

IMPERIAL COLLEGE LONDON
DEPARTMENT OF MATERIALS

MATE50003 ENGINEERING PRACTICE
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Studio A: Alpha Drills
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Contents

1	Introduction	2
2	Design Proposal	3
2.1	Key Features	3
2.1.1	Power and Performance	3
2.1.2	Battery Technology	3
2.1.3	Ergonomic Design:	3
2.1.4	User interface	3
2.1.5	Ease of Use	4
2.1.6	Safety Features	4
2.1.7	Accessories and Storage	4
2.2	Key Components	4
2.2.1	Motor	4
2.2.2	Gearbox	4
2.2.3	Battery	5
2.2.4	Casing and grip	5
2.2.5	Chuck jaw	5
3	Materials Selection and Manufacturing Methods	5
4	Cost Estimate	6
5	Intellectual Property	6
6	Sustainability	7
7	Conclusion	7
8	Appendix	8
8.1	Contributions	8

Executive Summary

This design proposal presents the development of a new cordless drill aimed at transforming the power tool market. Employing a user-centred design approach, the resulting product excels in performance, durability, safety and convenience. Engineered to meet the needs of DIY enthusiasts whilst still appealing to the broader consumer market, this new cordless drill offers a range of ergonomic features and attachments that enhance user experience and productivity based on findings from hands-on investigation into competitor products. Key aspects of the proposal focus on optimising sustainability and cost in material selection and design decisions. Both in-house and outsourcing production methods will be employed for efficiency. The casing will be injection-moulded from robust polylactic acid reinforced with glass fibres (30%GF) benefiting from its biodegradability. The planetary gear system will use PA6(30%GF), and the chuck will be made from martensitic low-alloy steel for excellent hardness and toughness. Thermoplastic elastomer, processed through over-moulding, will be used for the ergonomic handgrips. A lithium-ion battery and a braked brushless DC motor were chosen in order to maximise the lifetime and efficiency of the drill. The cost per unit will be £38.40, and the retail price will be £51.10, ensuring accessibility for the majority of our DIY household target market and achieving a healthy profit margin. Substantial research was done on the manufacturing process of each material utilised and a total emissions value was estimated to be 27.016kgCO₂eq/unit. The products design does not infringe on any current patents within the UK thus no royalty fee will be required. This cordless drill sets a new standard for power tools, promising to deliver exceptional performance and user satisfaction and make a breakthrough into this market.

1 Introduction

The cordless drill and screwdriver market is experiencing steady growth, driven by advancements in battery technology, the rise of smart features, and ergonomic designs. Major players such as DeWalt, Bosch and Makita dominate the market, with products ranging from £10-£700, catering to both DIY enthusiasts and professionals. However, as the consumer market continuously grows, new gaps in the market have been identified, which this design aims to fill. Key trends in market activity include the adoption of brushless motors, smart connectivity, and sustainable practices which fuel new design ventures; many of which will be discussed further. Despite competitors, the market's future looks promising with continuous innovation, development in material technology and undercutting the industry rivals in cost efficiency and expanding applications. This design proposal explores the development of a new cordless drill driver to make a breakthrough in this dynamic consumer market of DIY household projects.

Following an in-depth investigation of three distinct products—the Flintronic cordless screwdriver (priced at £15), the FADAKWALT 8212A cordless drill driver (£30), and the Katsu budget electric impact drill (£20)—and extensive market research, a new design has been proposed. This design aims to integrate the best features of these three models, including their cost efficiency, innovative technologies, ergonomic designs, and user-friendly benefits, while also addressing the evolving needs and preferences of today's market. This design is largely based on the FADAKWALT cordless drill, as it was analysed to be a successful DIY cordless drill, particularly its handle and keyless chuck system. The plastic gear system from the Flintronic screwdriver was utilised due its lightweight nature. The Katsu drill featured supplementary components such as a built-in spirit level and torch. This inspired the addition of these features, as well as additional accessories, into this design. The culmination of their respective strengths resulted in an optimised cordless tool that offers superior performance, durability, and convenience for DIY enthusiasts at a competitive price.

The characterisation investigation into the three previous existing products involved the deconstruction of the devices in order for them to be examined using techniques such as microscopy, XRD and DSC analysis. This revealed key areas for improvement, specifically in battery performance, sustainable material choices, and opportunities for user experience through multifunctional design. The main recommendations for improvements from the investigations include enhancing the function of the product through bettering the power system, integrating lighter material for the gears and providing additional support like a detachable accessories to combine several functions into one appliance. Further suggestions also involve incorporating speed and direction control triggers for user convenience, implementing alternative materials for improved durability, focusing on easier casing disassembly and cost-effective material choices. These improvements will help distinguish this new product in a competitive market.

The proposed design for a new cordless drill aims to revolutionise the market by addressing common user pain points and incorporating innovative features. By integrating user-friendly enhancements and carefully selected materials based on thorough research and substantial evidence, the new drill will not only meet the demands of modern consumers but also set a new standard for performance and reliability in the power tools industry. Through the inclusion of detachable elements, this device offers users a versatile selection of tools in one appliance. Additionally, the efficient material selection process, grounded from rigorous characterisation testing of competing products, ensures that this drill stands as a prominent competitor in the consumer market.

