33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

Kinetic Energy Recovery from a Landing Aircraft: Energy Analysis, Environmental and Economic Prospects

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Abstract

The Intergovernmental panel on Climate Change has sounded its alarm through its special report on the impact of global warming of 1.5ºC and called for a strengthened global response to the threat of climate change. Despite that the COVID-19 pandemic has left a devastating effect on the aviation industry, this is forecasted to bounce back and recover within a few years. It is therefore important now to revisit opportunities for a better balance between social, environmental and economic impact of the sector. The European Union has been leading the way in limiting the environmental impacts of aviation. Despite that most of the R&D effort has been focused on the airborne phase, the European Union is legislating so that all aircraft movements on the ground are set to be emission-free by 2050. The paper focuses on engineless aircraft taxiing with the aim to reduce emissions on the ground. We demonstrate that upon landing, an aircraft has enough kinetic energy, which if recovered could power a 5-minute engineless taxiing process. When scaled to a large fleet such as low-cost carriers, this emissions problem can be turned on its head and becomes an opportunity for fuel savings and a reduction in emissions on the ground. The paper also demonstrates that the cost to retrofit such technology can be recovered in a short timeframe and therefore there is an economic incentive to the airline.

Keywords: kinetic energy recovery, engineless taxiing

1. Introduction

This paper addresses the emissions of aircraft on the ground and proposes a novel concept for recovering energy from a landing aircraft. The energy is temporarily stored and used to allow engine-less taxiing. Aviation connects people, enabling commercial and cultural exchanges. It supports 87.7M jobs worldwide and contributes over €911 billion to the global economy. In the past two decades, air transportation experienced a yearly growth of 4.5%. Yet only around 10% of the global population have access to air travel. As more countries are pulled out of poverty, these two would want to travel. Therefore, despite that aviation accounts only about 2% of the global emissions, its contribution is expected to grow. While the COVID-19 pandemic has left devastating effects on the aviation industry, this has time and again demonstrated to be a resilient one. The aviation industry is forecasted to bounce back and experience significant growth by 2050. It is therefore important now to revisit the opportunities for a better balance between social, economic and environmental impact of the sector.

The European Union has been a leading force in curbing the environmental impacts of aviation. Flightpath 2050 [1] presents a strategy to achieve air travel in a sustainable manner while continuing to serve society's demands. The strategy set aggressive targets to reduce in flight CO_2 emissions by 70% and NOx emissions by 90% and a reduction of noise when compared to the year 2000. Despite that most of the R&D effort has been focused on the airborne phase, the European Union is legislating so that all aircraft movements on the ground are set to be emission-free by 2050 [3]. Airport carbon footprint analysis and accreditation demonstrate that aircraft ground movement accounts between 5-20% of all airport emissions [4]. Conventionally, thrust engines used during taxiing are set at 7% power setting while applying brakes on. A typical 10-minute aircraft taxiing process consumes approximately 100 kg of fuel with a considerable amount of carbon and NOx pollutants released at ground level. The reduction of emissions on the ground is important as it has strong links with respiratory illnesses, amongst others. As airports and cities continue to grow, these get in closer proximity to each other, heightening the effects of the problem.

To address this, a number of engineless taxiing concepts have been developed. These solutions can be grouped into onboard electric taxiing and external ground propulsion systems. Examples of onboard taxiing systems include The Electric Green Taxiing System (EGTS) project [5] and WheelTug [6]. EGTS developed electric motors for the main landing gear to enable aircraft to taxi autonomously under their own electric power. However, additional resistor banks were also required so that on landing the energy generated by the motor is dissipated into heat. Conversely, WheelTug installed twin electric motors in the aircraft nose wheel. However, this resulted in a prevailing concern that the nose gear drive system would not have sufficient traction in adverse weather conditions or an inclined ramp. The project was later re-focused for aircraft parking and pushback which limited its effectiveness. Both onboard solutions concluded that whilst motor technology was viable, the auxiliary power unit (APU) had to be redesigned such that the generator would be able to supply also electrical power to the in-wheel motors. This would result in a costly retrofit and an excessive addition in weight, thus offsetting any benefits on the ground to the inflight portion.

External ground propulsion solutions have been explored through specialized tow trucks, such as TAXIBOT [7] which carries the aircraft from the gate to the end of the runway. While this provides savings in airline fuel consumption, CO_2 and noise emissions around airports, they require a significant investment in tow truck fleet and added taxiway infrastructure to accommodate increased ground vehicle traffic. The increase in vehicle movement on airport grounds may also lead to higher accident risks and requires additional logistical management processes to avoid departure delays caused by the assignment of tow trucks. Despite the tow truck technology being successfully tested, there is a lack of air traffic operational procedures to deploy these new taxiing methods. New profit-sharing models also need to be implemented since while the airports are required to do the investment, the airlines are the ultimate beneficiaries through lower fuel consumption.

