

# Exploring the Sectoral Dynamics of Indian Electronic System Design and Manufacturing Sector

Chandhash Patel<sup>1\*</sup>, Kunal Sinha<sup>2</sup>

<sup>1</sup>PhD Research Scholar, Centre for Studies in Science Technology and Innovation Policy (CSSTIP), School of Social Sciences (SSS), Central University of Gujarat, Gandhinagar- 382030, India.

<sup>2</sup>Assistant Professor, Centre for Studies in Science Technology and Innovation Policy (CSSTIP), School of Social Sciences (SSS), Central University of Gujarat, Gandhinagar- 382030, India.

\*Corresponding Author: [patel.chandhash@gmail.com](mailto:patel.chandhash@gmail.com), Mob.: +91-8905170166

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**Abstract**—The electronics industry encompasses a diverse spectrum of products and applications, ranging from simple to complicated, with a presence in both domestic and international markets and the value chain. Design, manufacturing, assembling, and testing services are all provided by the Indian Electronic System Design and Manufacturing (ESDM) sector. India has a strong demand for electrical products, and the majority of those wants are met through imports. As a result, the import-export and demand-supply ratios have widened significantly. As a result, the research looked at the ESDM industry from three perspectives: 1) the sector's historical growth, 2) mapping with SSI elements, and 3) recent advancements in the sector that are and will assist India in focusing on domestic manufacturing and portraying India as a worldwide ESDM hub based on secondary sources

**Keywords**— Innovation; Electronics sector; Electronic System Design and Manufacturing (ESDM); Sectoral System of Innovation

## I. INTRODUCTION

The Electronics sector is a meta-resource with a broad spectrum of products and applications ranging from more uncomplicated to complex ones. Over the years, the electronics sector market has developed globally. Most electronic products are our daily life parts and play as essential commodities. Even they are infused in other sectors too. In the context of India, the demand is increasing day by day and is predictable to reach USD 400 billion in 2020 compared to USD 45 billion in 2009 at a 41 per cent of Compound Annual Growth Rate (CAGR). At the same time, the demand-supply ratio shows a vast gap for imports of around USD 300 billion. The worldwide electronics manufacturing market is currently US\$1.75 trillion valued and is the fastest developing and largest manufacturing sector in the world. Henceforth Ministry of Communications and Information Technology of India pointed to the domestic production needs for this sector. Therefore, the Electronics sector seems to have become a global industry of billions of dollars with products ranging from simpler to highly complicated devices. The consequence is that there is a significant discussion on electronics manufacturing and the technological context [1], [2], [3] [4].

The Indian ESDM Sector comprises various segments with their market shares and GDP contribution. The sector

offers services in designing, manufacturing, assembling, and testing. It is roofed under horizontal sections viz. (a) Electronic components; (b) Semiconductor Design Services; (c) Electronic Products as a part of high-tech manufacturing and having applications at various levels; and (d) EMS/Assemblers services. And vertically covered sub-segments as Information and Broadcasting; Strategic Electronics; Industrial Electronics; Automotive Electronics; Medical Electronics; Telecom Segment; etc.) [5], [6]

The electronics sector is not confined to one particular technique or technology, so the innovation pattern and manufacturing process. Most of the raw material in this sector is imported. As of Coronavirus Pandemic, most countries worldwide have gone and are going under lockdown and unlock phases. That has impacted not only the import aspect but the export ratio. Due to the sector's complexity and its infusion across other industries, it becomes essential to understand the various components running, developing, and enhancing this sector.

Thus, the study uses the SSI (Sectoral System of Innovation) conceptual model as a framework and maps it to the ESDM sector, intending to determine 1) the sectoral dynamics that evolved over the years; 2) to identify the fundamental development blocks and their interrelationship within the sectoral boundaries ambit, and

3) the recent development in the ESDM sector based on secondary sources. Henceforth, this mapping is specified as an Electronic System Design and Manufacturing Sectoral System of Innovation (ESDM SSI).

The paper is structured as follows. Section I starts with an introduction. Section II outlines the analytical framework and engagement with the Indian ESDM sector literature. Section III points to the methodology adopted to conduct the study. Section IV deals with historical evolution, mapping out the sectoral system of innovation constituents within the sectoral boundaries, and the recent developments in the sector that are helping India to focus on its domestic manufacturing and projecting India as a global ESDM hub. Lastly, section V concludes by summing up the findings and implications of the study.