The following proposal outlines the key design elements and ensures it delivers exceptional value and superior user experience.

2 Design Proposal

Following market trends, it was determined that cordless appliances are preferable for user convenience. This design decision is driven by the benefits of advanced battery technology, improved aesthetics, enhanced safety—especially in environments with children and pets—and the consistently growing consumer demand for cordless household appliances. The appliance combines drill and screwdriver functions with the addition of detachable components to improve functionally. Additionally, this drill is equipped with a powerful motor and variable speed control, allowing it to accommodate a range of applications. It features a bold, magenta casing to make a clear distinguishing statement against the competitors and comes with supportive accessories including an ergonomic grip. Incorporating a spirit level onto the body of the drill ensures further accuracy for the user and combines another tool box feature into this product. This results in a drill that delivers superior performance while maximising user experience.



Figure 1: CAD 3D render of full drill design on charging stand with all accessories attached

2.1 Key Features

2.1.1 Power and Performance

A motor rated at 1300 W is combined with a gearbox with multiple torque settings and variable speed control (0-650RPM) allows for a wide range of tasks, from drilling holes to driving screws. There is a direction reversal toggle to allow for the removal of screws as well. It includes multiple torque settings (19NM max) to accommodate drilling into different materials and several DIY applications.

2.1.2 Battery Technology

The drill is powered by a combination battery power system, allowing it to be used for short tasks as well as longer projects. The former can subsist on a permanent battery built into the handle, whereas for the latter, a DeWalt battery pack can be plugged into the drill in conjunction with the permanent battery in the device's handle. This avoids the need for frequent breaks to recharge the device and contributes to the convenience of the drill's use over longer periods.

2.1.3 Ergonomic Design:

The drill features a lightweight, compact design with an ergonomic grip, reducing user fatigue during extended use. The handle is crafted with soft, anti-slip elastomer to ensure a secure hold, facilitating ease of experience and comfort for the average home user.

2.1.4 User interface

A LED battery indicator provides real-time updates on the remaining charge, allowing a user to effectively plan out their usage. A dial allows selection between different speeds before operating the device, allowing optimum output for varying use cases and boosting the safety factor during use. From the previous investigations into the competitor products, it was found that variable speed was one of the key benefits from one of the existing drills, so this feature was improved further on this new design to allow the user to select the speed from the user interface panel for maximum accuracy.

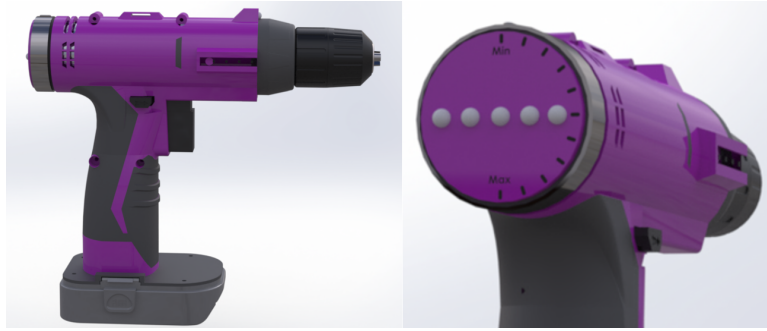


Figure 2: CAD 3D render showing the drill without attachable features and user interface featuring speed control and battery charge indicator.

2.1.5 Ease of Use

A keyless 1/2" chuck allows for quick and easy bit changes, and an integrated LED light illuminates the work area, improving visibility in dimly lit areas. The drill also includes a built-in spirit level to help users achieve precise, straight drilling. There are 4 screw holders integrated onto the drill at convenient positions so as not to hinder the maneuverability of the drill. There is a pin at the bottom of the casing that, when pulled out, allows for easy case disassembly. This means if any repairs need to take place, the drill can be easily opened and reattached. These features provide a smoother, more convenient experience for the user. This aspect also feeds into the sustainability of the design and plans for the product's life-cycle.

2.1.6 Safety Features

The design incorporates a motor with a built-in electric brake, which stops the motion of the drill bit as soon as the trigger is released. This allows the drill to stop immediately instead of coasting to a halt, allowing higher precision and preventing accidents. Overcharge and overheating protection circuitry features can be bought in and integrated into the design for further risk mitigation in regards to the internal electronics system.

2.1.7 Accessories and Storage

The drill comes with a comprehensive set of accessories and attachments; this includes a variety of drill bits and screwdriver heads. Specifically designed attachments to improve user experience can be slotted into its holder on the underside of the drill, all housed in a durable carrying case for easy storage and transport. Attachments include:

Alignment tray: Attachment with a flat end to ensure drill bit is perpendicular with desired surface. This is spring loaded and retracts as the drill bit embeds into the material. A stopper can be adjusted to a specific length allowing the user to drill to specific depths. The attachment wraps around the area being drilled meaning material removed during use is caught.

Handgrip: A supplementary ergonomic handgrip to provide extra support and control for a more comfortable user experience.

Drill bit holder: Allows for quick exchanging of the drill bit, resulting in a more efficient, streamlined user experience.