The environmental impact of the various taxiing techniques with reference to the baseline standard taxiing method was studied [8]. It was shown that onboard technologies have lower taxiing emissions than fuel powered tow-trucks. The latter can only be truly effective if electric trucks are used and the energy used to charge their batteries is provided by a high percentage of renewables with low emission index. Onboard solutions offer fewer logistical challenges to implement and allow aircraft to maintain their autonomy in airport operations. This characteristic is preferred by airlines which are keen to remove dependencies. However, the upgrade of the APU required to power the electrical motor is a major hurdle to retrofit the existing fleet towards zero-emission taxiing.

This paper addresses this shortcoming in onboard solutions and proposes that upon landing, the kinetic energy of the aircraft is harvested and temporarily stored so that it then enables engine-less taxiing to the gate. At the gate, the energy storage device can be recharged through the grid, allowing the aircraft to perform also an engine-less taxi-out process. The main engines would only be turned on for the warm up time before take-off. A schematic of the concept of operation for KERS upon landing is shown in Figure 1.

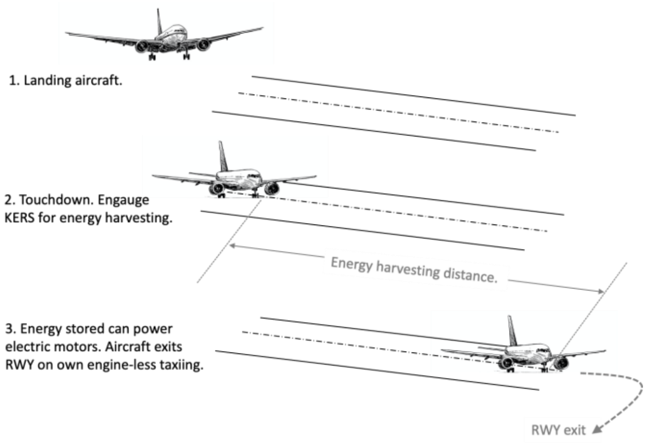


Figure 1: Schematic of the KERS concept for a landing aircraft

The concept studied here uses electrical motors installed at the wheels to produce regenerative braking during landing. This energy us stored temporarily into an energy storage device and is then transferred back to the wheels for engineless taxiing. A schematic of the components required and the energy flow between them is shown in Figure 2. While the application of KERS to aircraft has been explored [9], to the authors knowledge, this analysis is incomplete. This paper is therefore aims to fill the remaining gaps and is organised as follows: Section 2 produces an energy analysis by comparing the energy available from a typical single isle aircraft and the energy demands for a taxiing procedure. This ensures that the concept is feasible. Section 3 discusses the operational modes of low cost carriers within regional airports. This is important as it serves as the model upon which the following discussion on the environmental gains discussed in Section 4 and the economic opportunities discussed in Section 5 are assessed. A conclusion is drawn in Section 6.

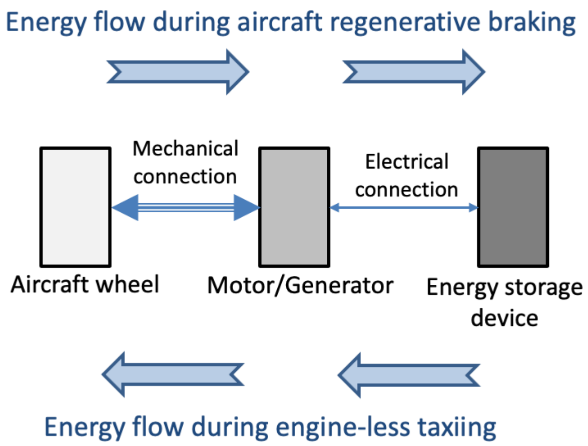


Figure 2: Schematic of the KERS components and energy flow

2. An Energy Analysis

2.1 Energy availability from a landing aircraft

The kinetic energy during landing has been defined in [9] as:

$$K.E. = \frac{1}{2} * (M_1 - M_f) * (v_{lan}^2) \qquad (1)$$

where M_1 is the Maximum Takeoff Weight (MTOW) of the aircraft, M_f is the mass of fuel burnt and v_{lan} is the landing speed. The mass of fuel burnt during the flight envelope can be computed using the following equation:

