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Fuel Saving and CO2 Emission Reduction Analysis During Single Engine Taxi-Out Implementation to Airbus A320 at Soekarno Hatta Airport in Jakarta

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Article Info	ABSTRACT
Article History: Submitted: December 29, 2025 Revised : January 05, 2026 Accepted : February 27, 2026 *Keywords:* Single Engine Taxi-Out, fuel efficiency, CO_2 emissions, Airbus A320, sustainable aviation operations.	The aviation industry faces increasing pressure to improve operational efficiency and reduce carbon emissions. This study investigates the potential fuel savings and CO_2 emission reductions resulting from the implementation of Single Engine Taxi-Out (SETO) procedures for Airbus A320 aircraft operating at Soekarno-Hatta International Airport (CGK), Jakarta. Using flight operational data and taxi-out duration observations via FlightRadar24, fuel savings were estimated by comparing conventional dual-engine taxi operations to SETO procedures. Results show that adopting SETO for all A320 departures at CGK could yield annual fuel savings of approximately 8,870,960 kg, equivalent to 28,032,233 kg of CO_2 reduction. The reported annual savings represent a theoretical upper-bound scenario assuming full (100%) SETO adoption, derived from Airbus reference fuel-saving data and a simplified average taxi-time assumption. These findings demonstrate that SETO offers substantial environmental and economic benefits while aligning with ICAO's net-zero emission targets. However, successful implementation depends on rigorous safety assessments, proper crew training, and regulatory approval.

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INTRODUCTION

The global aviation industry contributes a significant share of carbon dioxide (CO_2) emissions, accounting for approximately 2–3 % of total anthropogenic CO_2 emissions worldwide and continuing to grow as air traffic expands [1], [14]. In response to increasing pressures and decarbonization targets, both international policy frameworks and industry stakeholders have prioritized operational strategies that reduce fuel consumption and greenhouse gas emissions across all phases of flight [1], [8]. Among these operational strategies, ground taxi operations represent a notable opportunity for improvement because they consume fuel and emit pollutants while producing no transport benefit other than repositioning the aircraft between terminals and runways.

Fuel usage during ground operations—such as taxi-out and taxi-in—can constitute a non-trivial fraction of total flight fuel burn, especially at high-density airports where taxi durations are prolonged due to surface congestion [8], [10]. Efforts to optimize taxi operations have included technological innovations such as electric taxiing systems and operational procedures such as single engine taxiing (SET), taxi bots, and optimized ground routing [8], [10]. Among these, SET has garnered particular interest because it can be implemented within existing aircraft systems and standard operating procedures (SOPs) with minimal capital expenditure. Previous studies indicate that SET can reduce surface fuel consumption by approximately 20–50 % compared with conventional dual-engine taxiing, depending on taxi duration, aircraft weight, and airport layout [1], [5].

While traditional taxiing procedures maintain all engines operating, SET allows one engine to remain shut down during the majority of the taxi phase, thereby reducing fuel flow and associated emissions of CO_2 and other pollutants such as hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) [5], [6]. Stettler et al. analyzed thousands of flight data records at London Heathrow Airport and demonstrated that SET reduces fuel flow by approximately 27 % and NO_x emission rates by 29 % relative to conventional taxiing, although taxi durations increased moderately [9]. Similar environmental benefits have been reported at other airports; for instance, studies conducted at Kertajati Airport indicate substantial reductions in pollutant emissions during taxi-out when single-engine operations are applied [12].

Despite these advantages, SET adoption remains constrained by operational and human factors, including airline SOPs, air traffic control (ATC) procedures, and perceived safety considerations among flight crews—particularly during departure taxi phases characterized by higher workload and time pressure [7]. Pilot surveys suggest that while SET is commonly encouraged during taxi-in operations, its application during taxi-out remains more limited due to practical flight deck considerations [7]. Furthermore, recent research highlights that limited operational data availability and monitoring capability have constrained broader empirical evaluation of SET implementation, motivating the use of data-driven and model-based approaches [13].

