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Workshop: Performance for Non-Common Vehicles Based on advanced cell technology

Reference driving cycle for off-road electric vehicles

Referenzfahrzyklus für geländegängige Elektrofahrzeuge

Cycle d'essai de référence pour les véhicules électriques tout-terrain

ICS: 53.100

CCMC will prepare and attach the official title page.

Contents

Foreword

This CENELEC Workshop Agreement (CWA XXXX:YYYY) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations - Part 2. It was approved by the Workshop CENELEC “Performance for non-common vehicles based on advanced cell technology”, the secretariat of which is held by “UNE – Spanish association for standardization” consisting of representatives of interested parties on 2026-06-17, the constitution of which was supported by CENELEC following the public call for participation made on 2026-01-30. However, this CENELEC Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

Non common electric vehicle applications such as off-road electric vehicles suffer from a lack of specific standards adjusted to the unique characteristics of these applications. It is needed to provide standardized driving cycles for the different off-road applications such as the proposed here, the excavators.

Driving cycles are generally characterized by a set of fundamental attributes, including total duration, distance or working time, speed or power profile, average and maximum values, transient behaviour, and the proportion of idle or steady-state operation. Depending on their intended application, driving cycles may emphasize different aspects such as urban congestion, highway cruising, transient acceleration events, or sustained load operation. For electrified systems, additional characteristics such as power demand distribution, regenerative operation, auxiliary load contribution, and energy throughput are particularly relevant, as they directly influence battery performance, efficiency, and durability.

Standardized driving cycles are widely used for multiple purposes, including vehicle type approval, comparative performance assessment, energy consumption and range determination, system sizing, and validation of control strategies. In the context of electrified vehicles, driving cycles are also employed to evaluate battery stress, thermal behaviour, charging strategies, and overall energy management. By providing a common reference framework, driving cycles enable objective comparison between different technologies, vehicle architectures, and operational concepts.

1 Scope

This document provides a reference electric power profile for electric excavators as members of the off-road electric vehicle cluster, to set up an official driving cycle for these electric excavators inside the off-road vehicles.

Also, intended to provide a representative electric power profile for an electric excavator that considers the specific characteristics of this off-road vehicle while providing enough evidence of its robustness by comparing the proposed driving cycle with measured electric power profiles of real electric excavators. Additionally, the comparison with available driving cycles is performed to understand better why it is required this proposed new driving cycle for electric excavators.

The provided reference electric power profile for an excavator will help the battery developers to address the specific characteristics of the off-road applications into their design.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at http://www.iso.org/obp/

- IEC Electropedia: available at http://www.electropedia.org/

3.1

driving cycle

harmonized reference profile representing vehicle operation over time under defined conditions, used to assess performance, energy consumption, emissions, and system behaviour in a repeatable and comparable manner

3.2

duty profile

temporal distribution of operational states and loads experienced by a machine during its typical use, including speed, torque, power demand, and auxiliary functions

3.3

electric power profile

time-dependent representation of the electrical power demand of a system during operation, typically expressed as power versus time

3.4

reference electric power profile

standardized electric power profile defined to represent typical operating conditions of a specific machine category, used for testing, comparison, and design purposes

3.5

peak power

$\boldsymbol{P}_{\mathbf{pk}}$

maximum of the power as a function of time for a pulse

[SOURCE: ISO 11145:2018(en), 3.13.9]

3.6

mean power

average power demand over a defined time period within an operating profile

3.7

transient operation

operating condition characterized by rapid changes in power, speed, or load over time

3.8

steady-state operation

operating condition in which system variables such as power, speed, or temperature remain approximately constant over time

3.9

idle operation

operating condition in which the machine is powered but not performing active work, while auxiliary systems may remain active

3.10

auxiliary load

electrical power consumption associated with non-traction systems, including hydraulic systems, BTMS, HVAC, control electronics, and other support functions

3.11

traction power

power required to produce motion of a vehicle or machine through its primary propulsion system

3.12

battery stress profile

characterization of the electrical and thermal loads imposed on a battery system during operation, including current variability, peak demand, and cycling behaviour

3.13

regenerative braking

braking with conversion of kinetic energy into electric energy for charging the rechargeable energy storage system (RESS) (3.7)

[SOURCE: ISO 23274-2:2021(en), 3.8]

3.14

energy throughput

the total accumulated energy (typically in kWh or MWh) a battery system stores and discharges over its lifetime

3.15

state of charge (SoC)

available capacity in a battery pack or system expressed as a percentage of rated capacity (3.15)

[SOURCE: ISO 12405-4:2018(en), 3.20]

3.16

scaling of power profile

mathematical adjustment of a power profile to match a different nominal power level, typically using proportional relationships

3.17

nominal power

rated power output of a system or component under specified operating conditions

3.18

operating cycle

complete set of tasks carried out within a defined operation, such as digging or grading

[SOURCE: ISO 18497-1:2024(en), 3.11. modified]

3.19

digging and dumping cycle

operating cycle of an excavator consisting of material excavation, lifting, rotation, unloading, and return to initial position

3.20

grading cycle

operating cycle of an excavator involving controlled movement of the arm to level or shape a surface

3.21

thermal behaviour

response of a system in terms of temperature evolution under defined operating conditions

