White Paper

Accelerating Sustainable Production

A $5 billion annual opportunity for the automotive and electronics industries in Andhra Pradesh, India

In collaboration with Accenture Strategy

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Foreword

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Manufacturing is a cornerstone for economic growth and prosperity. Traditionally, however, manufacturing systems have consumed high levels of resources and generated large amounts of waste. In fact, production value chains generate an estimated 50% of greenhouse gas emissions. In a world of increasing competition and resource constraints, companies need to find new opportunities to drive competitive advantage by innovating for growth, profitability, sustainability and trust.

Innovating production systems for sustainable growth can go a long way towards mitigating negative environmental consequences and decoupling growth from using natural resources. The United Nations 2030 Agenda for Sustainable Development, specifically Goal 12 (Responsible Consumption and Production), provides an additional impetus for manufacturers to pursue more sustainable production systems. The emergence of innovative and scalable technologies represents an opportunity to transform the manufacturing sector so that it drives both profits and sustainability. Solutions such as advanced remanufacturing, cobotics and the use of new materials are paving the way for a world where enhanced market competitiveness, improved human well-being and less environmental damage are no longer mutually exclusive goals, and where local action can trigger changes to systems across global supply chains.

Over the past decades, India has transformed itself from an agrarian economy to one where manufacturing and production systems are positioned as the key pillars for growth. The state of Andhra Pradesh is one of the fastest growing economies in the country and is well-positioned to benefit from innovation emerging from the Fourth Industrial Revolution.

This White Paper assesses the opportunities that Fourth Industrial Revolution technologies could bring to Andhra Pradesh and its resident companies to enhance competitiveness in the automotive and electronics industries while creating positive social and environmental impact, resulting in a $5 billion annual opportunity by 2022. The key findings, case studies and recommendations are intended to inspire the public sector and local and international companies in the state to seize this opportunity. Leaders at the national and global level are encouraged to become aware of this new approach to technology, competitiveness and sustainability, and to support and magnify the effect of local action to trigger changes in global systems.

This paper is intended to foster public-private collaboration that can accelerate the transformation towards more competitive and sustainable production systems.

Executive summary

The World Economic Forum Accelerating Sustainable Production project aims to help countries and businesses achieve sustainable growth by adopting Fourth Industrial Revolution technologies for manufacturing. The project's first phase identified 40 disruptive technologies to deliver triple bottom line value in four manufacturing industries – automotive, electronics, food and beverage, and textiles, apparel and footwear. The ongoing second phase focuses on building regional perspectives of sustainable innovation benefits, with the first regional study enabled by the kind collaboration of the government of the state of Andhra Pradesh, India.

The study builds on the work of the project's first report, *Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation*, and develops it based on Andhra Pradesh's local needs and opportunities. Primary and secondary research established the industrial context for the sectors of focus, and the Accelerating Sustainable Production framework was applied to quantify the potential value created by each technology across the triple bottom line of society, environment and economy and mapped to the UN Sustainable Development Goals. The project is indebted to a highly engaged working group of industry and the state's government officials who provided input to the research, prioritized the solutions and validated the findings through workshops and interviews.

The study focuses on the Andhra Pradesh automotive and electronics sectors and identifies six Fourth Industrial Revolution technologies that present a sustainable value opportunity totalling $5 billion annually by 2022.

Value opportunity for the electronics sector in Andhra Pradesh

The state's electronics industry stands to gain more than $1.7 billion in value in 2022[1] by adopting the top three Fourth Industrial Revolution technologies – 3D printing, digital traceability of materials and advanced electronic design automation (advanced EDA or AEDA) – in its production systems. AEDA alone accounts for over $1 billion in potential value realized through the reduced risk of product failure, leveraging machine learning and artificial intelligence to design products. It also allows for a reduced environmental footprint by lowering water and material consumption through virtual design in product development. Moreover, it could potentially supply close to 36,000 people from the talent pool and trained in Andhra Pradesh.

3D printing represents $630 million in value through cost savings realized by just-in-time spare part inventory management and additional revenue through product premiums from customization. It also offers raw material savings from process efficiencies, thereby reducing the environmental impact of using virgin plastic.

Digital traceability of materials can boost sustainable sourcing practices, establish and record the place of origin and life cycle of inputs, and set the foundation for recycling electronics. It can improve transparency across the supply chain, making it easier to identify faulty and counterfeit components. Industry players can potentially realize about $127 million by leveraging digital tracing and tracking in their production systems.

Value opportunity for the automotive sector in Andhra Pradesh

The opportunity from Fourth Industrial Revolution technologies presents over $3 billion in value in 2022 for the state's automotive industry. The augmented workforce could improve workers' productivity and reduce training investments to help the industry realize value worth $1.5 billion. Virtual training modules can help Andhra Pradesh address the manufacturing sector's skills gap. In addition, the state can create greater impact of and access to vocational skills, thus overcoming the challenge of including more women in the workforce.

Collaborative robots (cobotics 2.0) could deliver about $1.4 billion in value by improving workforce productivity and assembly line efficiency, resulting in increased throughput. Cobotics may also significantly reduce the incidence of workplace accidents; the technology can help offload strenuous and mundane tasks, improving

shop-floor safety and resulting in a potential annual saving of about 150,000 man-days in Andhra Pradesh.

Bio-based plastics and composites offer about $424 million in value to the state's automotive industry through reduced externality cost of carbon emissions and potential premiums on eco-friendly vehicles. The technology can facilitate lighter cars with better fuel efficiency and reduced vehicular road emissions.

The way forward

The Andhra Pradesh automotive and electronics industries have a significant opportunity to gain competitive advantage and build sustainability and trust by embracing innovations from Fourth Industrial Revolution technologies. Accelerating this adoption, however, requires technological infrastructure, relevant skills, investments and a strong collaboration between the government, industry and academia. While Andhra Pradesh has already embarked on its Fourth Industrial Revolution journey with effective policy and industry initiatives, significant opportunity still exists to speed the execution. Some potential areas for action include:

Greater access to technology – The availability of and access to Fourth Industrial Revolution technologies is the first step towards promoting their adoption by industry incumbents. While progress has been made (a 3D-printing hub, a pilot to test blockchain for administration), the trend and thrust need to continue for other solutions with potential.

Smart skilling and upskilling programme – Providing the skills for the new talent pool of the state's future manufacturing sector is urgent. Smart solutions, such as augmented reality/virtual reality-enabled training modules for shop-floor workers, can help bridge the skills gap and create greater access to skilling. A strategy needs to be crafted to upskill the existing talent pool with skills of the future and to mitigate the risk of skills becoming obsolete.

Cohesive collaboration between industry, government and academia – A multistakeholder partnership is required to develop and test these proofs of concept and to test some of the solutions recommended in this paper for their effect in creating production systems of the future.

Chapter 1: The industrial context in India

India is attracting attention worldwide as it surpasses China as the fastest-growing major economy in 2018, with the World Bank predicting robust growth in gross domestic product (GDP) of about 7.5% over the next two years.[2] The Indian government's Make in India programme is driving this growth, focusing on increasing the manufacturing sector's 17% contribution to GDP to 25% by 2022.

Automotive manufacturing and electronic system design and manufacturing are among the six sectors that advance the Make in India programme.[3] The Indian automobile industry became the world's fourth largest by sales in 2017. Passenger vehicle production alone is expected to grow from 4 million units in the 2018 financial year to 9.4 million units annually by 2026.[4] The electronics manufacturing sector is also increasing in significance as the government strives for a net-zero electronics trade by 2020.[5] Almost two-thirds (65%) of demand is met by imports, presenting an opportunity to substitute imports with local manufacturing.[6] To boost growth, the Indian government has used enabling policies as well as infrastructure and skill initiatives for these sectors.