In Indonesia, rapid traffic growth at major hub airports such as Soekarno-Hatta International Airport (CGK) has led to extended taxi-out times and increased cumulative fuel consumption during ground operations [2], [11]. Previous studies have examined the impact of taxi duration on fuel consumption and emissions at Indonesian airports and have indicated that single-engine taxi operations can significantly reduce emissions compared with conventional procedures [11], [12]. However, a comprehensive quantitative assessment focusing on a specific aircraft fleet—such as the Airbus A320—using operational traffic data to evaluate both fuel savings and CO_2 emission reduction attributable to Single Engine Taxi-Out (SETO) procedures at CGK remains limited in the existing literature. Single Engine Taxi (SET) refers to taxi operations conducted with one engine shut down. In this study, the focus is specifically on Single Engine Taxi Out (SETO), which applies to departure taxi operations. This analysis initially assumes that all A320 departures utilize SETO. This idealized assumption is intended to quantify the maximum achievable reduction under full implementation and should not be interpreted as a fully realistic operational condition.

This study addresses this gap by evaluating the fuel saving potential and CO_2 emission reduction resulting from SETO procedures applied to Airbus A320 departures at Soekarno-Hatta International Airport. By integrating operational traffic data with aircraft performance parameters, this research quantifies the environmental benefits of SETO relative to conventional taxi operations and provides actionable insights for airlines, airport operators, and regulators seeking to enhance operational sustainability.

METHODS

SETO

This study adopts a quantitative observational approach to evaluate improvements in fuel efficiency achieved through the implementation of Single Engine Taxi-Out (SETO) procedures in commercial aircraft operations, with a specific focus on the Airbus A320 fleet. To obtain a conservative estimate of fuel savings, all aircraft are assumed to be equipped with LEAP-1A engines, representing a modern and fuel-efficient engine configuration.

The analysis utilizes flight operational data provided by the Directorate General of Civil Aviation, Ministry of Transportation of the Republic of Indonesia [2], supplemented and validated through online observations using FlightRadar24. The scope of the study is limited to domestic Airbus A320 departures from Soekarno-Hatta International Airport (CGK) to ensure fleet homogeneity and consistency in operational characteristics. Baseline fuel consumption during conventional taxi-out operations was estimated by recording taxi-out durations from pushback clearance to runway line-up using FlightRadar24. Given that CGK operates multiple runway entry and exit points, taxi-out times were recorded across different terminal–runway combinations to capture representative operational variability. These observed taxi-out durations were subsequently used as input parameters in the fuel saving calculations described in the equation 1.
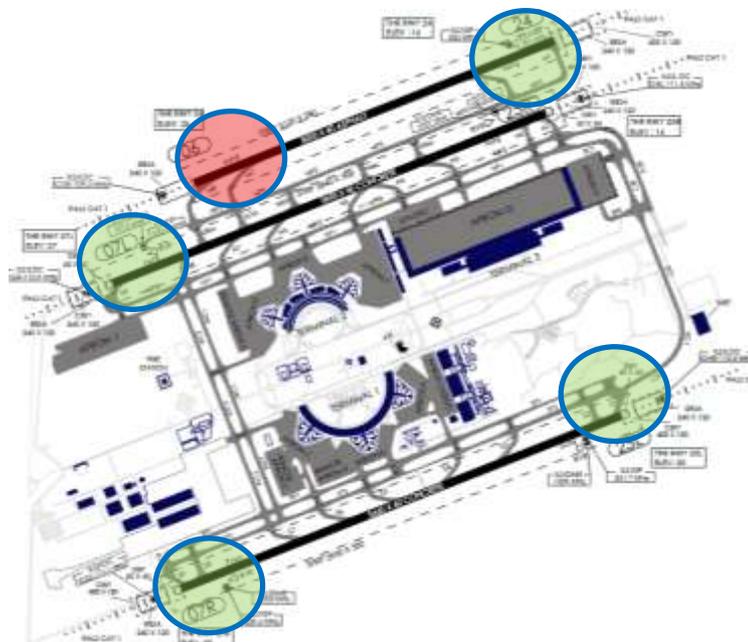

Figure 1 Aerodrome chart Soekarno Hatta Airport [3]