2.2 Key Components

2.2.1 Motor

To maximise performance as well as safety, the motor will be a braked brushless DC motor. The braking function is built into the motor and generally consists of an electrically actuated mechanical braking system. Although brushless motors are more expensive than their brushed counterparts, they are more energy-efficient and have longer lifespans, extending the lifetime of the drill. Suitable motors would have a voltage rating of 12V with a maximum rpm of 18,000RPM reduced to 650RPM using a gearbox.

2.2.2 Gearbox

The gearbox mounts onto the DC motor and reduces its RPM whilst increasing torque. To achieve a large reduction in speed in a small volume, a double stacked planetary design is employed in both the Flintronic and Fadakwalt example drills. This configuration is ideal for smaller form factor cordless drills whereby the full diameter of the drill can be utilised. A Ring gear (45 teeth) surrounds smaller spur gears (Planetary gears, 18 teeth), which revolve around a smaller Sun gear (9 teeth). This combination when used twice in series achieves a 1:36 ratio in only 30mm. Furthermore this gearbox design is sealed meaning any lubricants applied during manufacturing remains contained for the lifetime of the device. The gearbox outputs to a clutch which varies the level of engagement with the chuck (allowing the user to vary the torque for drilling or driving).

2.2.3 Battery

Cordless drills on the market are typically rated 12V or 18V. The former was chosen as it is more than adequate for home DIY jobs and allows the drill to be lighter, an important consideration due to possible extra weight from the accessories sold. Additionally, a combination battery power system is used. This involves a battery built in to the drill (1300mAh), with a charging port on the underside of the handle that connects to a charging base. For everyday DIY scenarios, once the battery runs out, the drill can be connected to the charging base which is plugged into regular electrical sockets. However, our drill can also be used for longer projects, as the charging port allows for a DeWalt battery pack (3000mAh) to be plugged into the drill in combination with the permanent battery in the drill handle, allowing the drill to be upright so it can still be used whilst being charged. This double battery approach ensures consistent power output and a longer run time for more time consuming scenarios, allowing users to complete projects without frequent recharging. With only the internal battery, the drill theoretically for an hour which is extended by 3 hours with the removable battery pack.

2.2.4 Casing and grip

No drill would be complete without a suitable case and grip for complete functionality. The casing protects the internal components, ensuring durability and safety, while also contributing to the drill's overall strength and lightweight design. The grip, typically made from a comfortable, non-slip material, enhances user control and reduces fatigue, allowing for precise and prolonged use without discomfort. Regarding the size of the casing, research was undertaken into the size of competitors products along with ergonomic aspects such as what would fit comfortably in the user's hand whilst being able to house all of the desired internal components.

2.2.5 Chuck jaw

The chuck is an integral part of the drill with its purpose being to hold various drill bits or attachments securely in place during use. The chuck is designed to accommodate different sizes and types of drill bits, allowing users to switch between various tasks quickly and easily. This device will be employing the use of a keyless chuck to further support the versatility of this drill and means that the device does not require a separate tool for changing the drill bits, making changes faster and more convenient.

3 Materials Selection and Manufacturing Methods

Each component had their materials and processing methods carefully selected in order to optimise their functionality, remain sustainable, and minimise cost. Overall, it was determined that only the casing and several accessories would be designed in-house then manufactured via a third party, while all other components would be outsourced in order to reduce start-up costs. The drill would then be assembled in-house.

Regarding the casing, three critical criteria were considered when choosing the appropriate material: sustainability, strength and cost. Based on these criteria, two leading candidates were identified: polylactic acid reinforced with 30% glass fibres (PLA-30%GF) and Nylon-6 reinforced with 30% glass fibres (PA6-30%GF). Cost-wise, both are on the expensive end; however, this is justified given their significantly better properties compared to cheaper alternatives such as HDPE. Both possess adequate mechanical properties, where PA6-30%GF has a better fracture toughness, whilst PLA-30%GF is considerably stiffer.^[1] However, PLA-30%GF far outperforms PA6-30%GF in sustainability due to its ability to biodegrade. The danger of degrading whilst in use is also negligible, given that the typical degradation time is approximately 100 years, which is safely outside the typical lifetime of a drill. Thus, to optimise the criteria above, the casing will be made from PLA-30%GF. The accessories and the charging stand will also be made from PLA-30%GF for similar reasons. In terms of processing, these will all be manufactured together via injection moulding. The various case studies and literature suggest this is the most reliable and cost-effective processing route, allowing complex geometries to be made with high precision.

Thermoplastic elastomer (TPE) presented as the optimal material for the handgrips. TPEs are a versatile set of polymer blends that combine the look and feel of conventional rubbers with the processing efficiency of plastics. Above their melt temperature, TPEs exhibit thermoplastic behaviour, allowing them to be shaped and mechanically bonded onto the shell.^[2] It was found that a range of 1.3mm to 2mm is needed to get the "soft-touch" feel from the grip.^[3] Another strong candidate that came up during the material selection process was silicone. Although it possesses superior properties in many aspects, ultimately it was not picked as it came at an increased price point and is only really needed for specialised applications.