## II. RELATED WORK

### Conceptual Framework

In the case of ESDM, the main focus is on design and manufacturing. Most industries, R&D institutions, and firms related to the sector are located in clusters, incubators, and centres of excellence. So this offers mapping and overlapping of the sectoral system of innovation (SSI). However, System of Innovation (SI) different visions give us an understanding of different phenomena in diverse contexts as its dynamic functions (Bergek et al. 2005; Chaminade and Edquist 2005; Hekkert et al. 2007) and thus creating interrelationship between different variables involved; innovation patterns (as radical, incremental, product or process); and types as National (Freeman 1995), Regional (Cooke and Uranga 1997), Sectoral (Malerba 2002), and Technological (Bergek et al. 2008) with insights on the geographical structure concerning particular sector/system and technology. [7]

Within the different visions, the study paper strains SSI. As this suits in discovering the dynamic building blocks as knowledge base and technology to understand existing knowledge and technological base; actors working in this domain (as firms, users, suppliers, financial institutions, universities, trade unions or technical associations with specific capabilities, government agencies, learning processes, expectations, goals, and organizational structures), networks and interaction to look at the sector operational mechanism (as of market and non-market form); institutions to determine rules, laws, acts, regulation which are governing the sector; and demand (demand, supply, and market structure) (refer to figure 1); concerning sectoral margins. The building block that determines SSI are interlinked and thus defined the pathways for sector development.

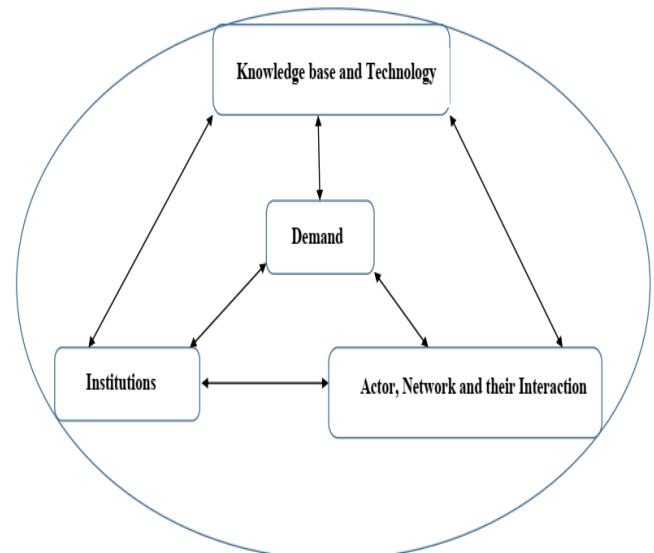


Figure 1. Sectoral System of Innovation Block Diagram

Source: Literature review

The SSI theory is grounded on three domains: The Evolutionary economic theory, Industrial transformation, and the innovation system approach. And that highlights the link and relationship between different variables among and in between technological regimes in non-manufacturing sectors. [8] - [15]

Scholars in India also have worked on the interdependencies and relationships of the structural components of SSI and the other sector as the ICT sector and SSI concept in developing countries [16], India's Aeronautical industry as one industrial sector [17], entrepreneur and its impact on SSI by taking a case study of crude oil refinery [18], Biopharmaceutical Industry [19], the Indian Pharmaceutical Industry more Innovative than Telecommunications Equipment Industry by contrasting sectoral system of innovation approach [20]. Besides that, there are Innovation Council (national and sectoral) with its council structure consisting of the secretariat, members, experts of domains, and multidisciplinary consultants [21], [22]. In addition, ministries (at the national and state level) play a role in finance, IPR, Legal Reform, etc., driving innovations in specific verticals.

### Engagement with the ESDM sector

The Electronics Industry development in India is realized from the year 1965. Still, the main focus started when there was a shift from the heavy industries (i.e., defence and space technologies) to consumer electronics, followed by the liberalization era where the ITA-I agreement was signed, custom duty relaxation was made. From 2000 onwards, this sector has been growing tremendously. [23] In the context of the evolution of the Indian ESDM sector evolution, the literature highlighted the three phases viz. before the signing of ITA, followed by the Post ITA to notification of NPE, and then post notification of NPE based on factors such as demand, regulations and taxes, capital availability, infrastructure and land, investment attractiveness, Technology, R&D Initiatives, IP creation,

Skill/Employment, SME sector, Supply Chain Network, Testing/Certification, Sourcing by Government/corporates. [24]

During every shift, there was a technological change in electronic products, e.g. T.V., started as Black & White (B&W) with picture tube technology to colour, LCDS, LEDS, curve T.V.s with different technological contents. Reports published by the ministry and associations show the production growth in India has been increased (in Rs. Crores) from Rs 110,720 in 2009-10 to Rs 322,938 (that is almost triple) as Electronics Production Annual Growth Trend. Other documents also highlight policy perspective, strategic importance, knowledge, human resources, electronics manufacturing, industry after liberalization, and practices in the Indian Electronics sector, role in the electronics industry value chain. [25] – [34]

### III. METHODOLOGY

The current research approach is based on secondary data, including research papers, articles, and relevant organization documents (working in this domain). Hence, to find data, “Indian Electronics Industry”, “Electronic System Design and Manufacturing Sector”, “Sectoral System of innovation”, “Electronics and Sectoral System of innovation”, “ESDM”, “Indian Electronics Sector and Policies” as keywords were used. Numerous pieces of literature have been found, but the research work is restricted to these keywords and found around 58 documents (considering all as stated) due to the limited period. After that, the relevant parameters have been found that are required in the study. It is secondary research.