Runways 06 and 24 represent the newest runway developments by the airport authority and are designated exclusively for landing operations due to their proximity to Runways 07L and 25R, which handle parallel traffic. Consequently, these two runways are excluded from the calculations in this study. Subsequently, the observed taxi-out time and number of flights were combined with estimated single-engine taxi fuel consumption rates, whereby fuel consumption was modeled as a variable function. The

fuel savings attributable to SETO were referenced from Airbus Getting to Grips with Fuel Economy. Based on this reference, the potential reduction in fuel consumption during single-engine taxi operations was determined and subsequently converted into the corresponding reduction in CO_2 emissions.

Figure 2 illustrates the variation of taxi-out time from terminal (T1, T2, and T3) to different runway entry points at Soekarno-Hatta International Airport (CGK). The taxi-out times are presented for departures toward Runways 07R, 25L, 07L, and 25R, representing the primary departure runways used in daily operations.The results show that taxi-out duration varies significantly depending on both terminal location and runway assignment. Aircraft departing from Terminal 2 (T2) generally experience the longest taxi-out times, particularly for operations toward Runway 25L, where taxi durations reach up to approximately 25 minutes. This can be attributed to the longer taxi distance and the need to cross or sequence with parallel runway traffic. These results are consistent with the spatial configuration of the airport as depicted in Figure 1. In contrast, departures from Terminal 1 (T1) exhibit moderate taxi-out times, typically ranging between 10 and 20 minutes, depending on runway direction. Meanwhile, Terminal 3 (T3) shows comparatively shorter taxi-out durations, especially for departures toward Runways 07R and 25R, where taxi times are observed to be approximately 5–10 minutes. This reflects the more favorable geometric proximity of Terminal 3 to certain runway access points.Overall, the figure highlights that airport layout and runway configuration play a critical role in determining taxi-out duration, which directly influences fuel consumption and emissions during ground operations. The observed variability reinforces the importance of adopting operational measures such as Single Engine Taxi-Out (SETO), particularly on longer taxi routes where fuel saving potential is highest.
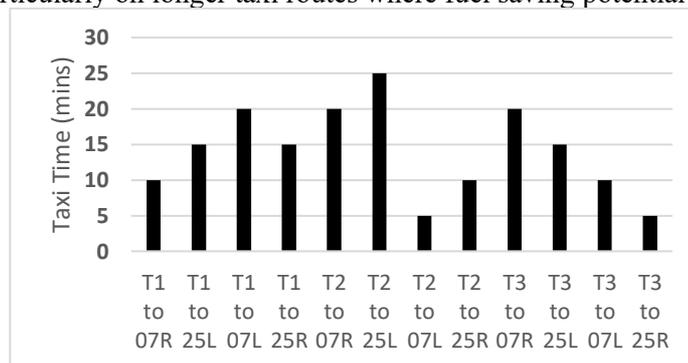

Figure 2 Total taxi time from terminal to runway line up

Table 1 presents the weekly flight frequency distribution of domestic routes operated by Airbus A320 aircraft departing from Soekarno-Hatta International Airport (CGK). The listed routes represent a wide range of short- to medium-haul domestic destinations, reflecting the dominant role of the A320 fleet in Indonesia's domestic air transport network. The data indicate that traffic density is highly uneven across routes, with a small number of high-frequency routes accounting for a substantial proportion of total departures. Routes such as CGK–DPS (303 flights per week), CGK–KNO (155 flights per week), CGK–PLM (98 flights per week), CGK–SUB (97 flights per week), and CGK–PDG (91 flights per week) dominate the operational profile. These routes typically experience high daily departure rates and are more susceptible to surface congestion, which can result in extended taxi-out times, as illustrated previously in Figure 2. Conversely, several routes exhibit relatively low weekly frequencies (e.g., CGK–PKN, CGK–MLG, CGK–SOC), yet collectively contribute to sustained background traffic levels throughout the day. This combination of high-frequency trunk routes and numerous lower-frequency routes leads to continuous runway and taxiway utilization, reinforcing the importance of optimizing ground operations to reduce cumulative fuel consumption and emissions. The distribution shown in Table 1 provides the empirical basis for estimating the total number of Airbus A320 departures used in the SETO fuel-saving and emission reduction calculations.