$$M_f = M_1 \left[1 - \exp\left\{ \frac{-s_{gr}}{H_{cr}\left(1 - \frac{V_{HW}}{M_{cr}\sqrt{\gamma R T_{cr}}}\right)} \right\} + \frac{\Delta M_{lost}}{M_1} - \frac{\Delta M_{rec}}{M_1} \right] \qquad (2)$$

where M_1 is the Maximum Takeoff Weight of the aircraft, s_{gr} is the ground track distance between two airfields, H_{cr} is the range factor, V_{HW} is the head wind velocity, M_{cr} is the cruise Mach number, T_{cr} is the temperature at cruise, γ is the specific heat, R is the gas constant os air, ΔM_{lost} is the fuel lost during climb and ΔM_{rec} is the fuel recovered during descent and landing segment of the flight.

As can be shown in (1) and (2), the energy available from a landing aircraft is dependent on the mass of fuel burnt during flight and flight time. To quantify this energy, this study considered a single aisle aircraft Boeing 737-800, with a flight time ranging between 1 – 3 hours. Data for the aircraft is shown in Table 1.

Table 1: Data for Boeing 737-800

Parameter	Symbol	Value	Units
Max. Take-off Weight	M_1	75300	kg
Range factor	H_{cr}	21666.7	km
Cruise Mach number	M_{cr}	0.785	
Temperature at cruise	T_{cr}	218.16	K
Fuel lost during climb	ΔM_{lost}	1536.12	Kg
Fuel recovered during descent	ΔM_{rec}	45.18	kg

To establish the energy available for the various flight times, this study considered Malta as the landing airport, as shown in Figure 3. The ground track distance was established [10] between the respective airports of Roma Fiumicino International Airport, Zurich Airport, London Heathrow and Malta International Airport.

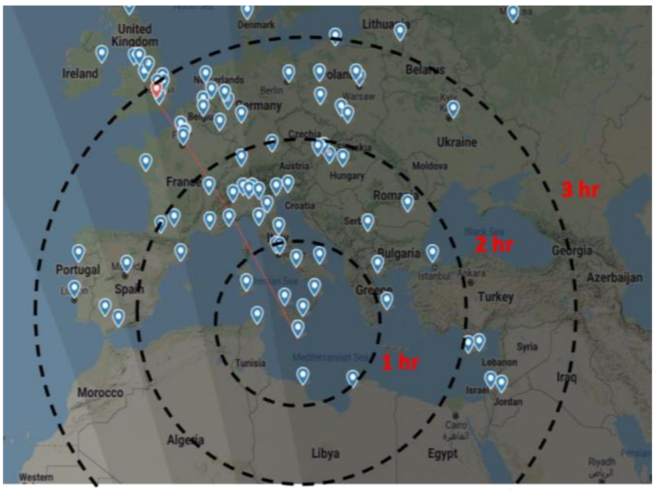


Figure 3: Examples of flight times between 1-3 hours from Malta, the southernmost country in Europe.

During landing, aircraft deploy a number of mechanisms to slow down such as aerodynamic spoilers, thrust reversers and wheel brakes. This study does not change this process. Since the proposed system recovers only the energy that would have otherwise gone into wheel braking, the amount of useful energy that can be harvested equates to:

$$Useful\ energy = 0.33 * (K.E.) \quad (3)$$

Table 2 shows that as the flight time increases, less energy is made available due to the higher fuel burn and lower aircraft mass.

Table 2: Useful energy from a landing aircraft according to flight time

Scenario	Mass of fuel burnt (Mf) (kg)	Useful energy (MJ)
Airports within a maximum of 1 hr distance from Malta	2257.2-4042.2	70.0-71.8
Airports within a maximum of 2 hr distance from Malta	4511.0-6794.3	67.3-69.6
Airports within a maximum of 3 hr distance from Malta	6411.5-8963.4	65.2-67.7

The range in fuel burn shown in Table 1 is due to the different distances within the zone from the landing airport. However, this is not seen to have a large impact on the useful energy of the landing aircraft. The useful energy for a landing aircraft from a 1-hour flight was found to be around 71 MJ. For every additional hour of flying time, the kinetic energy available is reduced by approximately 2 MJ. Having estimated the energy availability from a landing aircraft, the focus of the following section is turned on estimating the energy required for taxiing. This energy availability and energy requirements are then compared to establish if the concept of energy recovery in an aircraft is feasible.