For the planetary gear system, particular importance was placed on maintaining a lightweight yet durable gearbox system. Metal gears are mechanically strong and durable to wear, however, they add significant weight and cheaper metals such as cast irons or carbon steels are prone to rapid corrosion even in ambient conditions. Polymer gears made of polyoxymethylene or PA6 are typically more affordable, lighter, less noisy, and require less maintenance due to their self-lubricating nature.^[4] Mechanically, they are largely inferior to their metal

counterparts in wear resistance and hardness. By increasing the thickness of spur gears to 1cm, (factor of 3 compared to low carbon steel counterparts) the bending and compressive stress is reduced sufficiently for the torque and speed of the drill. However, calculation with the motor's rpm suggest most polymer gears will be well equipped for this drill. In terms of which polymer chosen, PA6 is considered the best candidate as it has excellent mechanical properties compared to other plastics and can be strengthened further via glass fibres similar to the PLA in the casing.^[1] This way, the gearbox is extremely lightweight and sturdy enough to sustain operations. Production-wise, PA6 gears are readily available to purchase at low prices and in different sizes which will then be assembled on site to minimise cost.

The chuck, which undergoes a high level of vibration and impact, requires excellent hardness, toughness, and abrasion resistance. As such, a martensitic low-alloy steel with elements such as Mn, Mo, Ni, Cr and V is ideal, delivering sufficient hardness values above 500 HV while remaining cheaper than tool or stainless steels. Appropriate steel grades include those in the AISI 43XX series of nickel-chromium-molybdenum alloys and those in the AISI 6XXX series of chrome-vanadium steels.^[1] Since two of the drills studied possessed martensitic low-alloy steel chucks, a mid-priced chuck would be suitable and relatively easy to find on the market. Stainless steel was considered as the chuck would be exposed to the environment, but as the drill would primarily be used indoors and in a non-corrosive setting, it was ultimately decided that low-alloy steel was the best fit.

Lastly, a lithium-ion battery was chosen over nickel-cadmium batteries and nickel-metal hydride batteries due to its longer life, shorter charging time and low weight.^[5] Lithium-ion batteries also do not suffer from the 'memory effect' experienced by nickel-cadmium batteries, where the maximum charge that can be held decreases over time.^[6] While more expensive, lithium-ion batteries perform better over a longer period of time and has high power density, improving the longevity and overall performance.

4 Cost Estimate

The cost per unit can be estimated by evaluating the potential direct and indirect costs. Direct costs include the various materials/components required, processing costs and the labour costs. Indirect cost encapsulates external factors such as overhead costs for example: lease, site preparation, permits and additional costs including the shipping and packaging. The total cost for producing one unit comes out to be £38.40. Applying a 33% profit margin results in a selling price of £51.10, which is strongly price competitive in the market for products that offer the functionalities that this device does. In addition, the costs for the add-on accessories come out to be £6.20, which are to be sold separately at a 100% profit margin, resulting in the selling price of £12.40. The full individual breakdown of each cost category can be found in the appendix.

It was decided that outside of the outsourced components such as the battery, gearbox, motor and chuck (which are to be bought in), the manufacturing of the casing, grip and accessories, which requires injection moulding, would also be outsourced. The cost of purchasing and setting up an industry standard hybrid injection moulding machine is upwards of £200,000 and more than one machine will be required for mass production. It would not be possible to justify this method for our relatively small scale production of 2000 units a month. Additionally, it became apparent that the overall cost would be significantly reduced if the assembly line was set up in a country with cheaper labour, rent and export tax. Vietnam was the clear choice as it is cheap, resources (human capital and space) are plentiful and 0% export tax, allowing us to maximise our profits and be price-competitive in an already saturated market.

The current plan for shipping is to have one shipment per month from Vietnam via Ocean Freight FCL (Full container load) in a 20' container, which can carry up to 3000 units per shipment. Each shipment takes 30-35 days, which means that there will be one delivery of up to 3000 units per month. However, as we experience economies of scale we can look to move to larger 40' containers or Air Cargo Freight which will be more cost and time-efficient, allowing flexibility for a greater demand.

5 Intellectual Property

To ensure compliance and to suitably protect our design, it is crucial to confirm the absence of any equivalent UK patents through the UK Intellectual Property Office's search tools and consider patenting our innovations in the UK to protect against potential future claims.^[7] Our electric drill features an integrated spirit level, integrated guide rails, a speed control dial, and a dual battery system. Any pre-existing patents for integrated spirit levels have passed the 25 year mark, so they are now free to use.^[8] The guide rails have no direct patents covering the integration of such rails into power tools, with the most similar patents focusing on different applications or being an additional detachable accessory kit.^[9] Therefore, filing a patent for the guide rail system should be considered. In regards to the variable speed function, although there are drills that offer the option to change rotational speed via flick switches or sliding switches, no similar patents were found that utilise a dial to control

this function. Thorough research on dust collectors showed that any versions of this feature involve a suction mechanism, making our tray mechanism distinct.^[10] Additionally the alignment mechanism in the collector also has no current patents involving integration and physical alignment. We plan to use the DeWalt DCB184-XJ 18V 5.0Ah XR Lithium-Ion Battery. While this would infringe on DeWalt's US patents for their connection system, a detailed search revealed no equivalent UK patents. Therefore, acknowledging the US patents protecting this technology, the lack of equivalent UK patents suggests an opportunity to patent our design in the UK to ensure our IP protection. By differentiating our design and securing legal protections, we ensure market competitiveness and safeguard our innovations from potential competitors, enhancing the drill's commercial viability and market advantage.