Table 1 Flight frequency at Soekarno Hatta Airport [2]

Route	Freq. Per Week
CGK - MLG	7
CGK - SOC	7
CGK - AAP	7
CGK - BWX	10
CGK - PGK	35
CGK - SOQ	7
CGK - KOE	7
CGK - BKS	14
CGK - TJQ	10
CGK - KDI	7
CGK - BTH	49
CGK - DPS	303
CGK - PKN	3
CGK - SRG	11
CGK - SUB	97
CGK - LBJ	8
CGK - KNO	155
CGK - PDG	91
CGK - PLW	7
CGK - AMQ	7
CGK - TKG	21
CGK - TNJ	7
CGK - DTB	14
CGK - MDC	7
CGK - LLJ	10
CGK - BPN	56
CGK - UPG	41
CGK - PLM	98
CGK - PKU	63
CGK - DJB	42
CGK - PNK	77
CGK - BDJ	49
CGK - PKY	7
CGK - YIA	33
CGK - LOP	31

Table 2 summarizes the aggregated operational frequency of Airbus A320 departures from CGK, derived from the route-level data presented in Table 1. The total number of 3,040 departures per week corresponds to an average of 434 departures per day, or approximately 18 departures per hour. This high departure intensity confirms that Soekarno-Hatta International Airport operates under high-density surface traffic conditions, where even modest per-flight fuel savings during taxi-out can accumulate into substantial annual reductions in fuel consumption and CO_2 emissions. When combined with the taxi-out time variability observed in Fig. X, the frequency data underscore the strategic relevance of implementing Single Engine Taxi-Out (SETO) procedures, particularly during periods of moderate to low congestion where operational feasibility is highest. The frequency values in Table 2 are subsequently used to extrapolate per-flight fuel savings to daily and annual scales, enabling a realistic assessment of the potential environmental impact of SETO adoption across the Airbus A320 fleet operating at CGK.

Table 2 Summary of Total Frequency

Aircraft Type	Freq. per week	Freq. per day (average)	Freq. per hour (average)
A320	3040	434	18

Fuel savings are calculated by subtracting the fuel consumption during single-engine taxi operations from the fuel consumption of conventional all-engine taxi operations. The calculation also accounts for the engine warm-up period, as the second engine must be started prior to takeoff. According to Airbus procedures, the additional engine is required to be started approximately four minutes before takeoff to ensure proper warm-up. Engine 1 is started first to provide the Green hydraulic system for normal braking and the Yellow hydraulic system for nose wheel. [4].
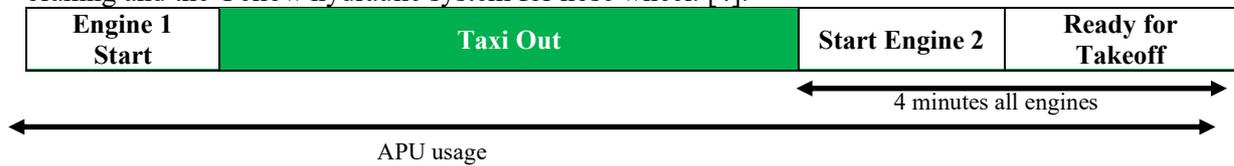

Figure 3 Time Frame A320 From Engine Start to Line Up Runway

According to Airbus A320 operating procedures, the Auxiliary Power Unit (APU) must remain active during single-engine taxi operations. In the event of an engine failure during taxi, the operative engine can be started immediately using APU power. Therefore, APU fuel consumption during both the single-engine taxi phase and the engine warm-up period prior to takeoff must be taken into account and incorporated into the following equation:

FS = [(Eng. 1 cons. + Eng. 2 cons.) – (Eng.1 cons + APU cons)] x (TT + 4)   (1)

Fuel Consumption

After completing aircraft preparation and prior to pushback, the flight crew must assess whether single-engine taxi-out is feasible under the prevailing operational conditions. Engine taxi-out requires increases thrust from the operative engine to overcome breakaway forces and execute 180 degree turns, elevating jet blast and FOD risk. For A320 at high gross weight, tight turns toward the operative engine may be performance limited. At lower weight, single engine taxi can reduce brake energy demand and associated carbon brake wear compared to all engine taxi [5]. Table 3 provides potential advantages of single-engine taxi, assuming 8 minutes of taxi time conducted with a single engine and 4 minutes allocated for engine warm-up [3].