### IV. RESULTS AND DISCUSSION

The ESDM sector constitutes four horizontal roofs, where the first two represent products and the other two highlight manufacturing and design services. The size of the Indian ESDM industry as of the IESA-FS report in 2014 is a combination of “Electronics TM + Electronics TE + Electronic Component Market Revenues from Local Manufacturing + Semiconductor Design Market Revenues + EMS Services Revenues”. Additionally, electronics manufacturing and assembly are focused around four important centres in the form of clusters: “(a) North - National Capital Region (NCR cluster), UP (Noida, Greater Noida cluster), (b) West - Maharashtra (mostly Pune cluster and Mumbai), Gujarat, (c) South - Tamil Nadu (mostly Chennai Cluster), Karnataka (mostly Bangalore cluster) and (d) East-West Bengal (mostly Kolkata)”. [35]

Concerning the SSI of India’s ESDM, it starts with 1) the historical evolution of the ESDM sector, 2) the mapping of ESDM with SSI; 3) the dynamic building blocks discussed in figure 1 of ESDM SSI; 4) the sectoral boundaries needed to be concerned while drafting any policies or law, and lastly 5) the recent development in the Indian ESDM sector.

#### A. Brief historical evolution of the sector

In historical prospect, it is found that till 1960 the focus of the Indian government was on agriculture and other industries. Then from 1960 onwards, it starts to focus on the defence sector (military electronics). After that, in the 1980s, the birth of India's consumer electronics industry begins with the development of television and telephones. Many policies and committees were framed during that period focusing on research and development (R&D) and futuristic research. Then the liberalization period (1990 to early 2005) came where liberalization policies were formulated to have investments primarily in electronics design. It was the period when the EMS companies entered catering to a niche market. Over these years, India's software and design capabilities were established in India, taking preference over hardware. After 2005, the focus shifted to revitalising hardware manufacturing. The huge demand and export prospects have attracted investment opportunities in this sector. And so, cluster formation (greenfield and brownfield), special economic zones, FDI, ESSCI, National policies, and other initiatives were taken for the sector's development. [36]-[40].

The sector's evolution can be seen through various committees, policies, schemes, and agreements, as stated in Joseph and Love's work as Bhabha Committee (1966), Hardware Imports (1992), Hardware Imports II (1976), Sondhi Committee (1979), Menon Committee (1979), Hardware Imports III (1981), Components policy (1981), Color TV Policy (1983), Telecommunication (1984), Computer Policy (1984), Integrated Policy (1985), Computer Software Policy (1987), Software Technology Parks (1988), Electronics and Computer Software Export Promotion Council (1988), New Industrial Policy (1991) and so. After that, the liberalization in economic policy took place that is after the new economic policy (1991), and more policies were formulated (refer to table 1) and defined the path for sector development in various phases.

Table 1. Milestones in Indian Electronics Industry (ESDM sector)

| Milestones  | Year                                    | Remark  |
|---|---|---|
| Foreign Direct Investment (FDI)                                       | 1997                                    | India, in 1997 allowed FDI in cash and carried wholesale.   |
| Special Economic Zone Policy  | (2000, amended in the form of act 2005) | This is to accelerate the setting up process for a manufacturing facility.  |
| Semiconductor Integrated Circuits Layout-Design (SICLD) Act and Rules | 2000/2001                               | The layout design of integrated circuits is examined, and then the registration certificates are given to the original layout designs of semiconductor integrated circuits.                       |
| The Information Technology Agreement (ITA)                            | 2005                                    | For zero custom duty on import of all telecom equipment.  |
| National Manufacturing Policy (NMP)                                   | 2011                                    | This policy's major objective is to increase manufacturing's GDP share from 16 percent to 25 percent by 2022. (Additional goals include the creation of jobs, the development of Small and Medium |