3.22

transient losses

energy losses occurring during non-steady-state conditions due to rapid variations in current, voltage, or load

3.23

standardized driving cycle

driving cycle formally defined and adopted by a regulatory or standardization body for testing and certification purposes

4 Abbreviations and acronyms

Abbreviation	**Meaning**
BEV	Battery Electric Vehicle
BTMS	Battery Thermal Management System
CLTC	China Light-Duty Vehicle Test Cycle
EPA	Environmental Protection Agency
FTP-75	Federal Test Procedure 75
HVAC	Heating, Ventilation and Air Conditioning
HWFET	Highway Fuel Economy Test
ICS	International Classification for Standards
IPR	Intellectual Property Rights
ISO	International Organization for Standardization
NEDC	New European Driving Cycle
SoC	State of Charge
WLTP	Worldwide Harmonized Light-Duty Test Procedure

5 Driving cycle

5.1 General

Within the CEN-CENELEC-ETSI framework, driving cycles are used as harmonized reference profiles to ensure repeatability, comparability, and transparency when assessing vehicle performance, energy consumption, emissions, and system behaviour under controlled and reproducible conditions. Driving cycles do not represent a single real-world journey but rather a statistically derived abstraction intended to capture typical usage patterns within defined boundary conditions.

Electric excavators exhibit operational characteristics that differ fundamentally from those of on-road vehicles for which most existing standardized driving cycles have been developed. Their duty profiles are dominated by low vehicle speed operation, frequent starts and stops, high and sustained torque demand, significant auxiliary and hydraulic power consumption, and extended periods of idling combined with active working functions. Furthermore, peak power demands may regularly approach or exceed nominal traction power due to simultaneous actuation of multiple subsystems. As a result, conventional driving cycles are not representative of the electrical, thermal, and energetic stresses experienced by electric excavators. The development of a dedicated driving cycle that accurately reflects these specific operational characteristics is therefore essential to enable realistic performance evaluation, battery system design, and fair comparison of electric excavator technologies.

5.2 Analysis of the existing harmonized driving cycles

There are driving cycles that are commonly used to determine the performance characteristics of the battery systems for electric vehicles such as the NEDC, WLTP, FTP-75, HWFET and CLTC.

Table 1 — Existing harmonized driving cycles

Cycle	Dominant Feature	Battery Stress Profile
NEDC	Low dynamics with long steady-speed and idle segments	Low peak power demand, limited transient stress, optimistic energy consumption and range estimates
WLTP	Higher dynamics with frequent speed variations and broader speed range	Increased transient current demand, higher peak power events, improved representation of real-world battery loading and thermal behaviour
FTP-75	Stop-and-go urban traffic	High current variability, low average power
HWFET	Steady highway cruising	Thermal steady state, low transient stress
CLTC	Congested urban focus	Auxiliary-dominated loads, frequent low-power cycling
WHTC	World Harmonized Transient Cycle	High thermal stress, elevated energy throughput, repeated high-power events
WHSC	World Harmonized Stationary Cycle	Stable continuous load, low transient stress, useful for efficiency mapping

5.2.1 New European Driving Cycle (NEDC)

The NEDC was developed in the early 1990s to provide a reproducible laboratory procedure for fuel consumption and emissions certification of light-duty vehicles in Europe. It consisted of a fixed set of urban and extra-urban phases executed on a chassis dynamometer under controlled temperature conditions.

It was structured in two phases: Urban and Extra-Urban driving. It starts with a sequence of low, constant, and moderate speeds with predefined acceleration steps with an average speed of 34 km/h and a maximum speed of 120 km/h. It contains Idle and steady-speed segments where the accelerations are gentle and not representative of modern traffic dynamics. The whole cycle lasts around 20 min and it covers 11 km.

Because of the high idle fraction and mild accelerations, NEDC produces relatively low peak power and energy demand on the battery or engine compared to real use. This characteristic historically led to optimistic range/consumption figures, poor representation of rapid load changes, and underestimated transient losses.

5.2.2 Worldwide Harmonized Light-Duty Test Procedure (WLTP)

WLTP was developed by UNECE and introduced in Europe in 2017 (fully replacing NEDC for certification). It is derived from real-world driving data across multiple regions and intended to represent urban, suburban, and highway conditions more realistically than NEDC.

It was structured in four dynamic phases: Low, Medium, High and Extra High speed segments with sharper accelerations and decelerations with an average speed of 46.5 km/h and a maximum speed of 131 km/h. It contains less idle time and greater representation of variable loads, acceleration patterns, and mixed-speed driving than the NEDC. The whole cycle lasts around 30 min and it covers 23.25 km.

WLTP places higher demands on traction power and on-board energy management systems. Instantaneous power peaks are greater than NEDC (higher accelerations and less cruising), making WLTP more sensitive to transient losses, regenerative braking potential, and auxiliary loads.

5.2.3 EPA Federal Test Procedure (FTP-75, USA)

The EPA FTP-75 driving cycle is the primary regulatory procedure used in the United States for assessing urban fuel economy, exhaust emissions, and energy consumption of light-duty vehicles. It is administered by the U.S. Environmental Protection Agency (EPA) and is intended to represent stop-and-go city driving conditions, including congestion, traffic signals, and frequent vehicle starts.