Table 3 Fuel savings with Engine out taxi

Aircraft Type	12 minutes taxi (all engines)	12 minutes taxi (8 with engine out)	Engine Out taxi savings
A300-600	300 kg	200 kg	100 kg
A310	240 kg	160 kg	80 kg
A318	120 kg	80 kg	40 kg
A319	120 kg	80 kg	40 kg
A320	138 kg	92 kg	46 kg
A321	162 kg	108 kg	54 kg
A330	300 kg	200 kg	100 kg
A340-200/300	300 kg	250 kg	50 kg
A340-500/600	420 kg	350 kg	70 kg

For engine out or all engines taxi, the use of a slow taxi speed costs fuel and time. A burst of power should be used to get the aircraft to taxi speed, then the power should be reduced to idle. However, 30kt should not be exceeded. [5]

Emission Factor

The Airbus A320 is equipped with CFM56, IAE V2500, or LEAP-1A engines, all of which utilize Jet A-1 fuel as the standard. For the purpose of this study, it is assumed that all aircraft traffic at the airport operates exclusively on Jet A-1 fuel, with no Sustainable Aviation Fuel (SAF) blended into the supply,

thereby representing 100% Jet A-1 usage. Once the total fuel consumption has been determined, the corresponding CO_2 emissions are calculated using an emission factor of 3.16 kilograms of CO_2 per kilogram of Jet A/A-1 fuel [15].

RESULT AND DISCUSSION

This study evaluates the potential fuel savings and CO_2 emission reductions associated with the implementation of Single Engine Taxi-Out (SETO) procedures for Airbus A320 departures at Soekarno-Hatta International Airport (CGK). For the purpose of assessing the maximum achievable environmental benefit, it is initially assumed that all A320 departures are conducted using SETO. This assumption represents an upper-bound scenario and allows the cumulative impact of SETO adoption to be quantified at the airport level. In practice, the feasibility of SETO implementation depends on multiple operational factors, including aircraft technical capability, flight crew training and workload, airline standard operating procedures, and airport-specific safety risk assessments.

Based on the taxi-out time distribution presented in Figure 2, the average taxi-out time during low-traffic periods—such as late night or off-peak daytime operations—was determined to be 11.4 minutes, measured from pushback clearance to runway line-up. Low-traffic periods were selected as the reference condition to ensure a conservative and operationally realistic baseline, minimizing the influence of excessive surface congestion or atypical delays. In accordance with Airbus operational procedures, a four-minute engine warm-up period prior to take-off is required, during which both engines must be operating. Consequently, the effective single-engine taxi duration is reduced to 7.4 minutes, after accounting for the warm-up requirement and continuous APU operation.

To estimate the fuel consumption for the mixed taxi scenario, the fuel flow rates for both all-engine and single-engine taxi operations were first derived from the reference data. Based on table 3, under conventional all-engine taxi conditions, 12 minutes of taxi-out correspond to a fuel consumption of 138 kg, yielding an average fuel flow rate of 11.5 kg/min.

The resulting per-flight fuel saving and associated CO_2 emission reduction are summarized in Table 5. For an average taxi-out duration of 11.4 minutes, the implementation of SETO yields an estimated fuel saving of 56 kg per departure, corresponding to a CO_2 emission reduction of approximately 172.2 kg. For the mixed-operation case, consisting of 4 minutes of all-engine taxi and 8 minutes of single-engine taxi with a total fuel consumption of 92 kg, the fuel used during the all-engine portion is calculated as $4 \times 11.5 = 46$ kg. The remaining 46 kg is therefore attributed to the 8-minute single-engine segment, yielding an estimated single-engine fuel flow rate of 5.75 kg/min.