|  |           |   |
|--|-----------|---|
|  |           | Enterprises (SMEs), National Investment and Manufacturing Zones (NIMZs), skill enhancement, green manufacturing promotion, and the rationalization and simplification of business rules.)   |
| <b>National Policy on Electronics</b>  | 2012      | The fundamental goal of this policy, which was first drafted in 2011, is to make India an internationally competitive location for electronics production. Preferential Market Access (PMA) and the Merchandise Export from India Scheme are also included in this (MEIS)   |
| <b>Modified Special Incentive Package Scheme (M-SIPS)</b>  | 2012      | To counterpoise disability and to draw electronics manufacturing investments  |
| <b>Electronic Manufacturing Cluster (EMC) scheme</b>   | 2012      | to aid in developing top-notch infrastructure for drawing in investments for electronics manufacturing.   |
| <b>Information Technology Investment Regions (ITIRs)</b>   | 2008/2013 | This was designed with the goal of accelerating the development of Electronic Hardware Manufacturing (EHM) and IT/ITES units.   |
| <b>Compulsory Safety Standards for Electronics Products</b>                                      | 2012      | Under the BIS Act's compulsory registration scheme, MeitY published the "Electronics and IT Goods (Requirement of Compulsory Registration) Order 2012" in the Gazette in 2012. This order required Indian Safety Standards to be met by 30 different categories of electronic products.   |
| <b>Electronic Development Fund (EDF)</b>   | 2016      | As a "Funds of Funds" to participate in "Daughter Funds," which in turn will give risk capital to companies working on novel electronics, nano-electronics, and IT technologies.<br>This was approved in 2014, notified in 2015, and launched in 2016.  |
| <b>National Policy on Electronics (NPE)</b>  | 2019      | The NPE 2019 aims to position India as an ESDM hub by fostering and advancing domestic competences for the development of core components and by fostering an environment that will allow the sector to compete internationally.  |
| <b>Production Linked Incentive Scheme (PLI) for Large Scale Electronics Manufacturing</b>        | 2020      | This provides a production-related incentive to increase domestic manufacturing and draw significant investments in the production of mobile phones and particular electronic components, such as ATMP (Assembly, Testing, Marking, and Packaging) units.   |
| <b>Scheme for Promotion of Manufacturing of Electronic Components and Semiconductors (SPECS)</b> | 2020      | By doing so, the country's ecosystem for the production of electronic components and semiconductors will be strengthened, and the disadvantage will be lessened.  |
| <b>Modified Electronics Manufacturing Clusters (EMC 2.0) Scheme</b>                              | 2020      | This has been advised to address the disabilities by supporting the development of infrastructure of world-class level along with shared amenities and facilities, to draw major international electronics manufacturers and supply chains to establish units in the country.<br>This Plan will increase the connection between the domestic and foreign markets by boosting supply chain responsiveness, consolidating suppliers, reducing time to market, cutting costs for logistics, etc. |
| <b>Electronics India B2B Platform</b>  | ----      | In light of the National Policy on Electronics, MeitY has developed a B2B platform to give PSUs and other private sector businesses an opportunity in ESDM.   |

Source: Compiled by Authors (adapted from [36], [39], and other secondary sources)

### B. Mapping the SSI

Based on secondary sources, the mapping of ESDM and SSI is done. This starts with framework conditions that include financial activities, innovation, entrepreneurship programs, and the policies which enable and support the activities related to the sector for its development in this competitive environment. Followed by the political system (depending on the government and governance); the education and research system dealing with the institutions, colleges, universities (at both the technical and non-technical aspects), public research units (for developing skills among the working force required in this field); the company (firm) system that is private, public, private-public, SMEs, MSMEs functioning in this domain (direct or indirect); the intermediaries (playing a role in connecting all constituents within and outside) that are mainly the suppliers, vendors, industry associations, NGOs and others; the demand depending on the market size and the commanding drivers; and lastly the infrastructure that offers a working environment where a better ecosystem can be created to give output (this includes banking, logistics, transportation, working place, collaborators, identification of the products that to be focused).

The block interaction level depends on the interdependences and interrelationships of heterogeneous and homogenous components within, outside, and amongst the sectors. The mapping might help in finding the new catch-up technologies and the windows of opportunity for innovators, entrepreneurs, policy-makers, and strategists to frame new policies and strategies for sectoral development. However, the basic building block that helped establish this sector are discussed in the upcoming section. In India, great value addition domestically is somehow restricted to final assembly, packing, and testing. But most of them have focused on developing architecture, design, and linked services, which in return gives extra motivation to the sector, industry, or firm to accelerate its investments and evolution.

### C. Building Blocks of the ESDM sector

#### 1) Technology and Knowledge- base

First, there is a look at the technological overview with its diversified nature wrapping numerous technologies and specialized services such as solar photovoltaics, LEDs, nanotechnology products, Notebooks, Desktops, Networking Equipment, Storage and Security, Servers, Printers and other Peripherals, Mobile Handsets, Data Cards, Modems, Adaptors, IP-Phones, Audio and Video Systems, TVs and strategic Electronics.

In this context, Parthasarathi [40] stated that electronics is such a type of industry where technological changes are rapid, so there is no look and focus on such a conceptual framework to develop this as an autonomous industry. Then Mody [41] highlights four ways of the electronics industry division focusing on the international perspective

(Advanced, Design-Intensive, Medium, and Low Technology) in the context to design, manufacturing, and investment scale. In contrast of, collaboration in the technological context during the liberalization period has been discussed in the work of Chaudhuri [42]. Furthermore, to carry out incubation and building ecosystem for helping entrepreneurs stressing on IP creation and Development of Products in the ESDM sector focuses on six mass consumption electronic products identified by the Committee for Advancing Research in Electronics (CAREL) viz. Consumer Electronics (Set-Top Boxes); Education (focus on Tablets)); Telecom (Smart Phones); Energy (Smart Energy Meters); Identification (Smart Cards); and Financial Services (Micro ATMs).