Andhra Pradesh's growth potential and industrial context

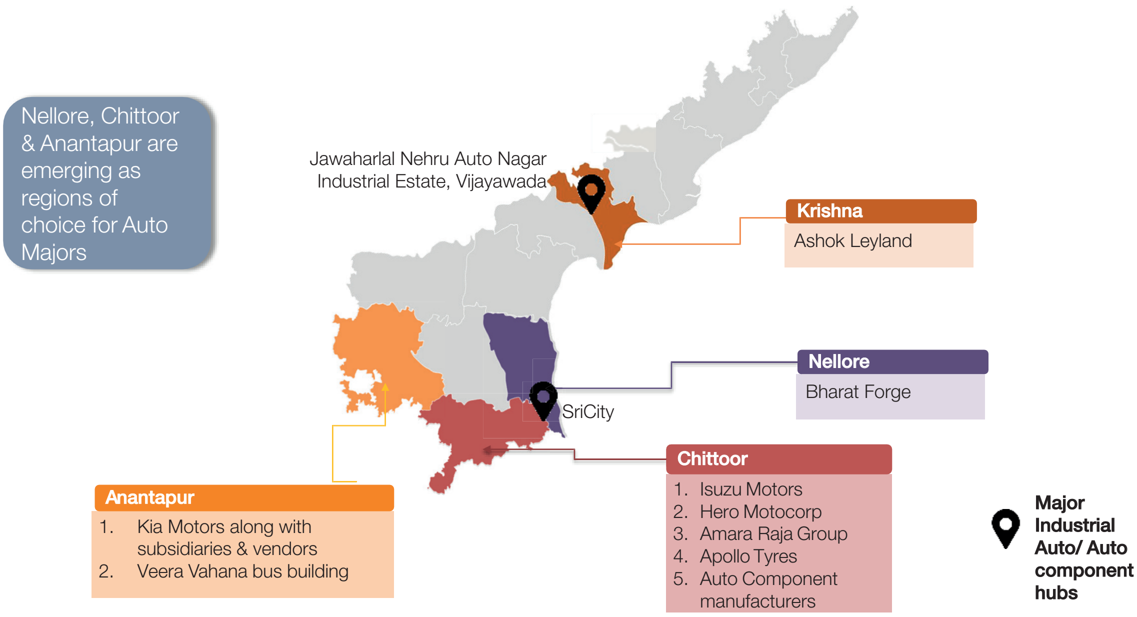
Within India, the economy of the state of Andhra Pradesh shows immense potential for growth, with a rate of 11.6% in 2017 versus the national average of 7.1%.[7] According to the World Bank and Indian industry rankings, the state ranked first in 2016 and 2017 for "ease of doing business",[8] and has enabled holistic growth through policy incentives, infrastructure development and public-private partnerships. This growth, combined with the state government's active and ongoing efforts to innovate for enhancing sustainable economic opportunities and overcoming challenges, made the region an ideal location for deeper analysis on accelerating sustainable production.

The state's government has included the automotive and electronics sectors among the 12 focus sectors for accelerating industrial growth.[9] Each has a 2014-2020 development roadmap that includes a value chain-based approach to bring in related industries by establishing dedicated industrial corridors. Given this strategic relevance, economic importance and commitment of the Government of Andhra Pradesh (GoAP) to support sustainable innovations in these industries, the automotive and electronics sectors were selected as the focus for this phase of the Accelerating Sustainable Production project.

Automotive sector

The automotive and auto components industry in Andhra Pradesh is emerging with prominent hubs, aiming to attract $3.2 billion in investments by 2020. The industry is expected to create 200,000 new jobs by 2020,[10] and has existing and upcoming projects across various automotive segments. Players such as Isuzu Motors, Ashok Leyland, Hero MotoCorp and Kia Motors have started production or are in the process of setting up plants in the state, which has a strong, complementing auto component ecosystem with players including Apollo Tyres, Bharat Forge and Amara

Figure 1: Automotive manufacturing clusters in Andhra Pradesh



Source: Andhra Pradesh Economic Development Board

Raja (Figure 1). The GoAP encourages the development of electric vehicles and the exploration of futuristic technologies for mass transportation (e.g. Hyperloop).

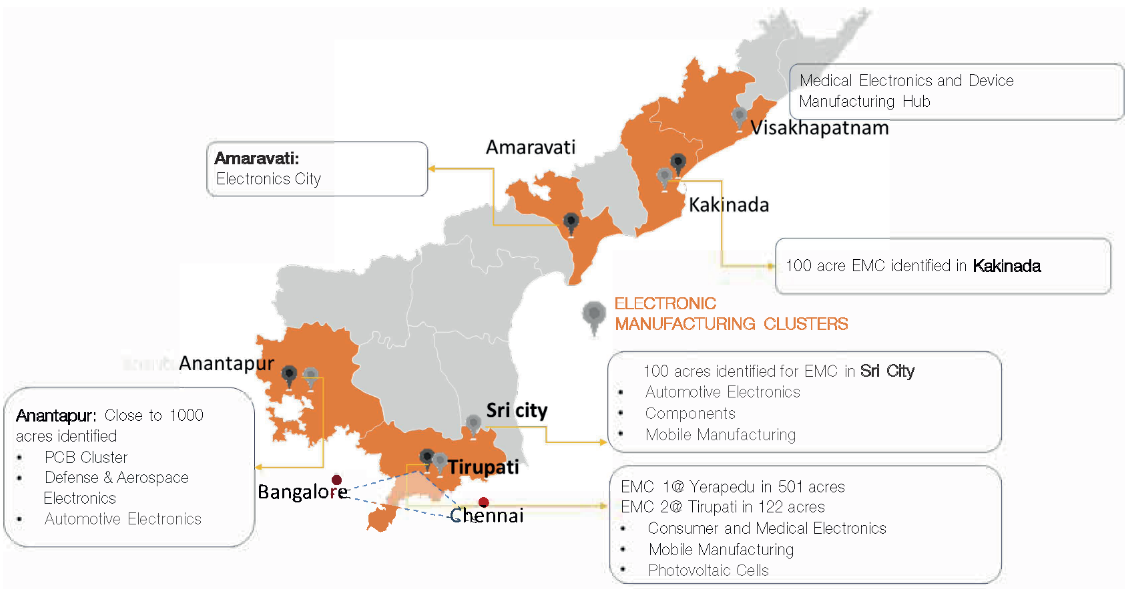
Electronics sector

The electronics manufacturing sector in Andhra Pradesh accounts for 23% of India's electronics production and is poised to grow to 50% by 2021.[11] The state is targeting to manufacture at least 100 million-150 million of the 500 million mobile phones produced in India by 2020.[12] Its electronic manufacturing clusters (EMCs) are becoming the preferred destination for domestic and foreign players, including Foxconn, Celkon, Lava, Holitech and Dixon (Figure 2). The state has made skill development a priority, with policies targeting 400,000 new jobs in electronics by 2020.[13] Public-private partnerships have been set up between the private sector (e.g. HP) and international universities to facilitate acquiring skills and domain expertise for the state's youth and to develop technologies such as 3D printing, blockchain, artificial reality (AR) and the internet of things (IoT).[14]

While the state has plans to accelerate growth and is looking to realize its targets, this anticipated growth intensifies the sustainability challenge. In 2013-2014, Andhra Pradesh emitted 103 million tonnes of CO_2 equivalent, with the manufacturing sector contributing 10.3% of the total.[15] In Vizag, the state's largest city, 321 metric tonnes of e-waste are generated annually, and although 25-30% of it is resold or exchanged through online marketplaces, the collection infrastructure has yet to mature.[16]

Andhra Pradesh, however, is positioned to address these challenges. The GoAP and heads of industry have already positioned it as a leader for innovative thinking to drive growth. The state has an opportunity to continue developing a sustainable competitive advantage by improving supply chain resilience, transparency, traceability and standardization of components, by upskilling the workforce to meet the latest tech needs, and by systemically reducing waste and emissions. A strategic collaborative approach for sustainable production by government and industry that maximizes the potential of emerging technologies will allow the state to maintain its growth momentum and realize the full potential of its production systems.