The FTP-75 consists of three consecutive phases: (1) Cold Start Phase (vehicle operation starting from ambient temperature), (2) Transient Phase (simulated urban traffic with frequent speed changes), and (3) Hot Start Phase (repetition of the initial phase after a short soak period). Key parameters include:

- Total duration: ~1,874 s (~31 min).
- Total distance: ~17.8 km.
- Average speed: ~34 km/h.
- Maximum speed: ~91 km/h.
- High proportion of idle time (~20–25%).

Compared to NEDC, FTP-75 exhibits:

- More frequent and sharper acceleration/deceleration events.
- Substantial idle periods with auxiliary power demand.
- Repeated low-speed transients.

For battery systems, FTP-75 imposes high current variability at relatively low average power levels. This makes the cycle particularly relevant for evaluating:

- Transient efficiency losses.
- Regenerative braking effectiveness at low speeds.
- Thermal behaviour under repeated current pulses.
- Energy consumption sensitivity to auxiliary loads (HVAC, electronics).

However, FTP-75 still underrepresents sustained high-power operation and does not capture highway-like or heavy-load conditions.

5.2.4 EPA Highway Fuel Economy Test (HWFET, USA)

The Highway Fuel Economy Test (HWFET) is used by the EPA to evaluate highway fuel consumption and energy efficiency under steady, free-flow traffic conditions. It complements the FTP-75 by representing long-distance driving with minimal congestion.

HWFET is a single, continuous cycle characterized by smooth speed variations and limited stopping events:

- Total duration: ~765 s (~12.8 min).

- Total distance: ~16.5 km.
- Average speed: ~77 km/h.
- Maximum speed: ~97 km/h.
- No complete stops and minimal idle time.
- Accelerations are gentle, and cruising segments dominate the cycle.

HWFET is fundamentally different from urban-oriented cycles:

- Power demand is relatively stable.
- Peak power events are limited.
- Regenerative braking opportunities are minimal.

From a battery engineering perspective, HWFET is useful for:

- Assessing steady-state efficiency.
- Evaluating thermal equilibrium under continuous load.
- Estimating range under highway conditions.

However, it lacks the transient stress and high peak-power demands that drive aging mechanisms in real-world use. As such, HWFET alone is insufficient for evaluating battery durability or dynamic performance.

5.2.5 China Light-Duty Vehicle Test Cycle (CLTC)

The China Light-Duty Vehicle Test Cycle (CLTC) is the official certification cycle for passenger vehicles in China, introduced to replace NEDC-based procedures. It was developed using large datasets of real-world Chinese driving behaviour, reflecting dense urban traffic, lower average speeds, and frequent congestion.

CLTC is composed of three main phases: (1) Low-speed urban driving, (2) Medium-speed suburban operation, and (3) Limited high-speed operation.

Typical characteristics include:

- Total duration: ~1,800 s.
- Total distance: ~14–15 km.
- Average speed: ~29 km/h.
- Maximum speed: ~114 km/h.
- High proportion of low-speed and idle operation.

Compared to WLTP, CLTC places greater emphasis on urban congestion and reduced cruising speeds. Comparing to these driving cycles, CLTC shows:

- Lower average traction power.
- Frequent low-power transients.
- Reduced sustained high-speed operation.

For battery systems, this cycle is particularly sensitive to:

- Low-speed efficiency losses.
- Auxiliary energy consumption dominance.
- Regenerative braking efficiency in dense traffic.
- State-of-charge drift during extended low-power operation.

CLTC often yields more optimistic electric range values than WLTP for BEVs, highlighting the strong dependence of battery energy consumption on cycle design and regional driving behaviour.

5.2.6 World Harmonized Transient Cycle (WHTC)

The World Harmonized Transient Cycle (WHTC) is an internationally harmonized test procedure developed within the UNECE framework for the certification of heavy-duty engines. The cycle was specifically designed to represent the transient operating behavior of commercial vehicles operating under real-world driving conditions, including urban, rural, and highway operation. WHTC is primarily used for evaluating exhaust emissions, fuel consumption, and energy performance of heavy-duty diesel, hybrid, and electrified propulsion systems under dynamically varying load conditions.

WHTC is characterized by continuously changing engine speed and torque demand, reflecting realistic heavy-duty vehicle operation. The cycle includes:

- Urban low-speed operation.
- Rural driving conditions.
- Highway/high-load segments.

Typical parameters include:

- Total duration: ~1,800 s (~30 min).
- Highly transient load profile.
- Frequent acceleration and deceleration events.
- Broad operating range covering low and high engine loads.

Unlike light-duty cycles such as WLTP or FTP-75, WHTC directly incorporates substantial load variability and sustained high-power operation representative of commercial vehicle duty cycles.

From a battery engineering perspective, WHTC generates:

- Significant transient current demand.
- Elevated thermal loading.
- High energy throughput.
- Repeated peak power events.

The cycle is particularly relevant for evaluating:

- Battery thermal management systems.

- High-power discharge capability.
- Dynamic efficiency under variable load.
- Power electronics and inverter stress.

Among standardized vehicle cycles, WHTC exhibits operating conditions that are comparatively closer to those encountered in electric construction machinery due to its strong load dynamics and sustained power demand.