Moreover, the Knowledge-base covers the technological context, R&D, Innovation, Universities, Colleges, and research organizations. Knowledge plays a dominant role in any innovation and innovative activity, covering its impacts on technological capabilities and the learning process. As for skill development, the two-sector skill councils are constituted related to the electronics sector under the NSDC (National Skills Development Corporation) viz Telecom Sector Skills Council and Electronics Sector Skills Council. In addition, there are universities and colleges (divided engineering colleges into Tier I (all IITs, IISc, NITs, IIITs, BITS PILANI), Tier II (top regional engineering colleges (20), mostly from state universities), Tier III (private engineering colleges), Local Polytechniques (Government and Private), ITIs/ITCs, and Others) for the development, diffusion, and integration of knowledge. In addition, there are other programmes related to this area that are assisting in the growth of this industry, such as the establishment of the Electronics Development Fund for encouraging Venture Funds, the establishment of incubators to aid start-ups, the development of the CAS (Conditional Access System) for Set-Top Boxes, the establishment of Centers of Excellence to support flexible electronics, technology for internal security, medical electronics, and other related fields, among others. [43] – [46]

2) *Actors, Networks, and their Interaction*

Actors here can be clustered under numerous sets as Indian ESDM value chain participants, Policy-making Structures, Investors, Consumers, Suppliers, Media, NGOs, Research and Academic institutions, PSUs; Research organizations; Associations and organizations, New entrants, Foreign participants, Integrated Device Manufacturers (IDM), fables companies; Manufacturing units (covering Semiconductor, Equipment, Electronic Manufacturing Services (EMS)), Electronic Design Automation and IP; Marketing and Distribution; Training Providers. It also involves the product value chain participants. ([47], [48], [49] and other secondary sources) (refer to table 2).

Whereas the actor's networking pattern is based on the supply and value chain at both national and international levels, where all stakeholders are involved as platform leaders (dealing with R&D and Design), suppliers

(concerning products and components), manufacturers (dealing in assemblies and subassemblies of the electronic components), Firms (covering the electronic products and components) Market Segments (as Consumer Electronics, Automotive, Medical, Aerospace & Defence, Communication & Networking), Distribution/Sales, Byers and After-sales services (regarding business, technology, maintenance and solution providers). And the interaction takes the form of the market (including customers, suppliers, contracts, market size, and strategies) and non-market (incorporates elements viz., law/regulation, political environment, activist, lobbying, media relation, litigation, etc.).

Table 2. ESDM Key Players (as Actors)