6 Sustainability

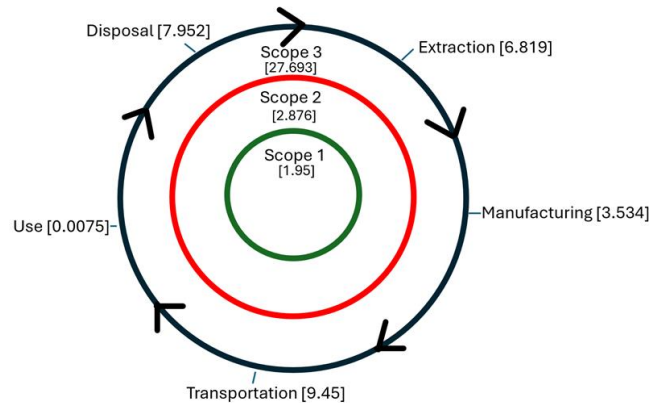


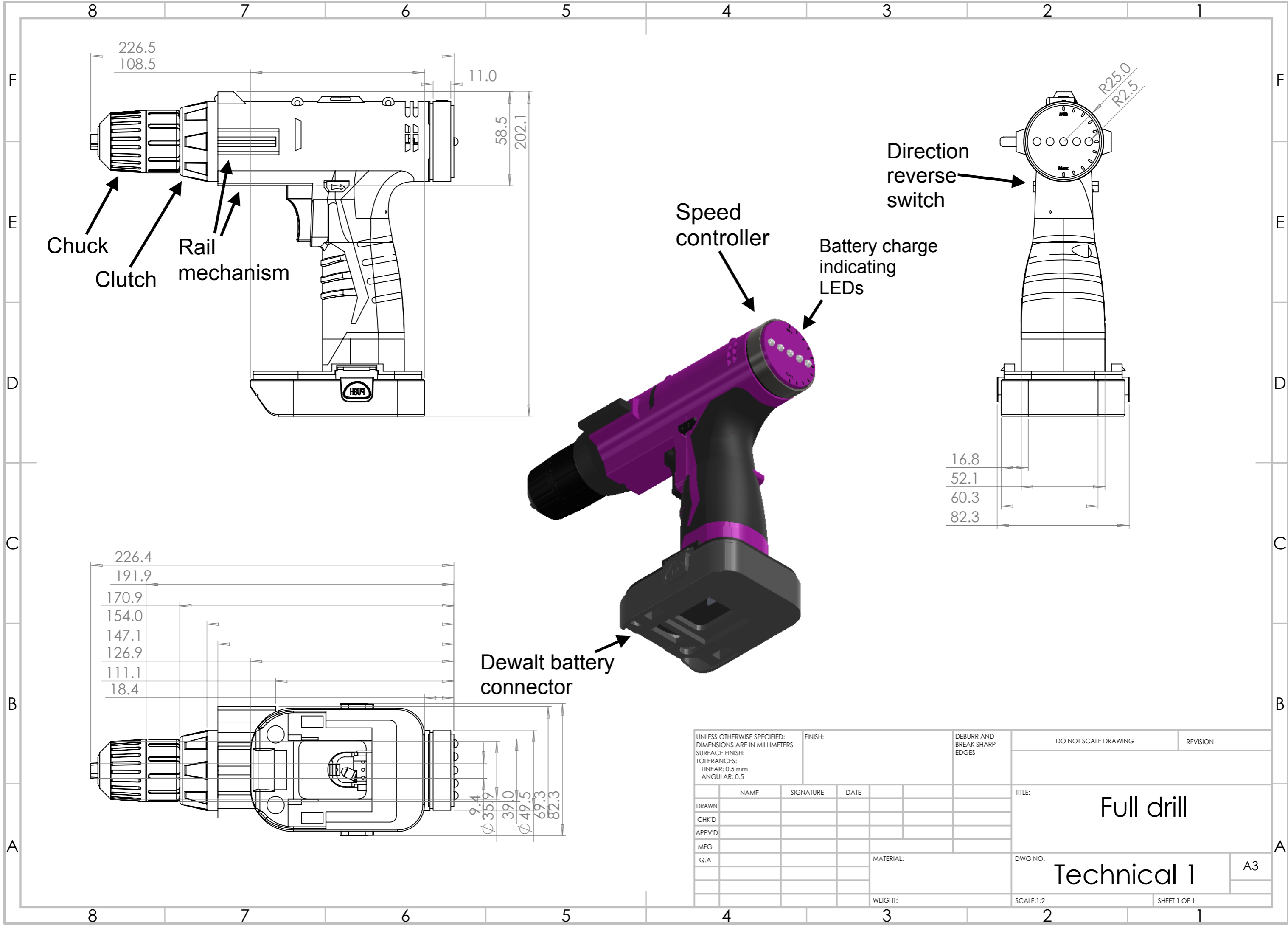
Figure 3: Lifecycle Assessment and CO2 footprinting graphic where the units are kgCO2eq/unit using unit process data.^[11]

Throughout the design process, sustainability has been thoroughly considered. Especially in terms of end-of-life. The drill is designed for disassembly through a metal slip-sheet that locks the two halves of the casing in place. This means that the interior parts can be taken out and reused, recycled or disposed of accordingly. In turn, the TPE used in the casing can be mechanically removed and remoulded for new purpose due to its thermoplastic properties. The PLA used in the casing is derived from corn starch and is compostable on its own. However, the glass fibre does complicate this process. The reinforced plastic can be thermally filtered by melting due to PLA having a lower melting point than the glass. On the other hand, chemical dissolution is possible through dissolving the PLA in chloroform.^[12] The electrical parts, battery and the motor can be sent for disassembly for recycling of the separate metallic parts. This can also be done with the chuck as the steel will be recycled for new use.