5.2.7 World Harmonized Stationary Cycle (WHSC)

The World Harmonized Stationary Cycle (WHSC) is a harmonized heavy-duty engine test procedure developed alongside WHTC for emissions and performance certification under steady-state operating conditions. Unlike transient driving cycles, WHSC evaluates engine behavior at predefined combinations of speed and load operating points.

The cycle is primarily intended for:

- Engine certification.
- Steady-state efficiency evaluation.
- Validation of emissions control systems.
- Repeatable laboratory characterization.

WHSC consists of a sequence of discrete stationary operating points, each defined by:

- Specific engine speed.
- Defined load percentage.
- Fixed duration weighting factors.

The cycle includes:

- Idle operation.
- Low-load conditions.
- Medium-load operation.
- High-load steady-state points.

In contrast to transient cycles, WHSC does not simulate continuous driving behavior or rapid load changes.

For battery-electric and hybrid systems, WHSC produces:

- Relatively stable power demand.
- Limited transient current variation.
- Reduced regenerative operation.
- Lower dynamic thermal fluctuations.

WHSC is particularly useful for:

- Determining steady-state efficiency maps.
- Characterizing thermal equilibrium conditions.
- Evaluating continuous power capability.
- Benchmarking subsystem efficiency under controlled loads.

However, the cycle does not adequately capture real-world transient stress mechanisms that dominate battery aging and power electronics loading in mobile machinery applications.

6 Electric power profile for electric excavators

A robust electric power profile for electric excavators has been developed based on a theoretical approach, which has been validated by comparing it with a real electric profile of an actual electric excavator.

6.1 Theoretical approach

The theoretical approach[1] presented in this document was developed studying a excavator with a total weight of 75 T with an internal combustion engine (diesel) of 410 kW, with an engine speed target of 1 200 rpm. The excavator evaluated is described in Figure 1.

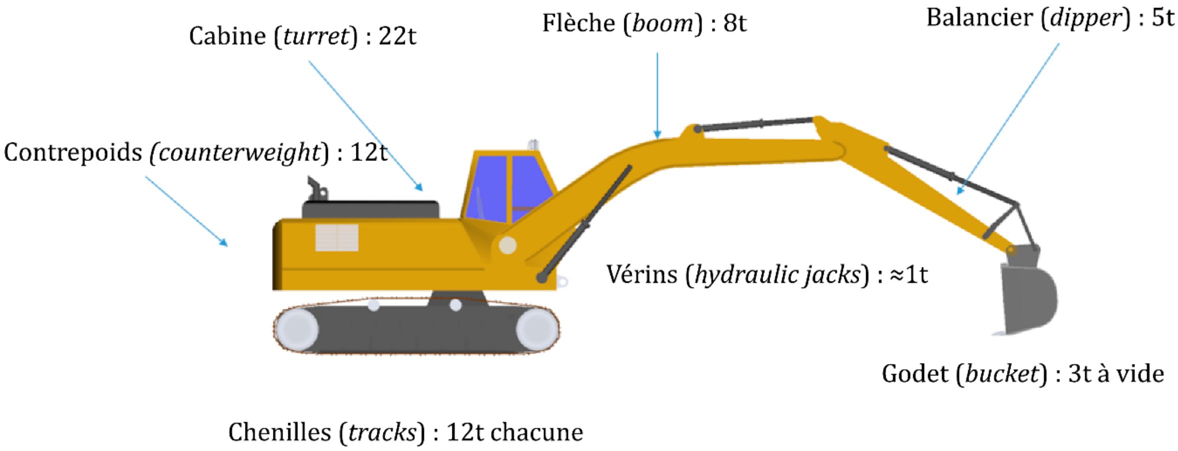

Figure 1 — Excavator analysed to get the theoretical electric power profile of an electric excavator

The theoretical approach was made evaluating the dynamics of an excavator at two different operating cases: (1) digging and dumping, and (2) grading.

The digging and dumping use case consists of the following repetitive movements:

- Arm goes down.
- Fill in the bucket.

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[1] The theoretical approach is based on the PhD thesis of Marco Fecke [2] evaluated in the framework of the Tranplhyn project [3]

- 90 °C turret rotation.
- Empty the bucket.
- Return to initial position.

Through this movement pattern, was possible to transform into the power profile described in Figure 2. The power profile was defined in 80 s, which is repeated continuously in a real operating case.