Figure 2: Electronics manufacturing clusters in Andhra Pradesh



Note: PCB = printed circuit board
Source: Andhra Pradesh Economic Development Board

Chapter 2: The potential of Fourth Industrial Revolution technologies to help drive sustainability and competitiveness across production systems

Industrial revolutions have disrupted the competitive status quo by introducing new means of production. The first Industrial Revolution saw water and steam-powered mechanical manufacturing, the second electricity-powered mass manufacturing and the third the application of information technology (IT) and electronics for automation.[17] The Fourth Industrial Revolution is a fusion of technologies, blurring the lines between the physical, digital and biological spheres.[18] Fourth Industrial Revolution digital transformations offer significant upside potential, affecting 79% of manufacturing industry players globally on cost reduction and/or additional revenue.[19] The transformations also have notable effects on accelerating the Sustainable Development Goals (SDGs). In India, 94% of the $1.2 trillion of potential value generated by digital technology in the next decade will benefit society rather than shareholders only.[20]

Andhra Pradesh has set a clear vision to be a developed state by 2029.[21] The GoAP is taking concerted efforts to position the state as a high-tech hub. To address the skills gap in emerging technologies, it is setting up the International Institute of Digital Technology (IIDT) at Tirupati.[22] The state is not restricting digital solutions for industrial use only; for instance, ePragati is an e-governance system for providing integrated services for its citizens.[23] Despite state-of-the-art technology infrastructure that enables its strong vision for growth, the state's industrial output trails the national average, with manufacturing contributing 10.2% to the state's GDP versus the national average of about 15%.[24] The trend can be reversed, however, as the state is positioned to capitalize on the Fourth Industrial Revolution to make its production systems sustainable and innovative for competitive advantage.

The first step for Andhra Pradesh to realize this potential is to clearly understand the most suitable Fourth Industrial Revolution technologies with the highest upside potential and local relevance for the automotive and electronics industries. Phase 1 of the World Economic Forum Accelerating Sustainable Production project identified the most relevant technologies across four industries – automotive, electronics, food and beverage, and textile, apparel and footwear. The findings were leveraged and further developed based on the local context for the automotive and electronics industries in Andhra Pradesh. After soliciting primary and secondary inputs from the regional working group, the technologies were analysed for their potential to create sustainable economic, social and environmental impact and to address the needs of stakeholders, including the GoAP and local industry (see the appendix for a detailed framework analysis).

The following technologies were identified:

Fourth Industrial Revolution technologies for the Andhra Pradesh automotive sector
(Figure 3)

– Cobotics 2.0 (collaborative robots) are capable of learning multiple tasks to assist human beings. While the automotive sector in India has already adopted varying degrees of automation, the use of collaborative robots at scale is just beginning. The GoAP is enhancing the relevance of cobotics 2.0 in Andhra Pradesh through a recent push to bring in world-class automation by establishing a university for artificial intelligence (AI) and robotics training in conjunction with Finland.[25] The use of cobots in manufacturing around the globe has led to remarkable efficiency gains (up to 100% in some cases, subject to the magnitude of scale).[26]

Honda's new two-wheeler manufacturing unit near Bengaluru has replaced human effort with a robotic hand to pick materials from one machine and feed them into another. The result has been a reduction of human effort and an increase of 20-25% in productivity compared to the company's first two-wheeler plant in India.[27]

– Augmented workforce refers to equipping employees with additional information through virtual interventions, such as AR and/or virtual reality (VR). The technology finds relevance and applications in areas involving servicing, defect identification and designing, thereby increasing worker productivity. In the state's automotive sector, AR/VR technology could help to skill the 200,000 employees predicted to join the sector by 2020.[28] The GoAP has laid the foundation for bringing this technology to the state with the Animation Visual Effects Gaming and Comics (AVGC) policy 2018-2020, targeting the development of expertise in infrastructure and technology.[29]

Honeywell introduced an AR/VR simulator to train its industrial workforce on critical industrial work activities. The simulator uses Microsoft's HoloLens and Windows Mixed Reality headsets to simulate various scenarios, such as primary failure and switchovers, and cable and power supply failure. The company seeks to improve skill retention by up to 100% and reduce training time by 60%.[30]

– Bio-based plastics and composites improve both the environmental footprint of vehicles and the efficient use of resources via lighter and fuel-efficient cars. The regulatory environment and growing consumer awareness are the key considerations for leading auto manufacturers to evaluate adopting bio-based plastics. The market for such plastics and composites showcases

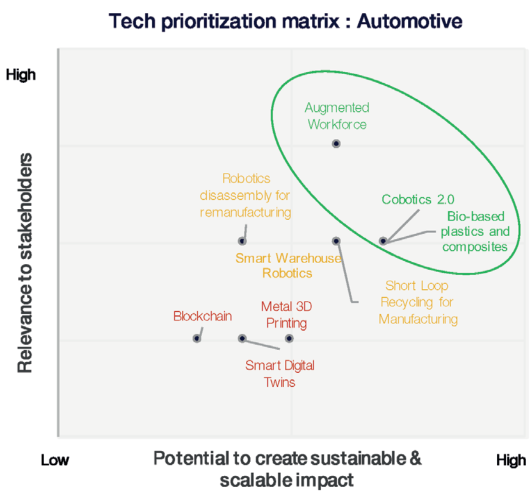
a promising future, with the Indian market expected to expand from 3 lakh tons in 2015 to 4.1 by 2020.[31] Andhra Pradesh is well positioned with agricultural input supply and a suitable talent base to support this solution's expansion and cater to its auto sector's needs.

Ford has experimented using plants, such as bamboo, wheat, rice hulls and coconut skins, to make reliable auto parts. It has partnered with companies including Heinz, Procter & Gamble, The Coca-Cola Company and Nike for sourcing and researching materials. Its soybean-based foam, incorporated in headrests and seat cushions, is a commercial success.[32]

Other potential technologies for the automotive sector in Andhra Pradesh:

- Short loop recycling involves recycling raw materials, such as steel, textiles and plastics, to keep them contained within the local automotive industry by leveraging value chain partnerships. Short loop recycling technology can be highly relevant for the GoAP, especially as it seeks to boost adoption of electric vehicles (EVs). Recycling lithium ion batteries used in electric vehicles could be a significant challenge because they are derived from scarce resources and pose toxic risks if negligently discarded. EV car batteries maintain up to 70% of their capacity after being removed from vehicles. While no longer useful for transportation, these batteries can continue to serve well for less-energy-intensive applications. To this end, Nissan has partnered with power management firm Eaton to repurpose car batteries for home energy storage.[33]
- Metal 3D printing involves using 3D-printing technology for building auto components and spare parts with metal substrates. Building objects layer by layer and using the material only where needed reduces waste and weight, and has a cost advantage. GE Aviation has taken 3D metal printing beyond prototyping. The company is printing fuel nozzles for its LEAP family of jet engines. It has built the Advanced Turboprop, pioneering additive manufacturing in commercial aircraft engines. The designers reduced 855 separate parts down to just 12.[34] The existing infrastructure within Andhra Pradesh and the thrust to accelerate the growth of 3D printing provides sound opportunity for the state's auto players to evaluate and use this technology.

Figure 3: Tech prioritization matrix: automotive sector



Technology	Brief overview
Cobotics 2.0	A robot that has been designed and built to collaborate with humans. A cobotic system includes a cobot and a human collaborating to perform a task in the context of a workstation.
Augmented Workforce	Augmented reality (AR) is a technology that layers computer-generated graphics and images on top of an existing reality, thereby making it more meaningful and informative.
Bio-based Plastics	Replacing heavier metal and other plastic components with high performance elastomers, thermoplastics and composites created partially or wholly by using plant feedstock and emerging chemical and nano technologies. These materials and parts must be suitable for multiple vehicle systems, including powertrain applications.

Source: Accenture Strategy analysis

Fourth Industrial Revolution technologies for the Andhra Pradesh electronics sector (Figure 4)

- 3D printing (or additive manufacturing for electronics) allows the product to be built layer by layer as opposed to the subtractive methods used conventionally. It can lead to significant material and cost savings of up to 70%.[35] The GoAP has laid the foundation for 3D-printing application in the state at the Andhra Pradesh MedTech Zone (AMTZ) near Visakhapatnam,[36] and along with HP has created an institute of excellence for disseminating knowledge on 3D printing in Amravati.[37] Industry players are starting to reap the benefits from this technology beyond the lab.