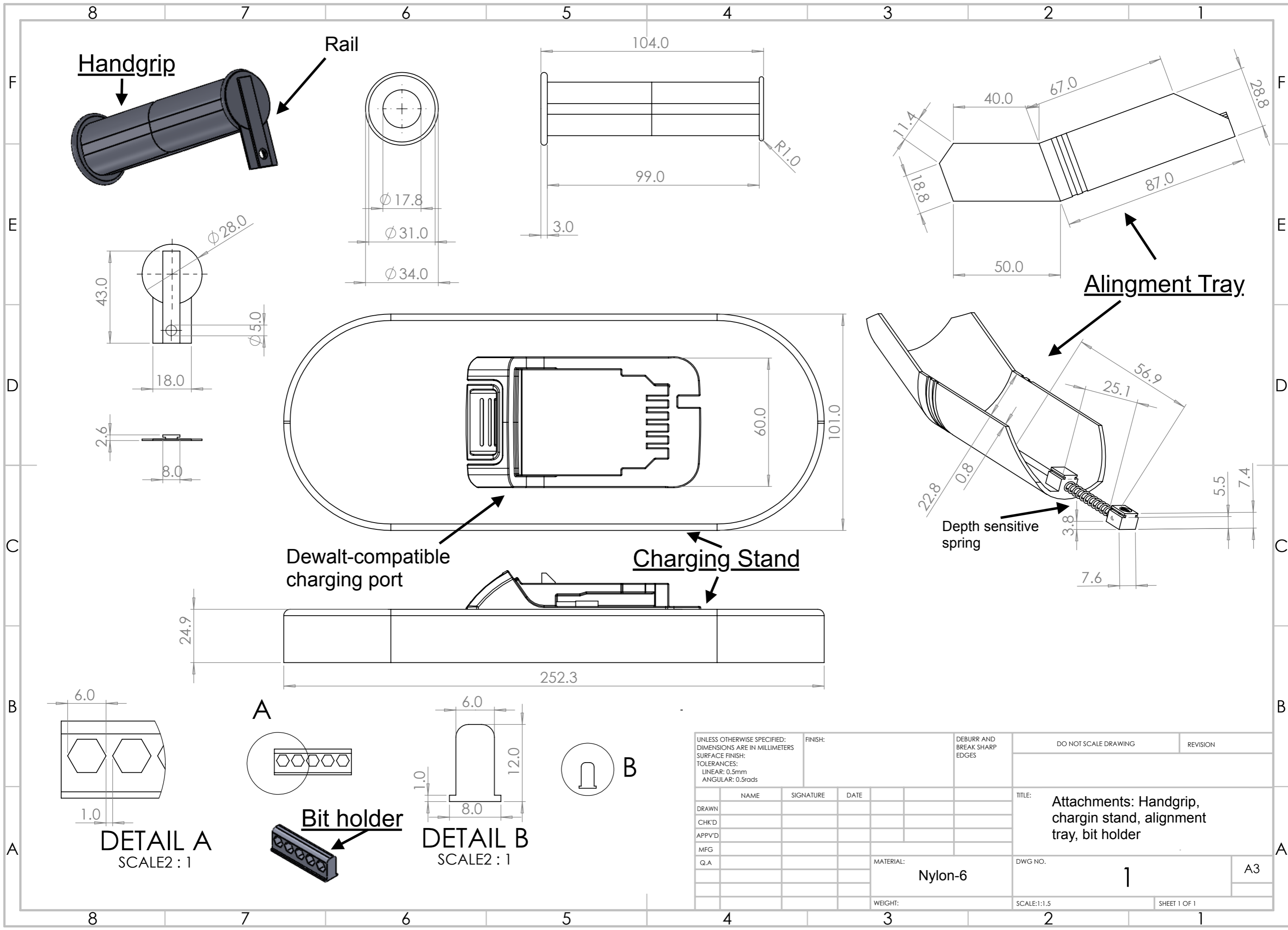
As a lot of the parts are bought in, the set-up and manufacturing emissions per unit are quite low. However, this means that the Scope 3 emissions, as shown in the lifecycle graphic in figure 3, are very high, 27.693 kgCO2eq/unit. The figure then shows the product's emissions at each stage of its life. In reality, the disposal emissions are much lower as most parts would be incinerated rather than an attempt at a recycling process. Therefore, the two glass reinforced plastics wouldn't be recycled meaning the emissions for disposal is actually, 2.448 kgCO2eq/unit. Therefore, the total emissions are 27.016 kgCO2eq/unit.