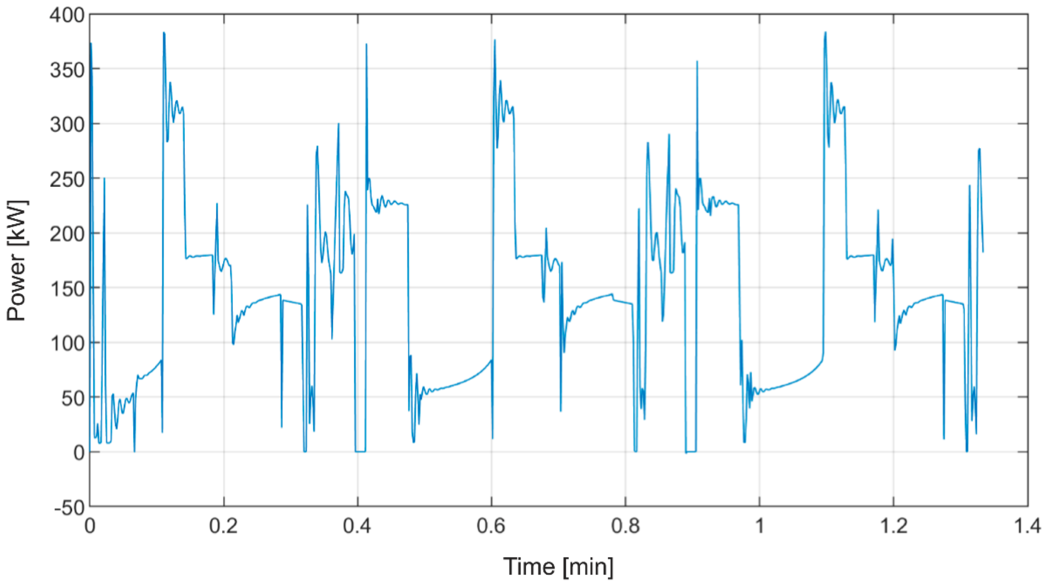

Figure 2 — Digging and dumping power profile of an excavator

The grading use case consists of the following repetitive movements:

- Arm goes forward and backward at ground level to flatten the floor.

Through this movement pattern, was possible to transform into the power profile described in Figure 3. The power profile was defined in 25 s, which is repeated continuously in a real operating case.

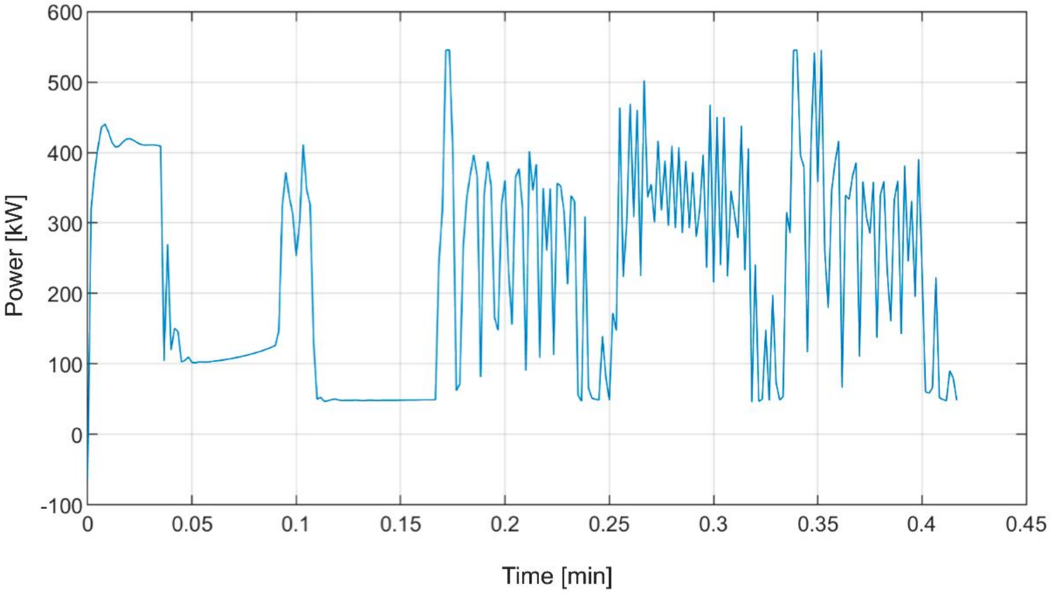

Figure 3 — Grading power profile of an excavator

6.2 Experimental approach

The experimental approach[2] is established with the power consumption profile of two actual electric excavators.

The first excavator is a tracked earthmoving machine belonging to the approximately 13-ton operating class, characterized by a compact excavator architecture with an overall length on the order of 8 m, an upper structure width of about 2.5 m, and an overall height close to 3 m. The configuration comprises a rotating upper structure mounted on a crawler undercarriage, providing stable load distribution, good maneuverability, and suitability for medium-duty construction and earthmoving applications. The geometric proportions and mass distribution are designed to balance stability, reach, and transportability while accommodating hydraulic actuation systems and structural components required for digging, lifting, and material handling operations.

The first evaluated electric excavator has a 81 kW electric engine. The power profile resembles to the theoretical digging and dumping, where the maximum power of the engine is not reached and a highly dynamic operation is conducted. The electric power profile of the first analysed excavator is shown in Figure 4.

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[2] The data presented for the experimental approach was gathered by BATSS project and presented in the D2.1 BS - Requirements and specifications.