HP has forayed into Multi Jet Fusion technology-based 3D manufacturing. It has globally inducted 3D printing to manufacturing and has realized savings of 70% in materials and 80% in time.[38]

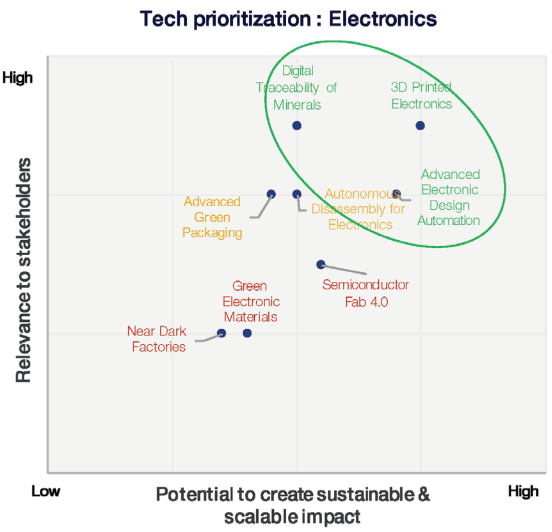
- Digital traceability of minerals, through the use of technology such as blockchain, leads to greater transparency in the material flows across the value chain and thereby helps companies gain greater visibility and control. The evolving technology has started to show pockets of advantages for the industry. For example, Plataforma Verde, a technology start-up, enables companies to trace and track the transport and destination of their waste. Apple uses digital tracking to ensure the cobalt used in its mobile phones is sourced from conflict-free zones.[39] Andhra Pradesh is on the way to becoming a prominent figure in blockchain. The GoAP signed a memorandum of understanding (MoU) with ConsenSys, which will provide technical advice and assist with educating on blockchain through a developer programme.[40]

Everledger, a technology start-up, uses a solution to trace and track and reduce counterfeit and theft in the diamond value chain.[41]

- Advanced electronic design automation (advanced EDA or AEDA) relies on AI and machine learning to crunch enormous amounts of data and create future ready and robust product designs. Its adoption and application are gaining momentum. While AEDA relies on higher-order machine skills, it also involves human thinking and evolving design skills. Andhra Pradesh has 24% of India's IT and electronics engineers, and is aggressively working towards becoming a knowledge hub for skilled engineers through partnerships with international institutes.[42]

Fujitsu MONOZUKURI Total Support Solutions added an AI-based designing platform in 2016, which could reduce the process required to design printed circuit boards (PCBs) by about 20%.[43] By feeding in the desired features of a new product, it could accurately generate the number of PCB layers needed, thus saving on iterations and prototyping.

Figure 4: Tech prioritization matrix: electronics sector



Technology	Brief overview
3D-Printed Electronics	3D printing can be used to print electronics. For e.g - By 3D-printing printed circuit boards (PCBs), designers can obtain faster prototypes, thereby accelerating time to market and ensuring efficient use of resources. This application of 3D printing is relatively new however companies are experimenting to use it for mass customization.
Digital Traceability of minerals	Blockchain-enabled software for precious and industrial metals markets can prevent "conflict minerals" from entering electronic products value chains. Private permissioned blockchain tech can chronologically and permanently log information across a computer network accessed by multiple collaborating parties.
Advanced Electronic Design Automation	EDA, a simulation technology in the field of electronics design, calculates and predicts materials and components performance to create the optimum configuration for products. Used in chip design, it is now extending to the entire development process for an electronic device in combination with machine learning to increase the efficiency and accuracy of both design and production.

Source: Accenture Strategy analysis

Other potential technologies for the electronics sector in Andhra Pradesh:

- Robotic disassembly technology uses robots to disassemble electronic products for reusing components and recycling. Tied with digital trace and track, it can enable short loop recycling in the electronics industry. Robotic disassembly could be a solution for overcoming e-waste issues, with an estimated 40% of lead and 70% of other toxins in landfills coming from e-waste.[44] Liam, Apple's first attempt at robotic disassembly, has been evolved to Daisy, a new robot that can reduce an iPhone into its recyclable parts in just two minutes.[45]

- Innovation in green packaging material allows electronic product companies to move beyond recyclable packaging or recycled material-based packaging. Firms can now incorporate sustainable packaging solutions from innovative renewable sources, such as mushrooms, sequestered carbon and leftover agricultural input. These materials reduce the environmental footprint and benefit the brand reputation of companies. Dell uses bamboo cushions and mycelium-based packaging materials to substitute petroleum-derived foams for shipments.[46]

Chapter 3: The value of sustainable production

An analysis of the potential upside of the top technologies suggests an opportunity to create over $5 billion in annual value for Andhra Pradesh's automotive and electronics industries by 2022 (Figure 5). The chosen Fourth Industrial Revolution technologies for each sector can positively affect output generation, unlock new revenue streams (through product customization), realize cost savings driven by process efficiencies across the value chain, and position the state as a leader in sustainable production.

Moreover, the technologies could accelerate the realization of the United Nations Sustainable Development Goals. Implementing these solutions can boost job creation (SDG 8 – Decent Work and Economic Growth), skill development (SDG 4 – Quality Education) and the inclusion of women in the workforce (SDG 5 – Gender Equality), and can reduce consumption of materials (SDG 12 – Responsible Consumption and Production) and emissions of greenhouse gases (SDG 13 – Climate Action).

Fourth Industrial Revolution technologies do, however, have risks associated with their adoption. Certain technologies have a high energy footprint, while others may lead to unemployment in the blue-collar job market. Industry needs to account for such potential negative externalities before implementing these solutions.

Figure 5: Summary of the annual value potential of the top technologies for Andhra Pradesh

Technology	Commercial Impact	SDG Impact	Associated Risks
3D-Printed Electronics	$630 million in value through cost savings and enhanced product premiums	Reduce material consumption Plastics: 170 tons	3D printing can cause potential health concerns from toxic fumes
Digital Traceability	$127 million in cost savings through reduced warranty claims and improved employee loyalty	Reduce risk of counterfeit phones impacting about 39 million phones produced in 2022	Digital traceability is an energy-intensive capability/technology
Advanced EDA	$1,022 million in costs averted through reduced product failures and prototyping	Create 36,000 new AEDA jobs addressable by AP talent pool Save 124,740 litres of water	AEDA technology is accessible by big players, thereby creating inequalities
Cobotics 2.0	$1,402 million in value through improved product throughput and enhanced labour practices	Save 150,000 man-days (about 20%) through reduced health and safety incidences in AP	Cobotics may threaten 28% of low-skilled jobs in the market
Augmented Workforce	$1,516 million in value through higher output from increased work efficiency and reduced training cost	Train 1 million Self Help Group women to include them in mainstream manufacturing using AR/VR	AR/VR content can overshadow realism and blur real-virtual experiences
Bio-based Plastics	$424 million in value through reduced manufacturing emissions and improved product premiums	Reduce 500,000 tonnes of CO2 emitted in 2022 due to lighter cars in AP	Bio-based plastics are costlier than petro-plastics and lack economies of scale

Note: AP = Andhra Pradesh
Source: Accenture Strategy analysis

Automotive sector

- The cobotics manufacturing industry in India has immense scope to create value. Synergies between robots and humans on the shop floor can increase process efficiency and throughput. Establishing a cobotic environment in Andhra Pradesh presents an opportunity to generate additional value of over $1.4 billion in 2022 in the state's automotive industry. Increased production of passenger cars could lead to $1.4 billion of that additional value. Cobots also positively affect employees' satisfaction by offloading monotonous, repetitive and strain-inducing tasks[47] from their role, thereby reducing the cost of hiring by $0.7 million. One of cobotics' biggest impacts is on the incidence of workplace accidents. The state's automotive industry can potentially save about 150,000 man-days, a 20% reduction, from improved worker safety and ergonomics.

  A potential downside of cobotics is its impact on low-skilled jobs. While it may boost high-skill job creation by 35%, there is a risk that 28% of low-skilled jobs will be lost.

- Augmented workforce has diverse application and scope for the manufacturing sector. Globally, automobile companies have implemented this technology and have seen a significant rise in labour productivity. In Andhra Pradesh, the technology can be leveraged to bridge the huge skills deficit in manufacturing and boost output generation through more productive assembly lines and labour. The state's automotive industry could gain more than $1.5 billion in value through AR/VR technology, with a potential upside benefit of $1.5 million through additional output generation (higher overall equipment effectiveness [OEE]). For skilling, AR/VR-enabled vocational courses can create greater access and impact and reduce the cost of training new employees, resulting in savings of $8 million. This translates into affecting over 1 million women who can then be recruited into manufacturing jobs.

  The technology's downside concerns speculation that AR/VR-enabled content could overshadow realism, blurring the line between real and virtual realms and leading to mental health issues.