Table 4 Fuel and CO2 Reduction During SETO

Description	Fuel Consumption (kg)	Result Description
Fuel for 4 minutes all-engine	46	Warm-up and all-engine operation
Fuel for 7.4 minutes single-engine taxi out	42.55	Single engine taxi out fuel
Total fuel consumption	88.55	4 minutes all-engine and 7.4 single-engine

For an 11.4-minute taxi-out under full all-engine operation, the estimated fuel consumption is 131.1 kg, based on a fuel flow rate of 11.5 kg/min. In comparison, a mixed configuration consisting of 4 minutes of all-engine and 7.4 minutes of single-engine taxi results in a total fuel consumption of 88.55 kg, this represents a fuel saving of approximately 42.55 kg per departure. These values are consistent with previous studies reporting fuel savings in the range of 40–60 kg per A320 taxi-out under similar operational conditions, thereby validating the adopted methodological assumptions.

Table 5 Fuel and CO2 Reduction During SETO

Total Taxi Out Time (minutes)	Warm Up (minutes)	Total SETO Time (minutes)	Engine Out taxi savings (kg)	CO2 Reduction (kg-CO2)
11.4	4	7.4	42.55	134.4

During low-traffic periods at CGK, Airbus A320 aircraft dominate domestic departure operations, as previously demonstrated in Tables 1 and 2. The aggregated traffic data indicate an average of 434 A320 departures per day, reflecting the high utilization of this aircraft type at the airport. When the per-flight fuel saving obtained from Table 5 is extrapolated across the daily operation volume, the cumulative impact becomes substantial. As shown in Table 5, full implementation of SETO across all A320 departures would result in an estimated annual fuel saving of approximately 6.6 million kilograms, corresponding to a CO_2 emission reduction of approximately 20.8 million kilograms per year.

These results highlight the non-linear amplification effect of operational frequency: although the per-flight fuel saving appears modest, the high departure rate at a major hub airport such as CGK transforms incremental efficiency gains into significant annual environmental benefits. Furthermore, the results emphasize that SETO is particularly effective at airports with long and variable taxi-out times, where ground operations contribute disproportionately to total fuel burn.

Table 6 Fuel and CO2 Reduction During SETO For A320 Departure

Engine Out Taxi Savings (kg)	CO2 Reduction (kg-CO2)	Freq. per day in average	Total Fuel Reduction Per Year (kg)	CO2 Reduction (kg-CO2)
42.55	134.4	434	6,648,012	20,874,757

It should be noted that the values presented in Tables 5 and 6 represent an idealized scenario intended to quantify the upper-limit potential of SETO implementation. In real-world operations, factors such as adverse weather, high surface traffic density, short taxi distances, and specific airline operational policies may reduce the achievable adoption rate. Nevertheless, even partial implementation of SETO—such as 50–70 % of departures—would still yield meaningful reductions in fuel consumption and CO_2 emissions, reinforcing SETO as a practical and immediately deployable measure within broader aviation decarbonization strategies.

CONCLUSION

Single-engine taxi-out (SETO) is one of the fuel efficiency initiatives increasingly encouraged by airlines as part of their operational management strategies. Its implementation has a direct impact on cost reduction and contributes to carbon emission monitoring programs.

Soekarno-Hatta International Airport (CGK) is among the busiest airports in the world, serving both domestic and international traffic. In this study, the adoption of SETO is shown to have a significant environmental impact. Assuming that all Airbus A320 operations at CGK implement SETO, the potential annual fuel savings are estimated at 6,648,012 kilograms, corresponding to a reduction of approximately 20,874,757 kilograms of CO_2 emissions. These results align with ICAO's long-term goal of achieving net-zero carbon emissions in aviation by 2045 through the use of Sustainable Aviation Fuel (SAF) and complementary efficiency measures.

Nevertheless, several factors may hinder the full implementation of SETO in practice, with safety considerations being the most critical. This poses a challenge for airlines, requiring them to ensure that all operational, technical, and regulatory requirements are fulfilled and formally approved by the local aviation authority.

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