| ESDM Components  | Important Key Players (Actors)  |
|--|---|
| Integrated device manufacturers (IDM), fables companies, and third-party design companies — Design and Manufacturing | <ul style="list-style-type: none"> <li>IDM: AMD, Freescale, Infineon, Intel, NXP Semiconductors, STMicroelectronics, TI</li> <li>Fables: Broadcom, Marvell, Mediatek, Qualcomm, Xilinx,</li> <li>Third-party companies: etfochips, Smartplay, Saksen, Tata Elxsi, Littium, Wipro</li> </ul>   |
| Semiconductor Manufacturing  | Wafer fab: SCL <ul style="list-style-type: none"> <li>The government has approved the setting up of two consortia fabs</li> <li>Outsourced Semiconductor Assembly and Test (OSAT): SPEL Semiconductors, Tesselvo Applied Materials, ASM Technologies, KLA Tencor, LAM Research</li> </ul>   |
| Equipment Manufacturing  |   |
| Electronic Manufacturing Services (EMS)  | Centum Electronics, Dixon Technologies, Flextronics, Jabal, Kaynes, Rangsons, SFO Technologies, Sammin, Sahasra Electronics, SGS Teknisk  |
| Electronic Design Automation and IP  | Cadence, Magna, Mentor Graphics, Synopsys   |
| Marketing and Distribution   | Arrow Electronics, Avnet, Element 14, Tonen Electronics, Electronica, Ramakrishna Sales Corp, WPG   |
| Research Institution Academic Institution Training Providers (relevant for the ESDM sector)                          | Key institutes: BEL-CRL, CDAC, SCL<br>Key institutes: BMS, PESIT, RVCE, IISc, IITs, NITs<br>Key institutes: CDAC, Electronic Sector Skill Council of India (ESSCI), Telecom Sector Skills Council, NEILIT<br>Design school: RV VLSI, Sandeepani School of VLSI Design, Seer Academy   |
| System Integrators   | HCL Infosystems, TCS, Wipro Systems   |
| Incubators and Centre of Excellence  | Incubation centres: DSL, Bangalore, Incubation Centers being set up at IIT Patna (Medical Electronics), Electropreneur Park set up by STPI, Delhi University, and IESA at DU, Electronics Incubator by IITM-Kerala and KSUM at Cochin Kerala, Fables chip design incubation center at IIT Hyderabad, Development of Conditional Access System (CAS) for Set-Top Boxes<br>Centres of Excellence Centers: National Centre for Flexible Electronics (NCFlexE) at IIT Kanpur, National Centre of Excellence in Technology for Internal Security (NCETIS) at IIT Mumbai, National Centre of Excellence on Medical Electronics and Bio-Physics set up at the Andhra Pradesh MedTech Zone Limited (AMTZ), Visakhapatnam  |
| Government agencies and boards (relevant to the ESDM sector)   | Key government bodies: Department of Electronics and IT (DeiTY), (under Ministry of Communications and IT), Ministry of Electronics and Information Technology (MeiTY), National Informatics Center (NIC), Standardisation Testing and Quality Certification Directorate (STQC), Unique Identification Authority of India (UIDAI), Controller of Certifying Authorities (CCA), Indian Computer Emergency Response Team (CERT), IN REGISTRY (appointed by the government of India and is operated under the authority of NIXI), MEDIAL LAB ASIA (Innovating for Digital Inclusion), National e-Governance Division (NEGD), National Informatics Center Services Inc. (NISCC), National Internet Exchange of India (NIXI), Centre for Development of Advanced Computing (C-DAC), Centre For Materials For Electronics Technology (C-MET), Education and Research Network (ERNET), National Institute of Electronics and Information Technology (NEILIT formerly DOEACC SOCIETY), Society for Applied Microwave Electronics Engineering and Research (SAMEER), Software Technology Park of India (STPI), Electronics Sector Skill Council of India (ESSCI)   |
| Associations and organizations (relevant to the ESDM Sector)   | <p><i>Industry associations:</i> India Electronics and Semiconductor Association (IESA), Manufacturers' Association for Information Technology (MAIT), Electronic Industries Association of India (ELCINA), Consumer Electronics and Appliances Manufacturers Association (CEAMA), Automotive Component Manufacturers Association of India (ACMA), Gujarat Electronics Industries Association (GEIA), Electronic Industries Association of Andhra Pradesh (ELLAP), LED-Products Manufacturers Association (LEDMA), India Electronics and Semiconductor Association (IESA), The Indian Printed circuit Association (popularly known as IPCA), Indian Electrical and Electronics Manufacturers' Association (IEEMA), Electronics and Computer Software Export Promotion Council (ESC), Electrical Research and Development Association (ERDA), Electric Lamp and Component Manufacturers Association of India" (ELCOMA), Consortium of electronics industry (CLIK), and so.</p> <p><i>Professional electronic/electrical engineering associations:</i><br/>Institution of Engineers in India (IE), Institute of Electrical and Electronics Engineers (IEEE), Institute of Electrical and Telecommunication Engineers (IETE)</p> |
| PSUs and Research organizations working in the electronics field (directly or indirectly)                            | Defense Research and Development Organization (DRDO), Bhabha Atomic Research Centre (BARC), Bharat Electronics Limited (BEL), Indian Space Research Organization (ISRO), Bharat Sanchar Nigam Limited (BSNL), Hindustan Aeronautics Limited (HAL), Electronics Corporation Of India Limited (ECLIL), Steel Authority of India Limited (SAIL), National Thermal Power Corporation (NTPC), National Aluminum Company Limited (NALCO), Hindustan Petroleum Corporation Limited (HPCL), Bharat Heavy Electricals Limited (BHEL), Bharat Petroleum Corporation Limited (BPCL), Oil and Natural Gas Corporation Limited (ONGC), National Thermal Power Corporation (NTPC), Coal India Limited (CIL), Power Grid Corporation of India Limited (POWERGRID), Neyvelli Lignite Corporation Limited(NLC), Central Electronics Engineering Research Institute (CSIR-CEERI), Steinbeis Centre for Technology Transfer India (SCTI, Germany), TERI technologies.  |
| Consumers  | ESDM segments: Commercial (Industries, governments (central and state), Enterprises, Retailers, Traders); Domestic; International   |
| Policy-Making Structure  | Centre and State  |
| Investors and Owners   | Investors (Banks, Government (Central and State), Angel, FDI, and so)<br>Owners (Private, Public, and Private-Public)   |
| Others   | Suppliers; Media; NGOs; New entrants; Foreign Participants  |

Source: Compiled by Authors (Based on the review of literature)

3) *Institutions*

The Indian ESDM sector, like others, is also governed by laws, regulatory structures, acts, and policies. That, in turn, defines a framework or working ecosystem necessary for operating. The ESDM ecosystem consists of VLSI design, Embedded software, Reference board under industry;

High-tech manufacturing; Electronic, system design industry, EMS industry, Pre-competitive research program; Components and accessories industry; access to the domestic and global market; policymakers; government (at national and state level).