- Bio-based plastics and composites promote notable economical value generation over and above their apparent positive environmental impact. In Andhra Pradesh alone, this solution could create $3.6 million of savings from reduced carbon dioxide emissions in manufacturing and from bio-based plastics reducing the weight of passenger vehicles.[48] They also unlock the potential for premiumizing revenue from sustainable and eco-friendly cars, amounting to $421 million in additional revenue capacity. The technological solution is energy friendly and has shown to consume 30% less energy than the manufacture of conventional plastic.

  Bio-based plastics are expensive, however; they can cost 20-100% more than petro-plastics and lack economies of scale.[49]

Electronics sector

- 3D-printed electronics present an opportunity of over $630 million in value for Andhra Pradesh in 2022. From a commercial perspective, 3D printing can open new revenue streams from product customizations worth $617 million in 2022. Additionally, the technology is an opportunity to save costs compared to conventional manufacturing. Just-in-time spare parts inventory management using 3D printing could lead to savings worth $14 million, while 3D-printed tools for smaller batch productions can help save $2.5 million in 2022. In manufacturing mobile phone cases in Andhra Pradesh, 3D printing could enable savings of 170 tonnes of plastic.

  While the technology has its potential upside, 3D printing can pose health concerns. Most of the printers release ultra-fine particles and volatile organic compounds during printing and may increase the risk of cardiovascular and respiratory problems.[50]

- Blockchain-enabled digital traceability for minerals, components and labour standards across the value chain presents a value opportunity of over $127 million in 2022 for the Andhra Pradesh electronics industry. The biggest scope for realizing value is for the electronics original equipment manufacturers (OEMs), who bear 85% of all warranty claims made for mobile phones. Research suggests that 50% of these claims are due to faulty components supplied by tier 1 and 2 suppliers.[51] By enabling robust trace and track, the warranty claims can be shifted to the accountable partner in the value chain, resulting in $120 million cost savings for OEMs. Ethical labour standards ensured by traceable value chains can bolster worker loyalty, saving $7 million in avoided attrition cost for the state's electronics industry. The technology can additionally address and enable sustainable sourcing of raw minerals, thereby reducing the use of conflict minerals (e.g. cobalt in mobile phones) by 15-20%.[52] Digital traceability can set the foundation for recycling electronic components because it can bring in greater transparency and thus establish provenance of the materials in the value chain.

  Blockchain technology is expensive to integrate, however, because of the amount of computing power needed and large operational costs (approximately $100 per gigabyte and $50,000-100,000 per user).[53]

- Advanced electronic design automation (AEDA) is a consequence of the rising demand for EDA, whose advanced version is enhanced by AI and machine learning. India's chip design automation industry is steadily growing, pegged to increase globally at a compound annual growth rate of 5.5% between 2017 and 2022.[54] In fact, AEDA presents a $1,023 million opportunity in 2022. Robust research and development (R&D) using AEDA for electronics designing can reduce the risk of product failure, which averages 35%,[55] by $1,022 million. It also has implications for the bottom line through reduced physical prototyping costs of electronic components. The rising demand for AEDA services requires an increase in skilled workers, which translates into 36,000 new jobs in 2022. The technology can also have a positive effect on the state's water footprint, with 124,740 litres saved through reduced physical prototyping.

  AEDA technology is expensive (a first-time investment of about $40,000) and can be accessed by only the big players, potentially leading to income inequalities in the industry.[56]

Chapter 4: The path to sustainable production

The GoAP has already taken proactive measures to boost manufacturing in Andhra Pradesh. In just four years, the GoAP has established sector-specific policies, created procedures to conduct business, incentivized companies to attract investments and constructed favourable physical infrastructure. Now is the time, however, to seize the additional opportunity by weaving Fourth Industrial Revolution advancements into the production systems to make them more competitive and sustainable. Building sustainable production systems requires a multidimensional approach to source the right technology, develop suitable skills and create partnerships. The analysis in Figure 6 highlights key considerations for each chosen technology.

The insights from the analysis indicate the state and readiness of Fourth Industrial Revolution technology adoption for the state's industries. While several technologies can be adopted and mobilized with relative ease, others will be better positioned in the next two to four years. 3D printing for electronics and automotive parts, for example, offers an immediate opportunity, with most of the state's operational ecosystem already in place. Likewise, implementing cobotics in the automotive sector will be less resource-intensive. While technologies such as AEDA for the electronics sector and the augmented workforce for the automotive sector have significant upside potential, their adoption and implementation would require a phased strategy over the medium to long term.

Figure 6: Key considerations for each technology and their readiness for adoption

Technology	Technology infrastructure	Skill maturity	Scalability	CAPEX requirements	Partnership opportunities
3D-Printed Electronics	The APMTZ has 3D-printing infrastructure available for the healthcare industry. It can also be leveraged for the automotive and electronics industries, among others.	A centre of excellence to impart 3D-printing skills has been set up in Andhra Pradesh (AP). The state, however, needs to build skills involving 3D design, technology internalization and execution.	3D-printing technology is maturing globally and being used for prototyping and mass manufacturing. AP can potentially scale it up across industries in the future.	The cost of a printer varies from $6,000 to $750,000, depending on the functionality, input print materials (metal, plastic) and output size.[57]	HP and the GoAP have partnered to develop a centre of excellence, with an experience centre to showcase 3D-printing applications and future scope. A partnership with the AP Innovation Society and AP Skill Development Corporation can be explored.
Advanced EDA	Infrastructure for machine learning and AI is evolving in AP. Dedicated systems for AEDA need to be sourced.	AEDA requires sophisticated designing skills, incorporating AI and machine learning. The GoAP has established the IIDT in Tirupati to aid with skilling in the domain.	AEDA showcases a promising future. The EDA market is already mature and continues to grow. With increasing sophistication in AI and machine learning, AEDA will have greater applicability in the future.	AEDA software can cost between $25,000 and $100,000, depending on the complexity of the designing features and the number of project phases in the development cycle.[58]	A consortium of companies is required to pilot R&D, develop use cases and create a service ecosystem to make it affordable for smaller players.
Digital Traceability	AP has created the ecosystem for using blockchain in fintech. The ecosystem can be leveraged for applications in electronics and related industries.	The technology requires blockchain expertise. The GoAP has collaborated for R&D and skill development in blockchain.	Traceability of information has immense potential, as multiple touchpoints in the value chain can benefit from it. Pilots for blockchain in other industries (banking, food) have been successful.	A single application (developed using blockchain technology) can cost about $80,000.[59]	Multiple MoUs by the GoAP are in place for all aspects of the ecosystem, bringing in technology, R&D and skilling.
Cobotics 2.0	Shop-floor automation and robotics is a mature technology. Cobotics needs a clear definition of how humans will coexist and of possible areas of dividing work.	Cobotics requires the upskilling of the existing workforce as workers move from mundane jobs to more technical roles of supervising cobots.	Globally, cobots are being used extensively on shop floors. More areas can be explored for applying them within and outside the industry.	A cobot can cost between $35,000 and $60,000. The cost depends on its capacity (the payload it can carry, the area its arm can reach).[60]	Cobotic technology is in a nascent stage in AP. The state is currently importing bots. The GoAP can look at incentivizing local manufacturing.
Augmented Workforce	Onboarding AR/VR players is needed in AP; the GoAP has taken steps towards this. Hardware is expensive and not accessible for all companies.	Application developers are needed to create relevant content. The AP gamification AR/VR centre can propel skilling to create a developer's base.	Technology has immense scope given that applications are still evolving. Customizing content will be a critical factor for future success.	The cost of hardware (e.g. Microsoft Hololens) is $3,000; the cost of software (platform, content) is $50,000-250,000.[61]	AP needs to address the skills gap in AR/VR. The GoAP has partnered with Veative Unity Technologies to provide skills to the workforce in developing AR/VR content. A partnership with the Andhra Pradesh State Skill Development Corporation could be explored.
Bio-based Plastics and Composites	The Indian market for composites is growing. Bio-plastics are used in the food and packaging industry. Technology can be leveraged for the automotive sector as well.	Material manufacturers for bio-based plastics are limited. Training for biomaterial manufacturing, disposal and recycling is needed.	Bio-based plastics are relevant for the future: they can replace existing petro-plastics used in automotive manufacturing.	Bio-based plastics are expensive and lack economies of scale.	The GoAP needs to onboard partners to encourage R&D and manufacturing to mainstream bio-based plastics and make them more affordable.