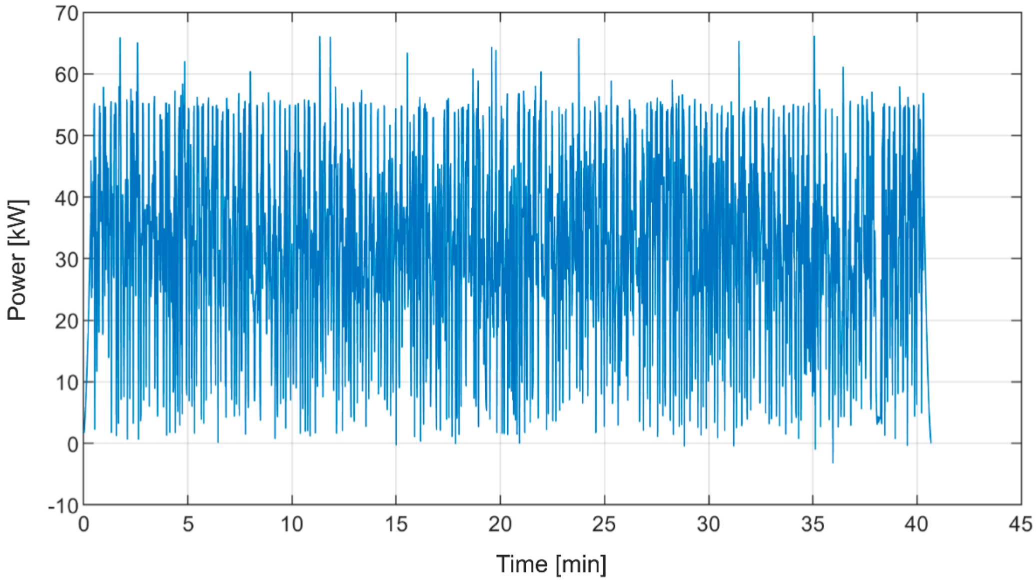

Figure 4 — Mission of an electric excavator with a 81 kW electric engine

The second excavator considered in this load case is a battery-electric tracked earthmoving machine in the 20-ton operating class. The assumed machine configuration corresponds to a conventional crawler excavator architecture with a rotating upper structure mounted on a tracked undercarriage, providing the stability, reach, and robustness required for typical excavation and material handling tasks. In dimensional terms, such a machine is generally characterized by an overall length of roughly 9 to 10 m, an upper structure width of about 2.5 to 3.0 m, and an overall height of approximately 3 m.

The representative duty profile assumes peak operating power demands of about 108 kW during active work phases and includes realistic charging behaviour for a battery-electric machine. In addition to productive digging and handling cycles, the profile contains a short charging event during the morning break, an extended charging phase during the lunch break, and a longer end-of-shift charging period with reduced charging power toward full battery state of charge. The resulting load cycle is intended to represent a realistic daily operating pattern for a 20-ton electric crawler excavator in general construction and earthmoving applications.

The second evaluated electric excavator has a 100 kW electric engine and has a 1 minute sampling time (common to find this sampling time in reality). The power profile resembles to the theoretical digging and dumping, where the maximum power of the engine is not reached and a highly dynamic operation is conducted. The electric power profile of the second analysed excavator is shown in Figure 5.

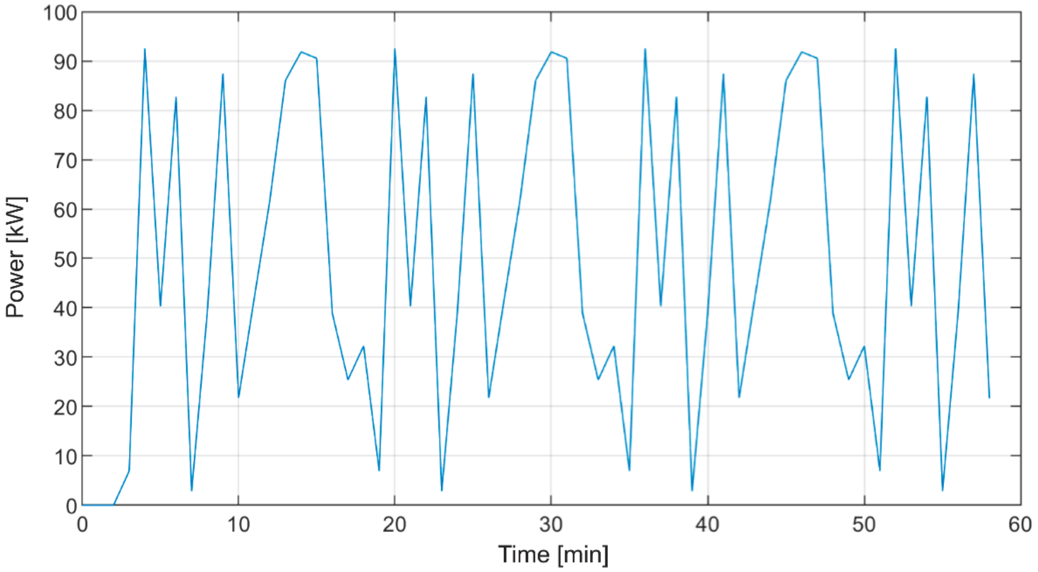

Figure 5 — Mission of an electric excavator with a 100 kW electric engine

6.3 Comparison of the theoretical and experimental approaches at a common scale

The gathered experimental electric profiles have been compared with the theoretical approach. Firstly, the evaluated profiles have been scaled to an electric engine of 100 kW to be comparable. To do so, the electric power profiles have been linearly scaled based on Eq. (1).

$$P_{scaled} = P_{profile} \cdot \frac{P_{objective}}{P_{nominal}} \tag{1}$$

Afterwards, the time constrains have been considered. The theoretical approaches have been repeated to match the experimental approaches. In the case of the first experimental electric power profile, it has been only shown the first 4 minutes in Figure 5 for better understanding. Visually, it can be confirmed that the energy balancing is the same (there is no regenerative charges) and that the spectrum of the electric profile looks alike (repetitive patterns can be detected at similar time periods).