7 Conclusion

In conclusion, the proposed design for the cordless household DIY drill encapsulates a perfect blend of innovation, functionality, and user-centred features. By prioritising ergonomic design, variable speed control, and advanced customisable features, this tool is engineered to meet the diverse needs of DIY enthusiasts and home users. The integration of a detachable battery (combination power system) and user-friendly interface ensures that this drill will stand out in the power tools market, offering unmatched reliability and performance. With the addition of carefully selected materials and implementing environmentally conscious decisions throughout the design process means we are confident that this design not only fulfills current market demands but also sets a new standard for cordless drills. We look forward to bringing this groundbreaking tool to market, providing users with a high-quality, versatile, and efficient solutions for all their drilling needs.



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: 0.5 mm ANGULAR: 0.5				FINISH:		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
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CHK'D											
APPV'D											
MFG											
Q.A										DWG NO. Technical 1	
										A3	



8 Appendix

8.1 Contributions

Leonardo Carretta: Sustainability

Marcus Chien: Intellectual property

Maliha Damania: Design proposal-CAD

Orla Dasgupta: Executive summary, Introduction, Key features and components, Conclusion

Freddie Johnson: Sustainability

Sebastian Lo: Materials selection and manufacturing methods

Irina Nigam: Overall design proposal, Intellectual property

Hiro Pakdeevutitam: Cost estimate

Jeanne Tay: Materials selection and manufacturing methods

Hiran Thuraisingham: Design proposal-CAD, Market research, Executive Summary

Nathanael Tjoa: Market research

Kevin Tang: Market research

Yi Fang Too: Materials selection and manufacturing methods

Peilin Yu: Market research

Poj Wanglee: Cost estimate

Felix Watson: Director, Design proposal-CAD, Report formatting

Mark Zangwill: Design proposal-CAD, Key features

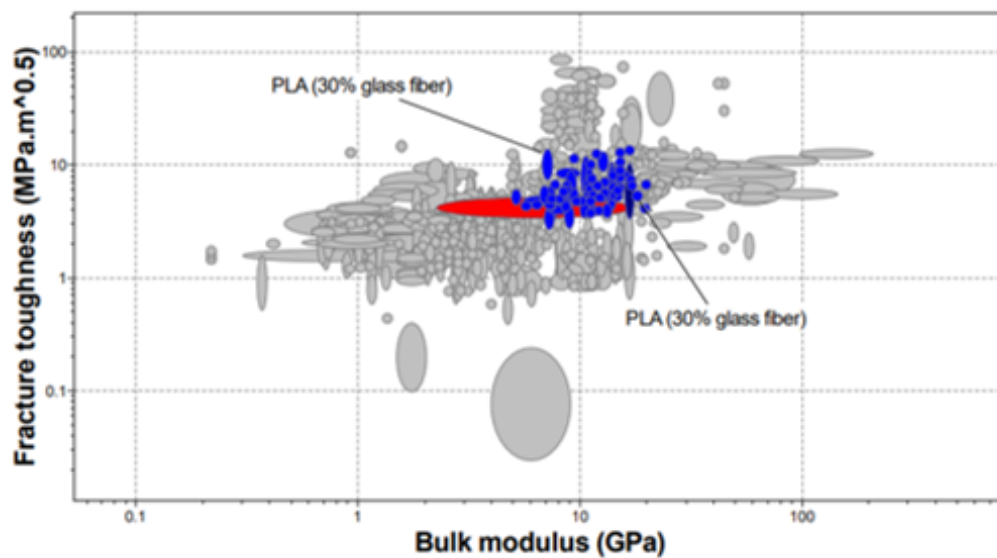


Figure 4: Ashby plot for casing polymer material selection

Material	Fracture toughness	Modulus	T range	Tm/Tg	Cost (GBP/kg)	CO2 Footprint (moulding) kg/kg	Remarks
PAG(30%GF)	7.52-13.9	5.34-6.66	-54 to 90	210/56	1.88-2.94	1.43-1.58	Very commonly used in power tools. Optimized for injection moulding.
PLA(30%GF)	4.88-5.91	10.1-10.3	-12 to 126	175/155	2.26-2.57	1.00-1.05	Biodegradable outside lifetime of drill and has adequate properties. <i>Abit</i> on the expensive side.
PLA(30%NF)	4.01-4.26	5.19-5.32	-20 to 55	175/52	1.97-2.25	1.09-1.14	The most ecofriendly and is a cheap option with good mechanical properties but has low operating T.
PE-HD(30%GF)	2.51-2.92	4.83-6.21	-82 to 90	140/125	1.4-1.46	1.37-1.52	Cheapest option but is very weak.

Ranking: Green > Blue > Orange > Red

Figure 5: Comparative data of multiple polymers for use in the drill

Table 1: Bill of components which are outsourced.

Part	No. required per unit	Cost per part (£)	Cost per unit produced (£)
Gearbox	1	1.9 ^[13]	1.9
Battery	1	5 ^[14]	5
Motor	1	1.5 ^[15]	1.5
Chuck	1	7.5 ^[16]	7.5
Ring Gear	1	1.5 ^[17]	1.5
Planet Gear	3	0.10 ^[18]	0.30
Sun Gear	1	0.10 ^[19]	0.10
LEDs	6	0.02 ^[20]	0.12

Table 2: Bill of components which are outsourced manufactured.