Maturity

High | High-Medium | Medium | Medium-Low | Low

Note: CAPEX = Capital expenditures
Source: Accenture Strategy research; Andhra Pradesh Economic Development Board data

Conclusion

This Accelerating Sustainable Production in Andhra Pradesh study set out to identify the Fourth Industrial Revolution technologies with the greatest potential to enhance competitiveness and sustainability in the state's automotive and electronics industries. The analysis suggests a positive upside potential commercially, socially and environmentally. The technologies also make a strong case by addressing some of the challenges raised by local stakeholders. Digital traceability, for example, can provide higher value-chain transparency to reduce supply outages and improve the quality of input. 3D printing can provide solutions to challenges in importing components. In the automotive sector, cobotics can address process inefficiencies for assembly lines, and augmented workforce can lead to improved worker productivity.

Andhra Pradesh has already embarked on its Fourth Industrial Revolution journey. The imperative next step is to develop a clear roadmap for accelerating the adoption of identified technologies. The key considerations for designing the implementation roadmap are:

1. **Access to technology** – Making the technological infrastructure available for industry is a critical step in enabling adoption. The state's government has made progress in introducing state-of-the-art technological solutions, such as 3D printing to manufacture healthcare equipment, and blockchain for administration. Continued action in this direction, through the creation of similar hubs and centres of excellence for other technologies, could put the state on a path for accelerated adoption of the relevant technologies.
2. **Access to skills** – Adopting technology at scale in the production system requires access to the right skills in the right numbers. The state's manufacturing sector needs to upskill the workforce to efficiently harness the opportunities presented by the Fourth Industrial Revolution.
3. **Access to partnerships –** Forging the right partnerships and creating an enabling ecosystem is a critical success factor. The GoAP could consider a multistakeholder collaboration between industry, government and local training institutes to identify relevant skill sets and impart them to its talent pool using Fourth Industrial Revolution technology (AR/VR). Another noteworthy partnership could be with niche technology suppliers and prominent industry players to source and pilot new solutions (AEDA, traceability). This will allow the state to attract participation and investment from diverse players around the globe, adding momentum to local efforts.

The study's insights are intended to spur conversation and foster collaboration between the automotive and electronics industries, the GoAP, academia and civil society for adopting Fourth Industrial Revolution technologies. The government and industry, together with the World Economic Forum, can champion the cause of sustainable production by serving as a model state via the adoption and success of Fourth Industrial Revolution technologies for manufacturing.

Appendix

Scope, methodology and terms

Scope of the study

The Accelerating Sustainable Production in Andhra Pradesh study builds on the World Economic Forum Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation study, which focused on four industries that were chosen based on the interest of the project community. These industries were low- and high-tech product manufacturing industries with high environmental productivity, end-consumer visibility and good potential for further transformation:

1. Automotive
2. Electronics
3. Food and beverage
4. Textiles, apparel and footwear

In addition, the Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation study identified 40 Fourth Industrial Revolution technological developments that could drive competitiveness and sustainable value across the value chains of the four industries (Figure 7).

Figure 7: Fourth Industrial Revolution technological developments for driving competitiveness and sustainable value

Automotive (9)	Electronics (8)	Food & Bev (11)	Textiles, Apparel & Footwear (12)
Short loop recycling	Green Electronic Materials	Precision Agriculture	Precision Agriculture
Bio-based plastics and composites	Autonomous disassembly	Advanced Bio Farming	Biofabricated Leather
Robotic disassembly for remanufacturing	Semiconductor Fab 4.0	Genome Editing	Alternative Natural Fibres
Cobotics 2.0	Advanced Green Packaging	Agriculture 5.0	Gen-edited Fibre Crops
Metal 3D printing	Digital Traceability of Minerals	Cellular & Tissue Engineering	Advanced Organic Wastewater Treatment
Blockchain	Advanced Electronic Design Automation	Automated Agriculture	Advanced Bio Farming
Augmented workforce	3D printed electronics	Advanced Organic Wastewater Treatment	Next Gen Bio-based Polyester
Smart Digital Twins	Near-dark Factories	Supply Chain Traceability & Control	Upcycled Textiles
Smart Warehousing		Vertical Farming	Blockchain for Fashion
		3D Food Printing	Footwear Factory 5.0
		Supply-side Advanced Packaging	Automated Sewing
			Nano-Tech Enhanced Fabrics

Source: World Economic Forum. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" White Paper, January 2018

For Andhra Pradesh, the automotive and electronics industries were selected as the industries of focus because of their relative economic importance to the state's economy and their strategic relevance for the region. The Andhra Pradesh government validated and confirmed their high relevance. The 40 Fourth Industrial Revolution industry developments identified in the other study were considered as the starting point to select the top-three developments presenting the most significant upside potential for competitiveness and SDG value creation in the state's automotive and electronics industries. (See Tables 1 and 2, for an overview of the developments evaluated for the two sectors.)

Local working group

A local working group was formed, consisting of select local and international companies from the state's automotive and electronics industries and its senior government officials. The group provided consultation and expertise to the project team throughout the study.

Methodology

To develop this study, a mixed method research combining qualitative (i.e. workshops, interviews) and quantitative (i.e. data collection, value quantification exercise) analysis was used.

Calls

Two calls were held, at the beginning and the end of the project. They brought together the local working group members and the project team.

In the kick-off call, the Accelerating Sustainable Production in Andhra Pradesh project was introduced to the potential members of the local working group, as well as the project's objective and scope. The study's key findings were discussed and validated by the group in the final call and refined accordingly.

Workshop

A workshop was held in Vijayawada, Andhra Pradesh, India in June 2018. The workshop, which brought together the local working group members and the project team, had the following objectives:

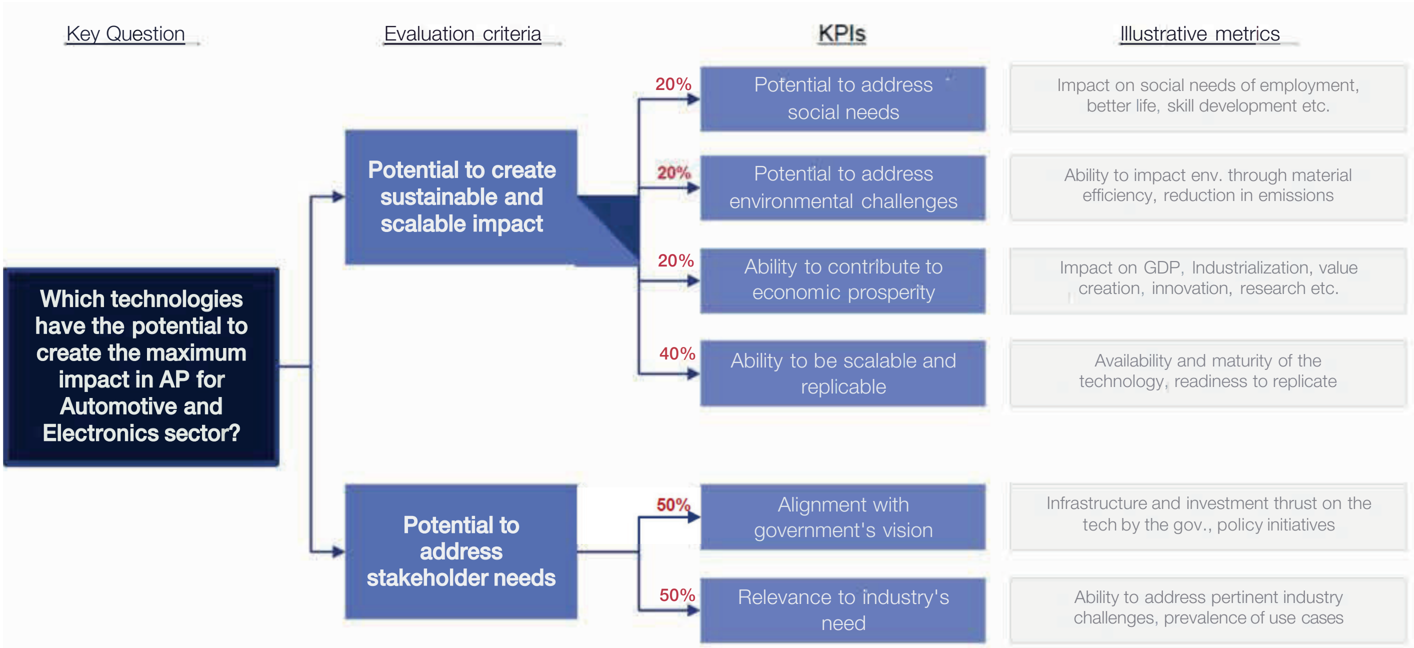
- To explain the project goals and outcomes to the working group and discuss and agree upon the roles and responsibilities
- To determine the challenges across the value chain for both sectors and the potential Fourth Industrial Revolution technological interventions to address those challenges

Secondary research and prioritization framework

A technology prioritization framework was created for a first assessment of the Fourth Industrial Revolution technological developments, to identify those with the most significant upside potential for competitiveness and sustainable value creation in the automotive and the electronics industries in Andhra Pradesh (Figure 8).