2.2 Energy required for aircraft taxiing

In current taxiing operations, aircraft using their main thrust engines at 7% power setting with brakes applied. To establish the energy requirement of a taxiing process, this paper uses a method by which the taxiing route is analyzed and broken down into a mathematical model. The energy required for taxiing an aircraft along an established route is then computed. This is dependent on the taxiing velocity, acceleration and standard airport taxiway characteristics as shown below:

$$\mathrm{A_{tot}} = \sum_{i=1}^{n} \mathrm{A_i} = \sum_{i=1}^{n} \left(\int_{s_{i-1}}^{s_i} \mathrm{F_i ds}\right) = \sum_{i=1}^{n} \left[\int_{t_{i-1}}^{t_i} \mathrm{F_i v_i(t) dt}\right] \quad (4)$$

Where: A_{tot} is the total energy, F_i is the force, *ds* is a small distance, v_i is the velocity and *dt* is a finite time, *n* is the number of segments in the taxiway.

Using Newton's second law of classical mechanics, the total force (in horizontal direction) acting on an aircraft during taxiing operation can be written as:

$$\mathrm{Force} = \mathrm{M_A a} = \mathrm{M_A.K.}\frac{\mathrm{dv}}{\mathrm{dt}} = \mathrm{F_{tract}} - \mathrm{D_a(v)} - \mu_{\mathrm{CRR}}(\mathrm{v}).\mathrm{W_A}.\cos\varphi - \mathrm{W_A}.\sin\varphi \quad (5)$$

Where: *v* is the instantaneous groundspeed and *a* is the instantaneous translational acceleration. W_A is the aircraft weight, M_A is the aircraft mass and *g* is acceleration due to gravity. F_{tract} is the traction force, D_a is the aerodynamic drag, μ_{CRR} is the rolling coefficient and φ is the taxiway slope in radians. For small angles $\varphi,\ \cos\varphi = 1,\ \sin\varphi = \varphi$

Equation (2) can be rearranged to establish the traction force as follows:

$$\mathrm{F_{tract}} = \mathrm{M_A.K.}\frac{\mathrm{dv}}{\mathrm{dt}} + \mathrm{D_a(v)} + \mathrm{\mu_{CRR}(v).W_A} + \mathrm{W_A.\varphi} \quad (6)$$

Hence the energy required can be achieved by substituting the traction force (3) into (1):

$$\mathrm{A_{tot}} = \sum_{i=1}^{n}\left(\int_{t_{i-1}}^{t}\left(\mathrm{M_A.K.}\frac{\mathrm{dv}}{\mathrm{dt}} + \mathrm{D_a(v)} + \mathrm{\mu_{CRR}(v).W_A} + \mathrm{W_A.\varphi}\right) * \mathrm{v_i(t)} * \mathrm{dt}\right) \quad (7)$$

The rolling resistance μ_{CRR} was defined as:

$$\mu_{CRR} = \mu_0\left[1 + \frac{v}{v_0}\right] \quad (8)$$

Where: μ_0 is the rolling resistance constant (assumed to be 0.01), *v* is the aircraft velocity and v_0 is a reference point of 25.7 m/s, (50 knots).

The aerodynamic drag was computed using:

$$\mathrm{D_a} = \mathrm{G.}(\mathrm{v} + \mathrm{v_w})^2 \quad (9)$$

Where G is defined as:

$$\mathrm{G} = \frac{1}{2}\rho_{SL}\mathrm{S}C_{D_{taxi}} \quad (10)$$

Where: ρ_{SL} is the density at sea level, S is the wing area. $C_{D_{taxi}}$ is the coefficient of drag during taxi, computed as:

$$C_{D_{taxi}} = C_{D_0} + \beta.K.C_L^2 \quad (11)$$

Where: C_{D_0} is the coefficient of drag at zero angle of attack, β is the ground effect influence factor, K is the coefficient of drag due to lift, C_L is the coefficient of lift.

The total tractive work or energy needed for taxiing for each taxiing route segment with constant headwind can be derived using the above-mentioned equations:

$$(\mathrm{A_{tot}}) = \frac{\mathrm{M_A.\kappa.v_i^2}}{2} + \mathrm{M_A.g.\phi_i.s_i} + \mathrm{M_A.g.\mu_0.s_i} + \mathrm{M_A.g.\mu_0.}\frac{\mathrm{v_i}}{\mathrm{v_0}}\left[\mathrm{s_i} - \frac{1}{3}\frac{\mathrm{v_i^2}}{2\mathrm{a_i}}\right] + \mathrm{G.}\frac{\mathrm{v_i^2}}{2\mathrm{a_i}}\left[\frac{\mathrm{v_i^2}}{2} + \frac{4}{3}\mathrm{v_iv_w} + \mathrm{v_w^2}\right] + \mathrm{G.}(\mathrm{v_i} + \mathrm{v_w})^2\left[\mathrm{s_i} - \frac{\mathrm{v_i^2}}{2\mathrm{a_i}}\right] \quad (12)$$

Where: v_i is the taxiing speed, s_i is the taxiing distance, κ is the rotational inertia factor, a_i is the taxiing acceleration and ϕ_i is the taxiing slope.