Part	Material	Cost (£/Kg)	Cost per unit (£)	Manufacturing cost included (£)
Casing	PLA with 30% GF	2.26-2.57	0.362	3.41
Grip	TPE	1.81	0.0101	3.06
Dust Collector	PLA with 30% GF	2.26-2.57	0.093	3.11
Accessory: Foregrip	PLA with 30% GF	2.26-2.57	0.064	3.14
Accessory: Screw bit holder	PLA with 30% GF	2.26-2.57	0.007	3.06

Table 3: Labour cost in Vietnam.

Labour Cost per Hour (£)	Assembly Time per unit (Hours)	Total Cost per unit (£)
2.82 ^[21]	0.5	1.41

Table 4: Overhead costs. The cost per unit is calculated through the assumption of 2000 units produced and sold per month over a year.

Category	Cost (£)	Cost per unit (£)
Lease	2032 per month ^[22]	1.02
Site preparation	One time payment of 20,000 ^[23]	1.2
Permits and Legal fees	One time payment of 2800 ^[24]	0.12
Installation of assembly line	One time payment of 50,000 ^[23]	2.1
Patenting	One time payment of 30,000	1.25
Miscellaneous Costs		1

Table 5: Additional costs.

Category	Cost per unit (£)
Shipping	0.8 ^[25]
Packaging	2 ^[26]

Table 6: Summary of all the direct and indirect costs in production of the drill with the assumption of 2000 units produced and sold monthly. All the calculations were done.

Cost Category	Total Cost per unit (£)
Bill of Outsourced Components	17.92
Bill of Outsourced Manufactured Components	9.58
Bill of Outsourced Manufactured Accessories	6.2
Labour Costs	1.41
Overhead Costs	6.69
Additional Costs	2.8

$$\sigma_c = 0.74 \times \frac{i+1}{a} \left[\frac{(i+1) \cdot E \cdot M_t}{i+b} \right]^{\frac{1}{2}}$$

Equation used to calculate the induced compressive stress on gears in section 3) Materials Selection and Manufacturing Methods. Where i : gear ratio, a : face diameter, b : face width, E : Young's modulus, M_t : moment.

$$\sigma_b = \frac{(i+1) \cdot [M_t]}{a \times m \times b \times y}$$

Equation used to calculate the induced bending stress on gears in the same section.

Part	Material	Stage	Process	Emissions	Units	Scope
Casing	PLA30	Extraction	Fermentation/polymerisation	1.833	kgCO ₂ eq/kg	3
Handgrip	TPE	Extraction	Petrochemical Synthesis: Cracking or Polymerisation	0.066	kgCO ₂ eq/kg	3
Planetary Gear	Nylon6 30	Extraction	Ring-opening polymerisation of Caprolactam	0.0452	kgCO ₂ eq/kg	3
Chuck	Martensitic Low Alloy Steel	Extraction	Mining	0.00314	kgCO ₂ eq/kg	3
Chuck	Martensitic Low Alloy Steel	Extraction	Smelting (Furnace), Steelmaking and Alloying and Heat Treatment	3.08	kgCO ₂ eq/kg	3
Perm. Magnet Motor	Hard Ferrite	Extraction	Mining	0.00314	kgCO ₂ eq/kg	3
Perm. Magnet Motor	Hard Ferrite	Extraction	Calcination and sintering	0.956	kgCO ₂ eq/kg	3
Battery	Li-ion	Extraction	Mining	0.00478	kgCO ₂ eq/kg	3
Battery	Li-ion	Extraction	Processing	0.388	kgCO ₂ eq/kg	3
Casing	PLA30	Manufacturing	Injection Moulding	0.0013	kgCO ₂ eq/kg	2
Handgrip	TPE	Manufacturing	Over-Moulding	0.000399	kgCO ₂ eq/kg	2
Planetary Gear	Nylon6 30	Manufacturing	Injection Moulding	0.0013	kgCO ₂ eq/kg	3
Chuck	Martensitic Low Alloy Steel	Manufacturing	Forging, rolling and cutting	1.899	kgCO ₂ eq/kg	3
Chuck	Plastic	Manufacturing	Injection Moulding	0.0013	kgCO ₂ eq/kg	3
Perm. Magnet Motor	All components	Manufacturing	Assembly and Transport	0.06536	kgCO ₂ eq/kg	3
Battery	All components	Manufacturing	Cell Production	0.38722	kgCO ₂ eq/kg	3
		Operations	Office	1.3	kgCO ₂ eq/kg	1
		Use	Charging of Battery	0.475	kgCO ₂ /kWh	2
		Distribution	Bought in Parts	1.125	kgCO ₂ /tkm	3
		Distribution	Product delivery	0.0782	kgCO ₂ /tkm	2
	PLA30	End of Life	Melting and Extrusion	1.8343	kgCO ₂ eq/kg	2
	TPE	End of Life	Thermal recycling	0.037	kgCO ₂ eq/kg	2
	Nylon6 30	End of Life	Melting and Extrusion	1.8343	kgCO ₂ eq/kg	3
	Martensitic Low Alloy Steel	End of Life	Steel Recycling	0.79758	kgCO ₂ eq/kg	3
	Hard Ferrite	End of Life	Steel Recycling	0.79758	kgCO ₂ eq/kg	3

Figure 6: Full carbon calculation table for product lifetime

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