The framework had a twofold purpose: (1) to measure the potential to create impact of the Fourth Industrial Revolution developments; and (2) to identify the top-three developments with the most significant upside potential in the state's automotive and electronics industries. It differentiated between the potential to create sustainable and scalable impact (the potential to address social needs and environmental challenges, and the ability to contribute to economic prosperity and to be scalable and replicable) and the potential to address stakeholder needs (alignment with the government's vision and the relevance to industry's needs).

Figure 8: Technology prioritization framework



Source: Accenture Strategy framework

Primary and secondary research was conducted to assess the technologies, including interviews of subject-matter experts, identification of case studies and analysis of available public and private data.

This assessment concluded with the preselection of the top-three technology developments for the state's automotive and electronics industries.

Subject-matter expert interviews

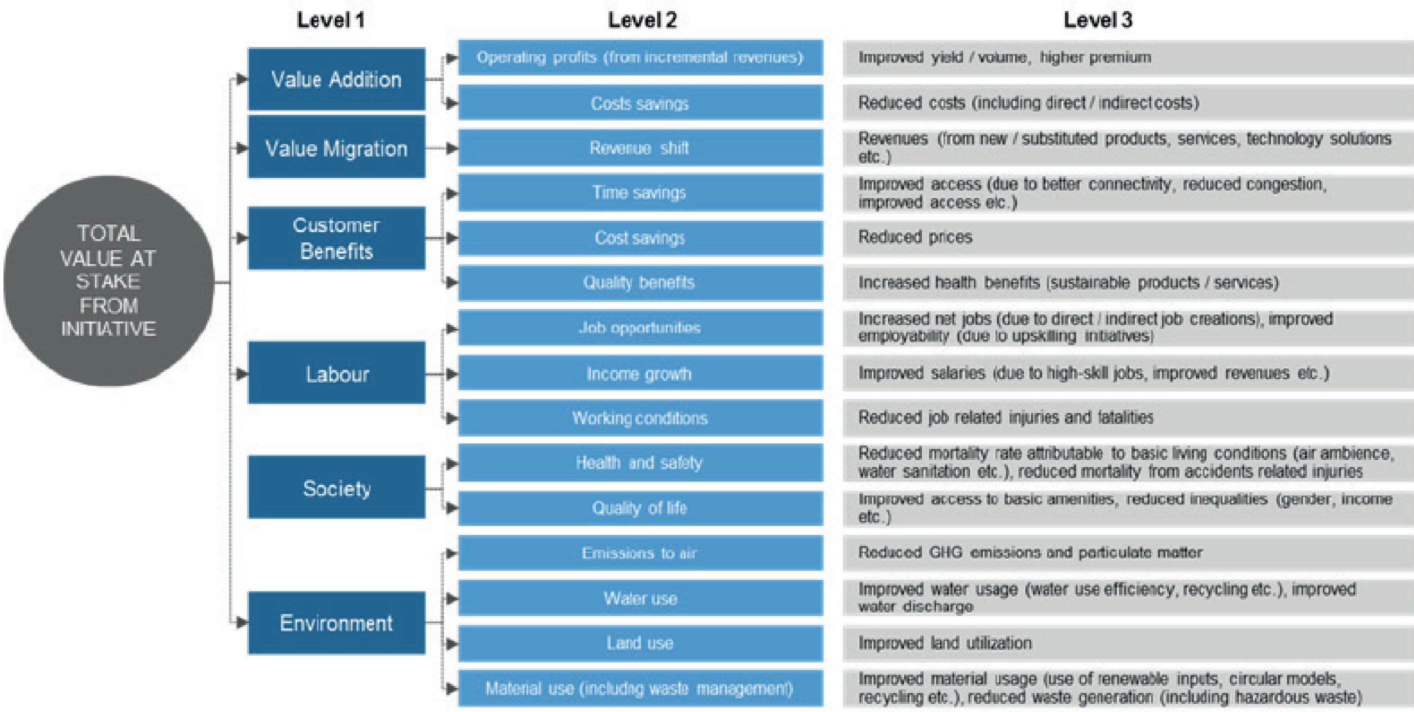
Subject-matter experts from the private and public sectors in Andhra Pradesh were interviewed to validate the top-three developments preselected according to the technology prioritization framework criteria. They also helped in understanding the relevance of the selected technology developments. One-to-one discussions were conducted with industry experts from relevant manufacturing domains.

The following people from the GoAP were interviewed: Solomon Arokiaraj, Secretary, Departments of Industries and Commerce, Government of Andhra Pradesh; J. Krishna Kishore, Chief Executive Officer, Andhra Pradesh Economic Development Board; and Ahmed Babu, Vice-Chairman and Managing Director, Andhra Pradesh Industrial Infrastructure Corporation.

Value quantification exercise

This exercise leveraged the Accelerating Sustainable Production framework developed in the World Economic Forum Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation study (Figure 9).

Figure 9: Framework for analysing value at stake for individual sustainable production technology developments



Note: Levels 1, 2 and 3 indicate different levels of value levers.
Source: World Economic Forum. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" White Paper, January 2018

The framework was applied to each of the top-three technological developments identified. The value levers with the potential to create the highest impact were selected for each and quantified to ascertain their commercial, social and environmental impact. The assumptions and resulting numbers that formed the basis of the quantitative analysis were gathered through primary inputs from industry experts and secondary research, and were validated by the local working group members in the final call.

Some of the critical scoping assumptions for the quantification analysis were:

- The quantification time frame was 2018 to 2022. The reported values for the potential impact from technologies are the 2022 annualized realized values.
- Technology procurement time was accounted for in the quantification analysis, and implementation for the technologies was assumed from 2020 onwards.
- The mobile phone market was chosen for the modelling exercise in the electronics sector because of its prominence in Andhra Pradesh (20% of mobile phones produced in India are manufactured in the state, which is pushing to increase its share to 70% or 80%).[62]
- The passenger vehicle market was chosen for the modelling exercise for the automotive sector because of the increasing demand in India and the high value commanded per product.
- The quantification analysis only modelled the potential upside value created. A deep case-by-case cost-benefit analysis is required when individual players evaluate the adoption of technology.
- The adoption of the technology was assumed to be less than 100% over the duration of the quantification analysis study. The adoption percentage taken varied depending on the technology's maturity and its relevance to the industry and state context.

For the mapping of the top-three developments for the automotive and electronics industries, see Figures 10 and 11, respectively.