A parametric study established that energy requirement in taxiing is highly sensitive to the taxiing speed, followed by acceleration, headwind and taxiing slope in decreasing order. Taxiing is very airport specific. There is no standard route with some taxiing processes include a number of stops along the way. To generalize the study as much as possible and ensure a wide applicability, the energy required was computed for a taxiing route with a number of segments varying between 1 and 4 as shown in Figure 4. The total taxiing time was considered to be 5 minutes. This time is an average time derived from the list of airports [11]. The aircraft parameters are shown in Table 3.

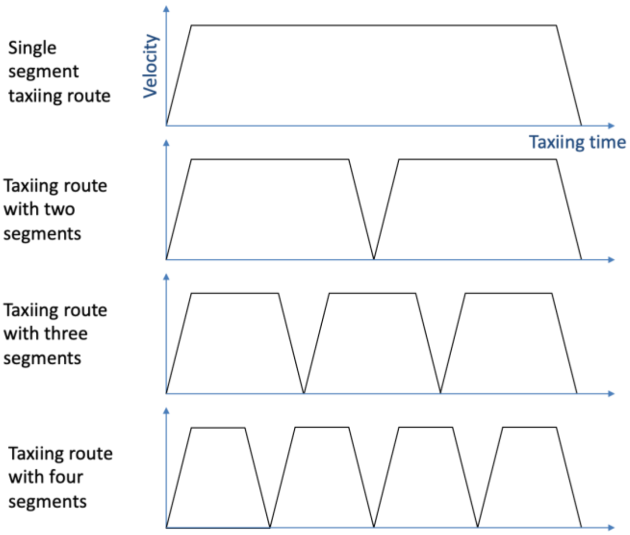


Figure 4. Example of an aircraft taxiing procedure with varying number of segments.

Table 3: Aircraft Taxiing parameters

Parameter	Symbol	Value	Units
Aircraft Weight	W_a	65310	Kg
Taxiway slope	φ	0.5	Degrees
Aircraft taxiing velocity	v	10	m/s
Headwind velocity	$\mathrm{v_w}$	10	m/s
Taxiing acceleration	$\mathrm{a_i}$	0.5	m/s^2
Rolling resistance coefficient	μ_0	0.01	
Wing area	S	124.6	m^2
Rotational inertia factor	K	1.01	

Table 4: Energy required for taxiing

Number of segments in route	Energy needed for taxiing (MJ)
1	50.13
2	51.41
3	52.69
4	53.97

It can be noted that the availability to regenerate energy from the wheels of a landing aircraft is bigger than the energy required for a 5-minute taxiing process, thus making energy recovery from a landing aircraft feasible. The energy availability is at its maximum when flight times are low. This is best utilized for short taxiing times of under 5 minutes, with the least number of stop segments. Low-cost carriers (LCCs) fit this operating profile, offering relatively short flights with high turnaround time. LCCs have historically preferred secondary airports due to cost, demand and efficiency. By nature, secondary airports are smaller thus having shorter taxiing times and lower segments. Thus prior to estimating the scaled up environmental and economic impact of adopting a kinetic energy recovery for aircraft, the following section shifts its focus to the operation of low-cost carriers. This would later act as the backdrop, for which the rest of the environmental and economic impacts are assessed.

3. Operation of low-cost carriers and secondary airports.

The liberalization of the market some two decades ago has seen an unprecedented growth of the

LCCs, especially in Europe. LCCs have increased tourism access to many parts of the EU more than any other type of airline and contributed immensely to local economies. Their affordable fares and development of new services have democratized access to flying, fostering social inclusion and labour mobility. They have also been important to countries facing challenging economic conditions such as Portugal and Romania. In the US, Southwest Airlines is the world's largest low-cost carrier with a fleet of over 736 [12] aircraft. In Europe, Ryanair and EasyJet dominate the European short haul flights, with an aircraft fleet size of 484 [13] and 310 [14] respectively. As Asia gains prominence in global air travel, and is expected to become the world's leading travel market in the next decade. AirAsia is one of the largest LCC in Asia with a fleet size of over 101 [15] aircraft. In Mainland China, airlines like Spring Airline, Capital Airline and Lucky Airline also adopted low cost, high turn-around strategies. Short haul flights are efficiently performed through regional jets and single-aisle, narrow body aircraft such as the Airbus A320 and Boeing 737 aircraft. Such airlines have a typical turnaround time of approximately 25 minutes, with each aircraft managing between 3-5 flights daily. This is important in our context as every aircraft in the fleet spends more time on the ground, and consumes over 1 tonne of fuel for taxiing operations per day.

