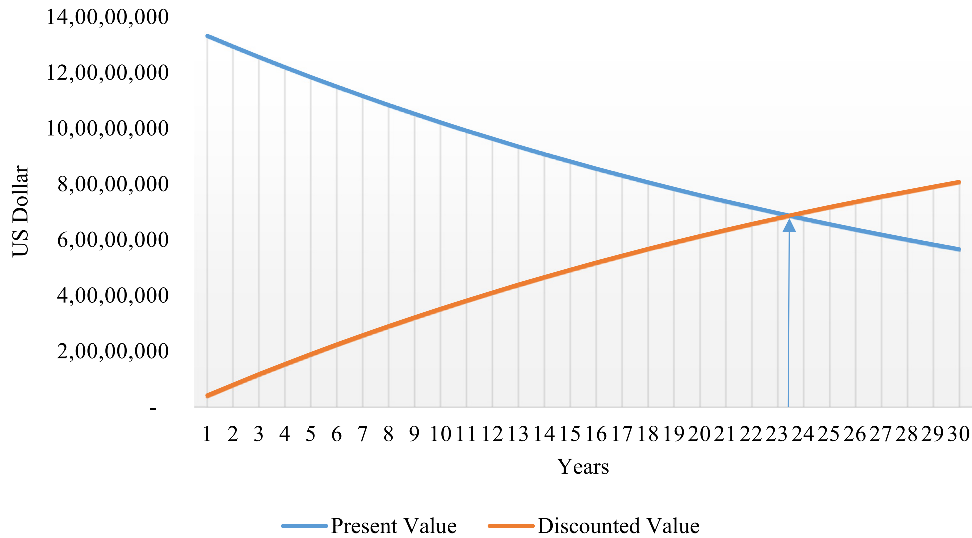

Fig. 3. Internal rate of return chart for NASA N3-X.

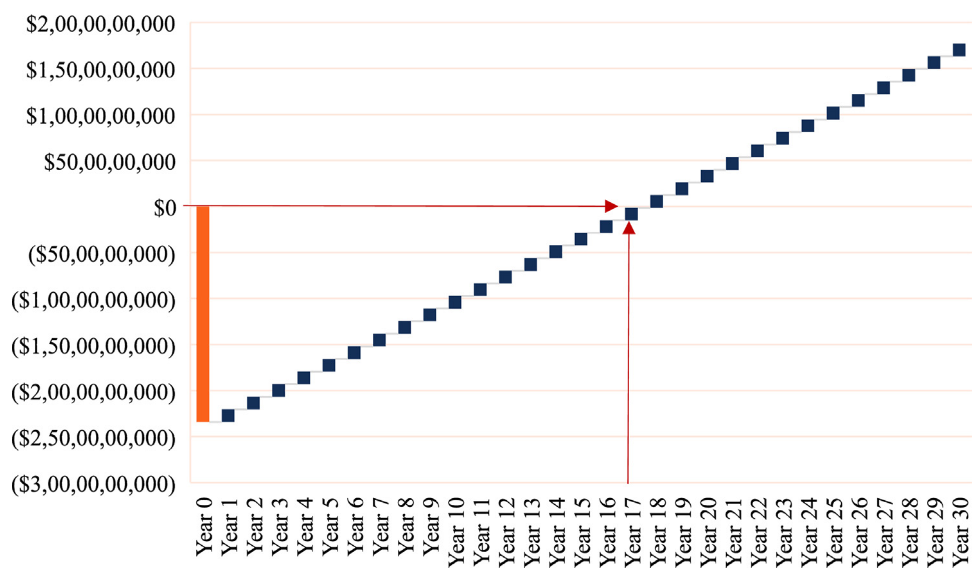

Fig. 4. Undiscounted payback period chart for NASA N3-X.

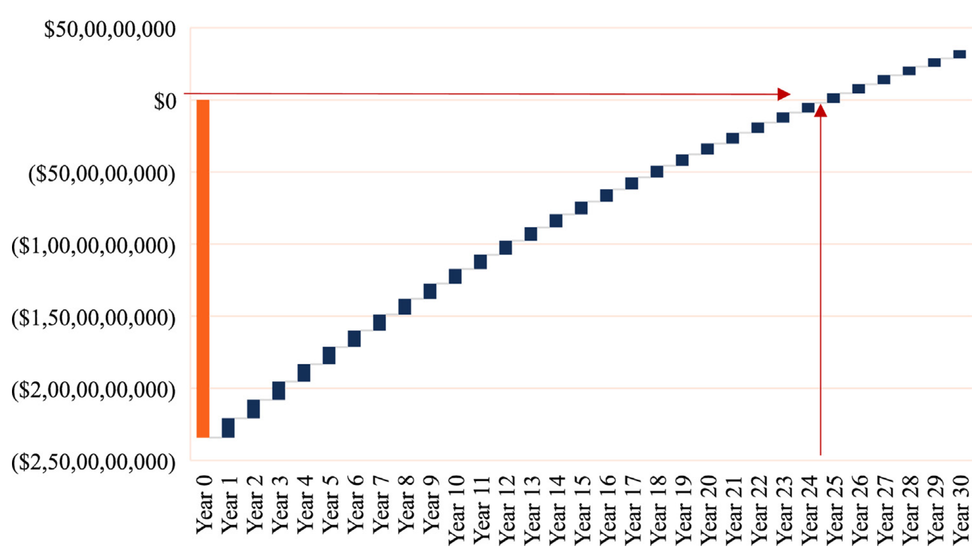

Fig. 5. Discounted payback period chart for NASA N3-X.