Figure 10: Mapping of the top-three Fourth Industrial Revolution technological developments for the Andhra Pradesh automotive industry

Direct Impact | Indirect Impact | Risks

Level 1	Cobotics	Augmented Workforce	Bio based materials
Value Addition	Improved production yield through combined worker-robot productivity	Improved worker productivity resulting in higher manufacturing OEE and resulting throughput	
Value Migration			Additional revenue through premium charged on eco-friendly cars
Customer Benefit			
Labour	EHS risk & attrition cost reduction Loss of blue-collar jobs	Addressing the skill gap using AR/VR technology, decrease in gender related opportunity gap	Improved working standards as biomaterials do not emit toxic fumes
Society	Improve gender inclusion in auto as may make jobs gender neutral	Inappropriately developed content may lead to cognitive overload	Potential to create indirect jobs given the rapid growth of composite industry in India
Environment	Lesser land utilization; Reduced environmental footprint due to precision manufacturing		Reduced carbon emissions Difficulty in degradation

Note: EHS = Environmental, health and safety
Source: Accenture Strategy analysis

Figure 11: Mapping of the top-three Fourth Industrial Revolution technological developments for the Andhra Pradesh electronics industry

Direct Impact | Indirect Impact | Risks

Level 1	3D Printing	Digital Traceability	Advanced EDA
Value Addition	Reduced tooling cost due to 3D prototyping; Lean inventory due to on-demand spare part availability	Cost savings due to warranty claims (being passed to relevant partners)	Reduction in product failures enabled by AEDA; Reduction in investment due to reduced physical prototyping
Value Migration	Higher premium for customized products		
Customer Benefit	Improved speed to market and access, customized products	Improvement in brand name due to ethical sourcing enabled by digital traceability	Improved speed to market
Labour	Increased jobs in ancillary services	Improvement in ethical labour practices enabled by digital traceability	Increase in employability demand in AEDA services
Society			Data and supporting technology is expensive making the access restricted to few players
Environment	Higher Energy utilization Reduced water footprint	Significant energy consumption Ethical sourcing of raw inputs	Reduced water footprint for prototyping process

Source: Accenture Strategy analysis

Table 1: Overview of the Fourth Industrial Revolution technological developments evaluated for the Andhra Pradesh automotive sector

Development	Brief overview
Short loop recycling	Short loops, in which all recycling processes remain in the automotive sector, that recover and recycle materials for (re)manufacturing and leverage multiple partnerships enabled by digital platforms and geoproximity. Such loops are set up to recycle raw materials, such as steel, copper, textiles and plastics, keeping them as much as possible in the local automotive industry.
Bio-based plastics and composites	Replacing heavier metal and plastic components with engineering-grade biopolymers and/or lighter natural-fibre-reinforced plastics, created partially or wholly from plant feedstock. For example, structures can use flax fibres and bio-epoxy resin intermingled with carbon fibres in hybrid composites, which are lighter, cheaper and more environmentally sustainable than conventional polymers. These materials and parts are suitable for multiple vehicle systems, including powertrain applications.
Smart Digital Twins	The convergence of existing digital twin technology with the industrial internet of things and machine learning technologies, providing nearly real-time updates and digital asset representation created by sensors deployed on the machines. The digital twin paradigm enables manufacturers to operate factories efficiently and to gain timely insights on product performance.
Cobotics 2.0	A system that includes a robot and a human collaborating to perform a task to achieve higher productivity. It also protects human workers from potentially hazardous jobs (i.e. those with a higher incidence of accidents). A lighter-weight, mobile plug-and-play generation is arriving on the factory floor to collaborate safely with human workers, thanks to advances in computing power and sensor and vision technology.
Metal 3D printing	A process that allows more flexibility in general and the use of application-specific materials. Applications in the automotive industry are characterized by the broad adoption of additive manufacturing technologies for production tooling, spare and custom parts, and increased industrial uptake to print components of end products. Building objects from the bottom up and using the material only where needed reduces waste and weight, and has a cost advantage, especially when using materials like titanium and nickel-alloy steels.
Blockchain	A distributed ledger technology for creating an immutable record of transactions to share with multiple participants in a business network. In the automotive sector, blockchain technology could enable all stakeholders to trace the origin of components back through every step in the supply chain, as well as in reverse logistics applications to enable remanufacturing and recycling.
Smart Warehousing	Advances in autonomous mobile robotics (AMR) technology allowing robots to be used in warehouses where they support high volumes of small, multi-line orders, often in collaboration with warehouse workers. This leads to productivity gains and a decrease in accidents and injuries among workers, and to opportunities for skills development and retraining. Current research focuses on incorporating machine learning into AMR solutions.
Augmented workforce	The use of AR technology in various stages of the vehicle production process. AR can support complex assembly, machine maintenance, expert support needs and quality assurance processes in the automotive industry. A collaborative tool, it facilitates automation on the shop floor, enables productivity gains and resource efficiency, and drives improvement in health and safety.
Robotic disassembly for remanufacturing	Robots widely used in automotive manufacturing but not in remanufacturing, particularly at the critical stage of disassembly. Advances in this sphere could mean that end-of-life product disassembly for remanufacture will become easier, faster and more cost-effective, driving the efficient use of resources and enabling the circular economy in the industry.

Source: World Economic Forum, January 2018. “Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation” White Paper

Table 2: Overview of the Fourth Industrial Revolution technologies evaluated for the Andhra Pradesh electronics sector

Development	Brief overview
Digital Traceability of Minerals	Blockchain-enabled software for precious and industrial metals markets to prevent "conflict minerals" from entering electronic product value chains. Private permissioned blockchain tech can chronologically and permanently log information that is copied across a computer network accessed by multiple collaborating parties. Transactions involving the source of ore can be linked back to previous sales transactions.
Semiconductor Fab 4.0	The application of advanced manufacturing techniques to the production of electronic components (e.g. silicon wafers, semiconductors, microchips), which is very energy and resource intensive. Optimizing operations can help to significantly improve sustainability with a focus on adopting IoT, big data, advanced analytics, machine learning and cobotics in both front- and back-end fabs (fabrications). This is especially the case in emerging markets, with their considerable opportunity to improve energy and resource efficiency.
Advanced EDA	A simulation technology in electronics design that calculates and predicts material and component performance to create the optimum configuration for products. Used in chip design, it extends to the entire development process for an electronic device in combination with machine learning to increase the efficiency and accuracy of both design and production. This results in faster time to market with accelerated prototyping, and fewer batch defects and product recalls.
Near-dark Factories	Automated factories with robotic systems that manufacture electronic products with limited or no human intervention. Though true lights-out production is still rare, more processes are running with limited human interaction. This results in considerable productivity gains and increased throughput and total capacity, while minimizing errors and waste.
Autonomous disassembly for electronics	The disassembly of electronic products for component reuse and recycling, reducing the demand for virgin material and enabling closed material loops and circular economy business models. This development is enabled by modular design technology and advanced robotics and automation within mini disassembly factories. It decreases supply chain risk, mitigates reputation risk in the case of electronics and conflict minerals, and ensures the continuous reuse and valorization of raw materials.
3D-printed electronics	The use of 3D printing to produce hardware components of electronic products. Using 3D printing for printed circuit boards (PCBs), designers can obtain prototypes faster, thereby accelerating time to market and ensuring efficient use of resources. This new application of 3D printing is currently limited to prototyping, but companies are already experimenting with a focus on conductive inks to match the properties of traditional metals used for electronics.
Green Electronic Materials	Synthetic biological materials from organic sources, such as bacteria and microbes, that can help meet the increasing demand for making smaller and more powerful devices. Currently functioning as wires, transistors and capacitators, these materials can decrease the dependence on non-renewable resources and the use of toxic components in electronics in a cost-efficient way. Proposed applications include biocompatible sensors, computing devices and components of solar panels.
Advanced Green Packaging	Sustainable packaging developed through material science innovation that leading electronics companies can incorporate in products leaving their factory gates. Mycelium-based protective foam, AirCarbon® and leftover wheat straw processed by enzymes are some examples. The benefits include a positive reputation for companies and a reduced carbon footprint.

Source: World Economic Forum, January 2018. "Driving the Sustainability of Production Systems with Fourth Industrial Revolution Innovation" White Paper

Key terms and definitions

Production: The full spectrum of value-adding activities in the cradle-to-factory-gate part of a given industry value chain. It excludes those assumed to be out of scope for this analysis.

Sustainable production: The manufacturing of products and product inputs, and the creation of related services, which respond to consumer and market needs and bring a better quality of life. At the same time, it minimizes the use of natural resources and toxic materials. In the process, emissions of waste and pollutants are also minimized to avoid jeopardizing the needs of future generations, based on the definition of sustainable consumption and production from the Oslo Symposium of 1994.

Fourth Industrial Revolution sustainable production development: A set of digital, physical and/or biological Fourth Industrial Revolution technologies converging together to change manufacturing inputs, processes and outputs. They enable new business models with the potential to increase value creation across the triple bottom line (economic, social and environmental).

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Endnotes

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