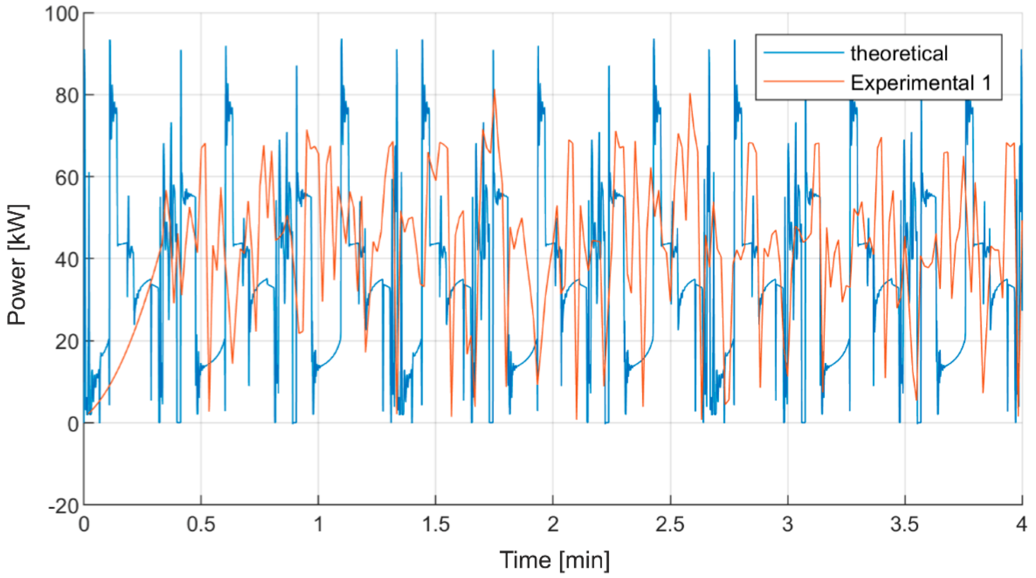

Figure 6 — Comparison of the first experimental and theoretical approach in the first 4 minutes

In the case of the second experimental electric power profile, it has been taken the whole electric profile, see Figure 7. In this case, the visual inspection shows that the energy balancing is the same (no regenerative charges), but the spectrum is quite different. It is assumed to be the low sampling rate of the original power profile, which even though it is common to find in real applications, it does not provide enough information to design the representative driving cycle.

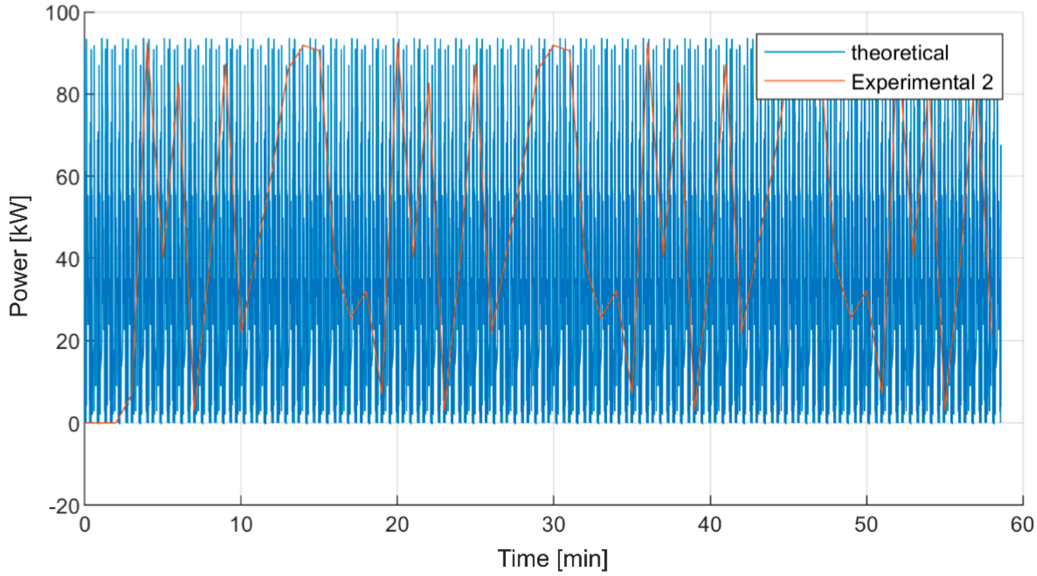

Figure 7 — Comparison of the second experimental and theoretical approach

Additionally, the most interesting metrics have been calculated and gathered in Table 1. The values from the theoretical and experimental approaches have been gathered, but also the metrics of the available standard driving cycles.