At the national and state government level, institutions are seen to regulate and develop underlining manufacturing, infrastructure development, and facilities, gaining investments, marketing, R&D, Innovation, and Human resource/skill development where national policies and schemes are PLI, SPECS, Modified EMC 2.0 Scheme, NPE 2019, NPE 2012, National Manufacturing Policy (NMP), M-SIPS (Special Incentive Package), EMC (Electronics Manufacturing Clusters), Semiconductor/LCD FABs; Preferential Market Access (PMA), Standards, Tariffs, Export Promotion (Export Promotion Capital Goods (EPCG) Scheme), Electronics Development Fund (EDF), Centres of Excellence, Incubators, Indian Conditional Access System (iCAS), PhD. Scheme, E&ICT Academies, and Sector Skill Councils as National Skills Development Corporation (NSDC), Electronics Sector Skills Council (ESSC), Semiconductor IC Layout Design Rules 2001, Semiconductor IC Layout Design Act 2000, and so [50]. Whereas at the state level, this varies depending on their approach and need. [51].

Furthermore, in the perspective of standards and markets, there are Policies related to Standards and Market so that a good quality product can be manufactured, marketed, and commercialized. Process and Quality Control Standards (Production), Interface standards (Strategic Planning), Transaction Standards (Market Development), Standardization of Technology elements, Market and Test Method, Materials Characteristics Databases, Test Standards, and Technical Basis of Standards [52]. In addition, there are also informal rules that regulate organizational culture norms and barriers.

#### 4) Demand

This core structural block directly or indirectly interconnects all the ESDM sectoral components relative to sector transformation, evolution, and dynamics. As most of the electronics products demand through imports is met, this demand is increasing day by day (IBEF report). Therefore, to understand the demand pattern, there is a focus on two aspects first is the market size as the major component of the ESDM industry (Electronic products (consumer electronics, mobile devices, industrial electronics, IT/Office automation, automotive electronics), Electronics Components (electro-mechanical, active components, passive components), Design Services (very large scale integration (VLSI), embedded systems, printed circuit boards (PCB), and Electronic Manufacturing Services. In addition, the demand for electronics products (Mobile devices, Consumer Electronics, Industrial Electronics, IT? Office Automation, Automotive, Telecom and Strategic Electronics (Aerospace and Defence). [53] The second is on the demand drivers as they not just accelerate sector growth but also define and decide the decline of a particular segment. There are various drivers,

but generally, they can be corporate spending on electronics and Growth in per capita income; infrastructure development; spending is increasing on IT equipment; the Need for innovative products at low cost; the role of Intellectual property rights; and the Knowledge Capital giving strength to the sector. Besides the general drivers, the ESDM segments have their drivers based on their uses, collaboration, and schemes for development.

#### D. Sectoral Boundaries

The ESDM SSI structural components give insights into the complex nature of this sector, which raises concerns over the conditions in which the sector has to operate. Once these are known, a vision can be developed on what more to focus on to enhance or upgrade sectoral development. The highlighted boundaries (conditions) are *Environmental and Social Concerns* (is seen at local, regional, and global level at various stages as designing complexity, materials variety, manufacturing, dematerialization, and recycling concerning health, safety, business ethics, and code of conduct); *Regulatory Bodies* (those who designs and regulates the sector by laws, regulations, and rules. And if this unstable then the blurriness developed and thus creating problems and cause limitations for any sector); *Infrastructure and Business Model* (this deals with the workforce, transportation, logistics, proper supply of power, availability of raw material, space for work, etc. If such facilities are not there, then the sector cannot survive); *Investment* (this is needed for the sector to work and developed to its fully flashed mode. The most common way of investment is government funding, but there are also other forms such as FDI, venture capital, private banks, state governments, from selves, and so); *Customer and Demand Pattern* (This depends on the market demand and supply pattern, and this is controlled by and for consumers depending on the adaptation of technology or product that in turn define the life cycle); *R&D and IP Creation* (this is understood in terms of sector enhancement by giving pathways to carry out innovation for the creation and protection of new innovative products); *Value Chain Network* (that has to cover both national and international perspective for infrastructure, human resource management, technology development, procurements, logistics, services, and support activities in overall demand and supply chain. Whatever the products are developed, they all add value in the socio-economic context.); and *Skill* (The ESDM sector involves various stakeholders and the requirement of skill and knowledge in terms of technology, knowledge, and understanding. If not, there is to be developed so that employment can be generated.).

#### E. Recent developments in the Indian ESDM SSI

The Indian ESDM SSI mapping shows the sector involved in various technologies in itself and others concerning their actors, institutions, market, and demand in inter and intra contexts. But, at the same time, the discussion on the recent development in this sector is done in this section. In the previous few decades, there have been significant changes in the worldwide electronics market. By 2025, it is



anticipated that the worldwide electronics market would develop at a 3 percent of CAGR and reach a value of more than USD 7.3 trillion. Whereas electronic product production has moved from destinations of high-cost to geographies at low-cost, thus making a pivotal input to the country's economic growth. In 2018, the highest contribution to global electronics production was made by China (37 percent), followed by U.S. (13 percent), Taiwan (6.9 percent), South Korea (6.8 percent), Japan (5.4 percent), and India (3.1 percent). However, in the Indian context, the electronics manufacturing sector accounts for India's GDP of 2.5 percent and hires over 13 million people with direct and indirect jobs. The demand-supply gap points to the vast gap between current and expected domestic production and underlines the significant opportunities for improvement. [54]

Out of the overall electronics demand, imports fulfil 50 percent around of the electronic product demand, whereas of the production, 16 percent is exported to different countries. However, the Indian Government has taken multiple measures in the form of incentives, supporting schemes, increased import duty, and stiffened the imported products quality standards to create a local electronics manufacturing ecosystem to reduce electronics imports. Therefore, in the F.Y. 19, electronics imports have declined for the first time compared to the previous year. Whereas in terms of FDI from 2014-18, there was a 49 percent increase in FDI. That is due to changing government norms and a push for the ESDM sector domestic manufacturing [54].