The European Union (EU) hosts a significant number of secondary airports, accounting for over 260 million passengers per annum[16]. Secondary airports are very diverse. Some serve remote communities and play a key role for their socially inclusivity. Others serve large densely populated regions and cities, providing essential connectivity and are catalysts to their economies. Some secondary airports are major gateways to tourism, for example in Greece, Italy and Spain or the islands of Cyprus and Malta [16]. Some of the secondary airports have now developed into hubs for LCCs, thus raising their profile as European Airports. Secondary airports are typically small and contain taxiing times under five minutes. This makes them compatible with the technology for recovering energy from landing aircraft and utilizing it for engineless taxiing. The combination of LCCs with big aircraft fleet and high aircraft utilization, operating from secondary airports provides us with a unique opportunity to turn an existing emission problem into a green solution with multiplier effects. The following section aims to establish the fuel consumption and environmental impact of taxiing while scaling the environmental and economic impacts to the fleet size of LCCs as shown in Table 5.

Table 5: Fleet size and daily flights for the big four LCCs

Airline	AirAsia	EasyJet	Ryanair	Southwest
Fleet size	101	310	484	736
Daily flights	3	3	5	5
Taxiing per flight	2			

4. The environmental impact of aircraft taxiing

Having defined the modus operandi of LCC's and established the compatibility between KERS and their general operating procedures, the environmental impact of aircraft taxiing, is assessed. The method established earlier to compute the energy requirement for taxiing is also used to compute the fuel consumption and emissions released during taxiing. In this section, the environmental benefit of KERS technology is compared to a typical full engine, thrust powered taxiing. The full engine taxiing method involves usage of all aircraft engines for taxiing operation. The aircraft engines are typically run at 7% thrust while applying brakes on. The pollution emitted during taxiing process has been the topic of interest.

4.1 Fuel consumption for a 5-minute taxiing process.

The fuel consumption of an aircraft using full engine taxiing was defined in [17] as:

$$M_{fuel} = \sum t * n * f * \alpha \qquad (13)$$

Where: *t* is the taxiing time, *n* is the number of engines, *f* is the fuel flow and α is the coefficient of low visibility weather. The fuel flow *f* is defined as:

$$\mathrm{f} = \text{Thrust needed for taxiing} * \mathrm{TSFC} \qquad (14)$$

Where $TSFC$ is the thrust specific fuel consumption. The coefficient for low visibility (α) is defined as:

$$\alpha = \frac{\mathrm{v}}{v_{low\ visibility}} \qquad (15)$$

Where: v is the average taxiing velocity and $v_{low\ visibility}$ is the average taxiing velocity in low visibility conditions.

Alternative fuel consumption models [18] defined in Table 6 were used to verify the results.

Table 6: Alternative taxiing models

Model 1	$M_{fuel} = (a_1 + b_1 * t + c_1 * n_s + d_1 * n_t) * \sqrt{T_{amb}}$			
	a_1	b_1	c_1	d_1
	-0.26	0.0125	0.1	-0.02
Model 2	$M_{fuel} = (a_2 + b_2 * t + c_2 * n_a) * \sqrt{T_{amb}}$			
	a_2	b_2	c_2	
	-0.0896	0.0124	0.1174	

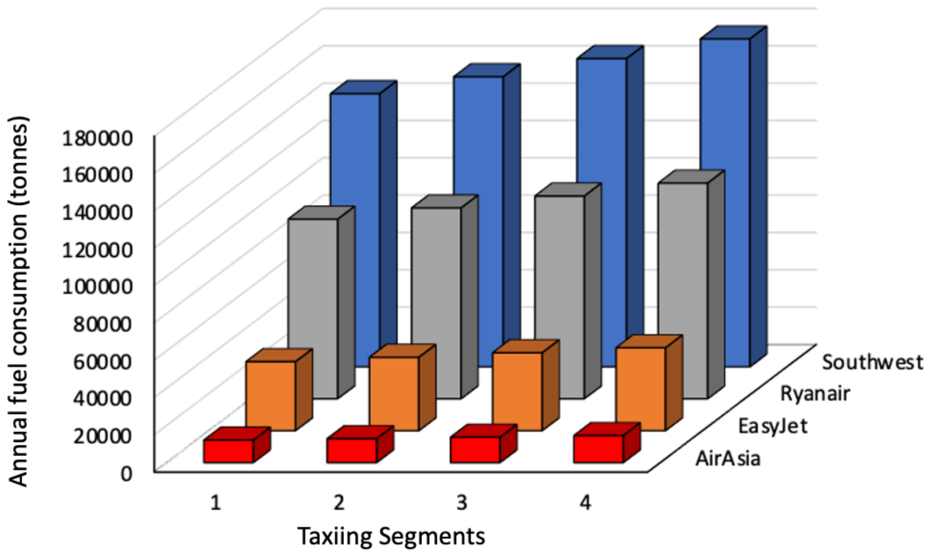
Where T_{amb} is the ambient temperature at the airport, a_1, b_1, c_1 & d_1 are the empirical parameters estimated by regression, t is the taxiing time, n_s is the number of stops during taxiing, n_t is the number of turns during taxiing and n_a are the acceleration events during taxiing. The taxiing models were compared and the fuel consumption for the 5-minute taxiing process with various segments are shown in Table 7.