Table 2 — Most relevant metrics of the electric profile comparison

	Digging theoretical	**Grading theoretical**	**Real 1**	**Real 2**	**NEDC**	**WLTP**	**FTP-75**	**HWFET**	**CLTC**	**WHTC**	**WHSC**
Max power [kW]	93	133	81	92	45-55	80-90	65-75	55-65	60-70	100-120	70-85
Mean power [kW]	35	56	40	49	12-15	18-22	17-20	22-26	14-17	35-45	40-50

NEDC exhibits the lowest average and peak power demand, reflecting its low dynamic content and long steady-state segments. WLTP shows the second highest peak power among road vehicle cycles due to aggressive accelerations and higher maximum speed but a low mean power due to extended time at steady state. FTP-75 emphasizes transient operation, resulting in relatively high peak power but moderate average power. HWFET produces the highest average power among road cycles due to sustained cruising, despite limited peak demand. CLTC is dominated by low-speed urban operation, leading to reduced average power and moderate peaks. WHTC shows the highest peak power among road vehicle cycles due to its application being customized for heavy-duty vehicles. Among standardized vehicle cycles, WHTC exhibits operating conditions that are comparatively closer to those encountered in electric construction machinery due to its strong load dynamics and sustained power demand. Nonetheless, WHTC has regenerative power events, which in an electric excavator is not likely to happen (commercial excavators do not have hydraulic systems with energy regenerative features). The WHSC has the highest mean power of all the road driving cycles. It describes well heavy duty applications with long steady states. However, it has reduced peak power in comparison to WHSC.

The real excavator profiles and the proposed theoretical excavator cycle fundamentally differ from available road vehicle cycles in the following aspects:

— Average power is significantly higher (35–56 % of nominal) due to continuous working operation.

— Peak power frequently reaches or exceeds nominal motor power (133kW respect to 100kW).

— No regenerative events available.

The resulting energy throughput and battery stress are substantially underestimated by almost all existing standardized driving cycles, and there is not any that could provide enough insight to all the characteristics of this kind of driving cycle (above nominal power peaks, 35-56% mean power and no regenerative events).

Regarding the comparison between real and theoretical power profile of an electric excavator, the values of Table 1 show that both, the real and theoretical profiles are quite similar in terms of stress and duty pattern. There are differences in terms of absolute values, but it can be claimed that the digging and grading theoretical values are representative enough to the actual values (the theoretical mean power range of 35-56 kW considers the real 40 kW and 49 kW) and that represents the dynamics of the excavator characteristics better than the actual available standard driving cycles (continuously repeated identical profiles).

Besides, it has been observed that the linear approach for downscale or upscale of driving cycles for electric excavators has relevance enough to describe the maximum values observed in both experimental electric power profiles of real electric excavators (maximum power rates of the experimental electric profiles of 81 kW and 92 kW are in near or in between the theoretical peak power range of 93-133 kW).

6.4 Reference electric power profile

The comparison between the theoretical approach and the experimental approach has led to conclude that the theoretical approach is relevant enough to describe the specific characteristics of an electric excavator, where the scaling factor of the provided reference electric profile is linear respect to the nominal power rate of the electric engine of the excavator.

In consequence, a reference electric profile has been generated based on both operating conditions evaluated in the theoretical approach. These power profiles have been repeated to match a minimum of 30 minutes operating window where the time for each operating case has been equally divided, see Figure 8. Firstly, the grading profile has been repeated 36 times, and then the digging profile has been repeated 11 times. The proposed profile is available with the theoretical power profiles in [1].

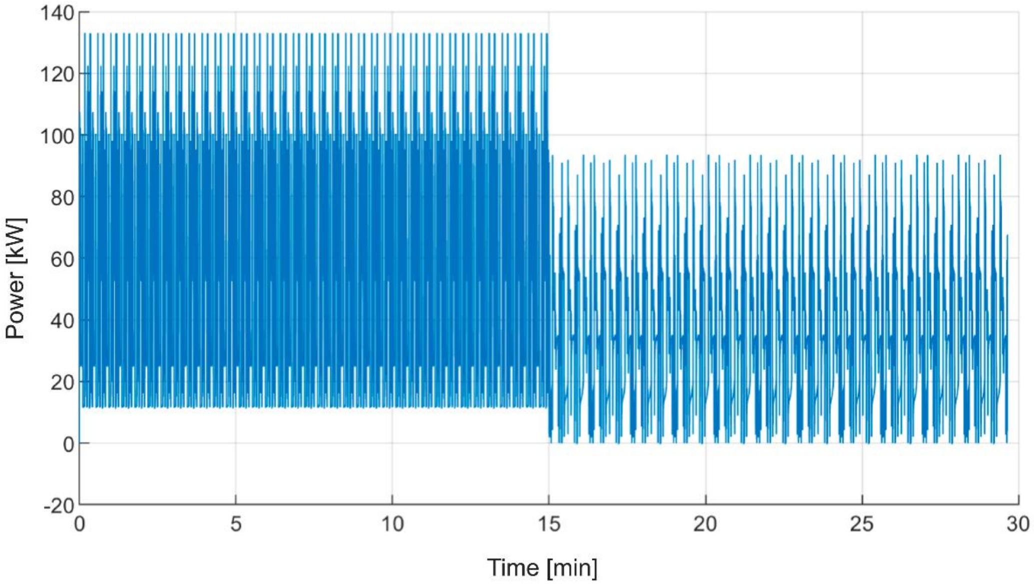

Figure 8 — Proposed standard driving cycle for electric excavators

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