Due to the COVID-19 pandemic, there was a huge impact on the import aspects as most of the countries are and were gone/going through the lockdown phases, and of which there was a transportation shutdown. The same is in the case of India too. During this, the GoI approved three key schemes, viz. PLI Scheme to boost domestic manufacturing by offering a production-linked incentive and attract great investments in ATMP units and mobile phone manufacturing; The SPECS to provide of 25 percent of a financial incentive on capital expenditure for selected electronic goods; and Modified EMC 2.0 Scheme to create infrastructure industry-specific, to enable the electronics manufacturing sector and attract new investments into the country under the umbrella of the electronics sector. In addition, the 'Atmanirbhar Bharat Abhiyaan' featuring five pillars (Infrastructure, System (technology-based), Economy, Vibrant Demography and Demand) has created a floor for the development of more autonomous and indigenous technologies for the nation. The Electronics for You (EFY) in the COVID-19 pandemic situation comes with its first online event, "India Technology Week", to bring different stakeholders on a single platform [56], [57], [58].

The technology does not seem to be constant due to continuous changes and advancements in the R&D. The same is in the ESDM sector too. Therefore, the sector cannot be estimated as fully developed but is in the way of

development and needs more sustainability in technology, economic and social aspects.

## V. CONCLUSION AND FUTURE SCOPE

Whether simple or complex, electronic products have diffused in our daily lives and become an essential commodity. That, in turn, has increased the demand, due to which the demand-supply gap has increased. To stimulate that, the GoI has taken several initiatives. Slowly but steadily, the Indian ESDM sector is moving towards reducing the import ratio by focusing on domestic manufacturing. Today, the contribution to the global electronics industry is being increased.

This article, through mapping, has presented a historical analysis of the evolution of the Indian electronics sectors to provide a dynamic and contextualized perspective on developments in the emerging competitive era. The paper also highlighted the boundaries in which the sectors are operating and so the policies, technologies, key drivers, boundaries, and impacting parameters.

The study, in short, has stressed key points as institutions concerning technology, technological acceptance, demand, knowledge, and boundary edges (sectoral boundaries). The paper tried to cover all aspects under one roof so that a better understanding of the sector can be done. In a situation where the sector has to develop and maintains its stability, there this paper might help and encourage various scholars, researchers, policy-makers, technologist, and strategists to work for and in the ESDM sector to make the sector more efficient not only in terms of products, technology, knowledge pattern but also in the socio-technical, socio-economic and techno-economic aspect concerning sustainability and long-term goal.

As of Coronavirus Pandemic, where most of the countries worldwide have gone and are going under lockdown and unlock phases, has impacted the import and export aspect. In that aspect, the paper might offer a perspective on the sector's complexity and its infusion across other industries, the understanding of different blocks needed to be considered while formulating any policies, laws, acts regulations for developing, and enhancing this sector considering the sustainability context.

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#### AUTHORS PROFILE

Chandrasah Patel is Ph.D. Scholar in Studies in Science, Technology and Innovation Policy (STIP), from Centre for Studies in Science, Technology and Innovation Policy (CSSTIP), School of Social Sciences (SSS) Central University of Gujarat (CUG). He received his Bachelor's degree in Electronics and Communication Engineering (ECE) from the BBDNITM (UPTU), Lucknow, Master's degree in Micro Electronics and VLSI Design (MEVD) from TIT Engineering College (RGPV), Bhopal, and M.Phil. in SSTIP from CSSTIP, SSS CUG. His research interest includes Innovation System, Technological Transition, Technological Convergence, with particular emphasis on Telecommunication, ESDM sector.



Kunal Sinha is an Assistant Professor (Senior Grade) at the Centre for Studies in Science, Technology and Innovation Policy (CSSTIP), School of Social Sciences (SSS) Central University of Gujarat, Gandhinagar. He holds a PhD degree in Science Policy from CSSP JNU New Delhi. He also has BA(HONS) degree in Political Science from DU New Delhi, followed by MA degree in Social Systems from JNU New Delhi, and M.Phil. degree in Science Policy from JNU New Delhi. His area of research interest includes (but is not limited to) Innovation System, Vaccine Innovation System, Technology Foresight, Intellectual Property Rights and Development, Diffusion Studies, Innovation and Socio-economic Change, ESDM, Telecom, and Research Methodology.