Table 7: Fuel Consumption for a 5-minute taxiing process with route made of various segments

Number of segments in route	Fuel consumption (kg)
1	54.46
2	57.84
3	61.47
4	65.38

Due to the economic advantages and environmental concerns, single engine taxiing concepts are increasingly being used. In the single-engine taxiing scenario, one engine is employed during taxiing. When considering the slight increase in engine thrust and engine preheating requirements before entering into the runway, this study found that single engine operation consumes approximately 78% of the full engine configuration. Figure 5 shows the potential yearly fuel savings expected from the taxiing processes by the big four LCC's, if an energy recovery system is implemented.

Figure 5: Annual fuel savings for the big LCCs with a 5-minute taxiing process with different taxiing segments.



4.2 Emissions Analysis for a 5-minute taxiing process.

Using the fuel consumption results and the emission indices, the pollutants during taxiing process have been quantified. Table 8 shows the emissions indices for different pollutants. The emissions from taxiing when the route is made of the different number of segments is shown in Table 9. Figure 6 shows the potential yearly emission savings by the big four LCC's.

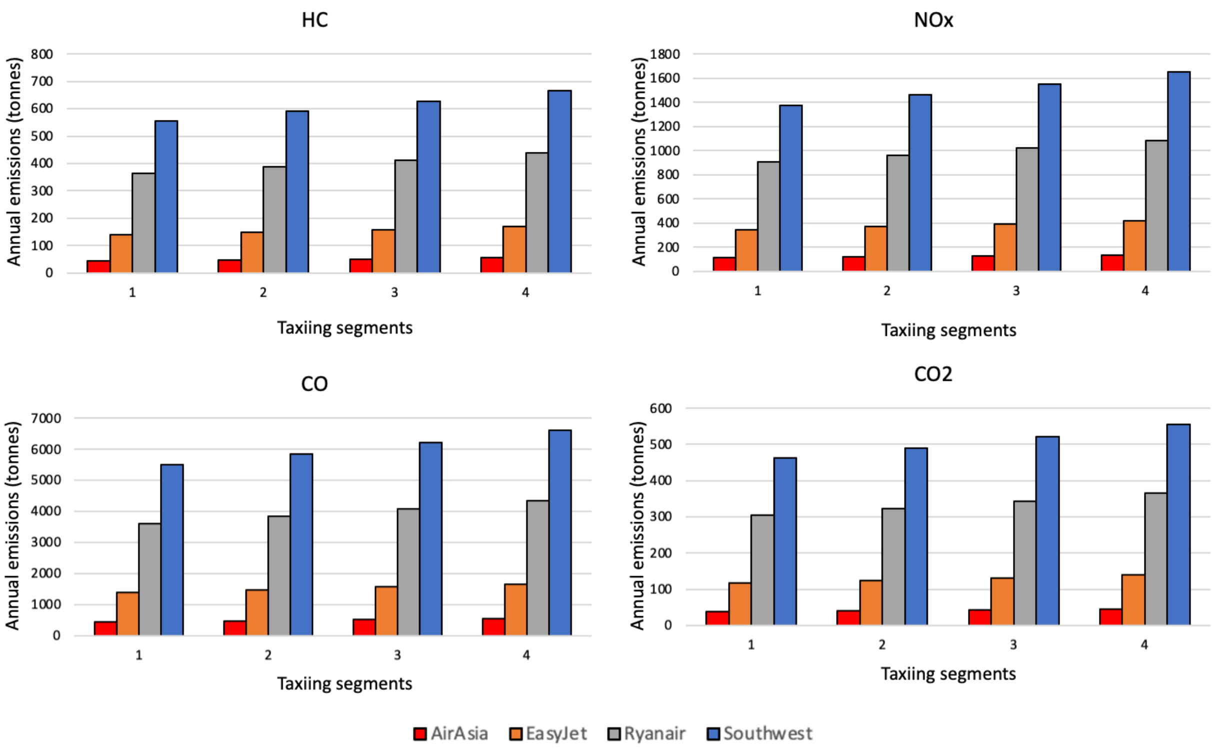
Table 8: Emission indices of pollutants from various types of fuel