Table 9
Economic added value for NASA N3-X.

Economic value added calculation			
Years	**2019**	**2020–2024**	**2024–2029**
Capital invested (beginning of year)	$2,412,614,081	$70,571,181.25	$70,571,181.25
Weighted average cost of capital	7.00%	7.50%	8.00%
Finance charge	**$168,882,985.67**	**$5,292,838.59**	**$5,645,694.50**
Net operating profit after tax	$126,765,639.80	$126,765,639.80	$126,765,639.80
Finance charge	$168,882,985.67	$5,292,838.59	$5,645,694.50
Economic value added	**($42,117,345.87)**	**$121,472,801.21**	**$121,119,945.30**

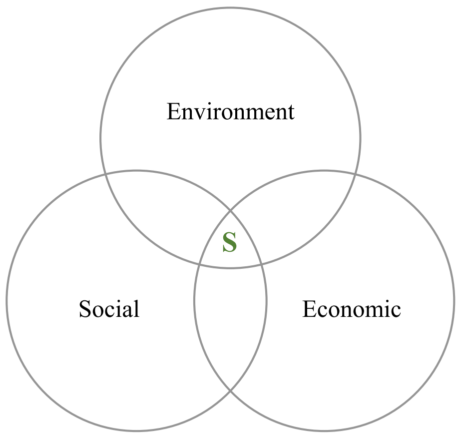

Fig. 6. Sustainability schematic (S represents sustainability).

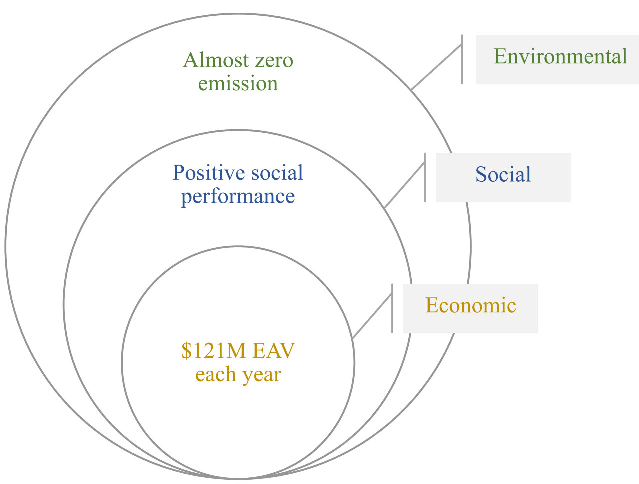

Fig. 7. TeDP sustainability triple bottom line.

An in-depth analysis of the managerial and policy implications is needed since the policy implementation and managerial qualities would shape the future of transportation technology. The literature analysis shows a policy gap in regard to the implementation of TeDP. There are no policies or robust rules to limit the emission of different types of pollutants. Some organisations attempt to shape the implementation of futuristic technologies with targeted goals. There is a need for polices to limit the emissions of NO_x, CO_2, and CO based on scientific principles, with penalties imposed for violation. Thus, managerial strategies to control the application of future technologies need to be formulated to minimise risk and improve quality. Also, a managerial plan to upgrade the legacy systems with more efficient propulsion alternatives is a critical target for governments and stockholders. Nations and organisations need to support these initiatives for the realisation of the global vision of the future.

Table 10
NASA N3-X input–output model.

Input–Output analysis model		
Input → Hydrogen (H_2)	Gas turbine	→ Output Oxides of Nitrogen (NO_x)

Table 11
NASA N3-X emission sizing (Berton and Haller, 2014).

Turboelectric propulsion emission sizing	
Type of emission	Amount (g/kN)
CO	∼0
CO_2	∼0
NO_x	17.6
Total emissions	17.6

Table 12
NASA N3-X effective perceived noise (Berton and Haller, 2014; Follen et al., 2011).

Turboelectric aircraft effective perceived noise	
Lowest noise level	32 dB
Highest noise level	64 dB
Average noise prediction	48 dB

Table 13
TeDP social performance analysis.

Social performance of TeDP
Social gains
• Affordable passenger tickets compared to the conventional system • Cargo flexibility with competitive costs • Improved aircraft cabin • New jobs in TeDP operation, maintenance, and development • Compatible with future regulation of clean sky • In charge of governments future plans for transportation sustainability • Establish new business partners and suppliers • Better local community facilities and housing due to reduced runway length
Social pains
◦ Effect on the number of traditional jobs ◦ Number of legacy business providers and supplies significantly reduced ◦ Passenger concerns about the new technology ◦ New transportation experience

This research has a few methodological and theoretical limitations concerning the availability of real economic cost and environmental data. On the economic aspect, the integration of multiple configurations of TeDP systems with customised services and products is limited. Besides, environmental emission needs to be simulated for different types of fuel and flight conditions. As for avenues for future work, comparison and application of different futuristic propulsion systems could have a significant impact on the knowledge base. Also, key performance indicators for the three bottom lines (social, economic, and environment) could be integrated to illustrate the optimum configuration based on flight conditions, distance, and purpose.

CRediT authorship contribution statement

Mosab Alrashed: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software. **Theoklis Nikolaidis:** Supervision. **Pericles Pilidis:** Supervision. **Wael Alrashed:** Validation, Fnding acquisition. **Soheil Jafari:** Review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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