Pollutants	Jet fuel (g/kg)
HC	3.8
NOx	9.4
CO	37.6
CO_2	3155

Table 9: Emissions for full engine taxiing for 5-minute with various taxiing segments

	Pollutants (g)			
Number of segments in route	**HC**	**NOx**	**CO**	**CO_2**
1	206.93	511.89	2047.54	171.82
2	219.79	543.68	2174.73	182.49
3	233.59	577.83	2311.34	193.94
4	248.46	614.61	2458.45	206.28

Figure 6: Emissions savings for the big LCCs with a 5-minute taxiing process with different taxiing segments.

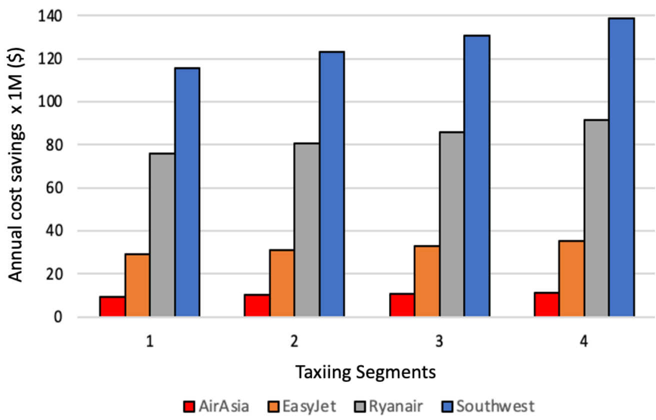


5. The economic opportunities for an aircraft kinetic energy recovery system

Having demonstrated the energy feasibility and emissions savings by introducing an energy recovery system to power the taxiing process, the focus of the final section is turned towards the economic analysis for a system which recovers energy from a landing aircraft, thus enabling engineless taxiing.

The economic analysis takes into consideration the cost to implement the technology and the savings achieved, thus estimating the pay-back period. It does not consider snowballing effects such as the cost of cleaner environment and the health costs associated with the community living close to secondary airports and which may be affected by pollution. The cost of Jet fuel is volatile. Towards the end of 2021, this was surging above pre-pandemic levels and found to hinder the recovery of the aviation industry [19]. The International Air Transport Association (IATA) estimates that the average price of jet fuel in 2022 will be $100.1/bbl [20]. Using the fuel savings shown in Figure 5, the annual cost savings for the big four LCCs is estimated and shown in Figure 7. It can be shown that the savings are substantial and range between $10M for the entire fleet of AirAsia to approx. $140M for the entire fleet of SouthWest airlines. The spread is a result of the dependent on the size of the fleet and the daily useability of each aircraft.

Figure 7: Cost savings for the big LCCs with a 5-minute taxiing process with different taxiing segments.



Using these figures, and assuming that the airlines would want to recover their investment in a timeframe of 3 years, it is estimated that each aircraft installation should cost between $340k - $570k. This estimation takes only the fuel savings into account, and thus making it quite conservative. It is noteworthy highlighting that in Europe, several countries plan to introduce pollution taxes on airlines. These will act as a further financial incentive to invest in greener technologies.

6. Conclusion

This paper presented a concept for a kinetic energy recovery from a landing aircraft. The energy is stored temporarily and is then channeled to enable engineless taxiing. In this work we demonstrate that there is enough energy from a landing aircraft to enable a taxiing process of around 5 minutes. The taxiing process may be made of various segments thus including a number of interruptions. Despite the different energy demands, these can still be fulfilled. Low-cost carriers, particularly those operating from secondary airports show a very promising potential to benefit from such technology. These provide a unique opportunity to turn an existing emission problem into a green solution with multiplier effects on environment and health.

Finally, the paper produces a brief economic analysis which demonstrates that green technology does not need to be a financial burden but presents economic incentives to airline operators. The authors are aware that the success of the solution being proposed assumes that the added weight from the KERS does not offset the benefit through higher in-flight emissions. Therefore, a careful assessment of the energy storage technologies available is required.

7. Acknowledgement

The findings presented in this paper are a result of the Project KERS-air, financed by the Malta Council for Science & Technology, for and on behalf of the Foundation for Science and Technology, through the FUSION: R&I Technology Development Programme.

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