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A Circular Economy Approach to Improve E-waste Recycling in California: Economic Potential and Policy Options

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This Master's Project

A Circular Economy Approach to Improve E-waste Recycling in California: Economic Potential and Policy Options

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List of Abbreviations

Circular Economy	CE
Covered Electronic Waste	CEW
Cathode Ray Tube	CRT
Covered Electronic Devices	CEDs
Waste from Electronic and Electrical Equipment	WEEE
Extended Producer Responsibility	EPR
Sustainable Development Goals	SDGs
Department of Toxic Substances Control	DTSC
Material recovery Facility	MRF
Electronic Product Environmental Assessment Tool	EPEAT
California Department of Resources Recycling and Recovery	CalRecycle
Global Electronics Cycle	GEC
Swiss Association for Information, Communications and Organization Technology	SWICO
Stiftung Entsorgung Schweiz/ Swiss Foundation for Waste Management	SENS
Restriction of Hazardous Substances	RoHS
Secondary Raw Materials	SRM
Recovery Economic Potential	REP
California Department of Tax and Fee Administration	CDTFA
California Code of Regulations	CCR
Office of Administrative Law	OAL
Producer Responsibility Organizations	PROs

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Abstract

The high consumption rates of electronic devices, along with their short life cycles and few repair options, pose a huge challenge for E-waste industries to manage them effectively. E-waste is comprised of hazardous materials and toxic constituents that can impact the environment and public health through improper disposal. However, they also contain valuable materials that, if recovered, can reduce the dependence on virgin raw materials. A circular economy has the potential to utilize these valuable materials and gain environment and socio-economic benefits. This research examines how the adoption of a circular economy approach can improve E-waste recycling in California by evaluating its economic recovery potential and policy options. The economic analysis estimates E-waste generation in California and evaluates the recovery potential of resources embedded in E-waste which is estimated to be 0.31 billion dollars for CRT electronic waste. The analysis identifies copper, silver, glass, plastics, and lead as the high potential materials that, if utilized, can reduce the burden on mining and importing them. The policy analysis of California's proposed Futures Project—an Extended Producer Responsibility (EPR) policy—recommends that CalRecycle make payments to recyclers based on their efficiency rates and not based on the weight of device. The comparative analysis of California's E-waste recycling program with the Switzerland WEEE recycling program identifies the potential for greater collaboration among manufacturers in California to manage E-waste effectively. Comparative case studies of organizations who have adopted a circular economy approach finds that the giant tech companies have initiated a circular electronics path, while small and medium-sized organizations still need to develop circular strategies.

Chapter 1: Introduction - E-waste a global environmental problem?

Waste from Electrical and Electronic Equipment (WEEE) or E-waste has become a major concern today because they are increasing at high growth rates from 3% to 5% annually (Cucchiella et al. 2015, 263-272). United States generates the second highest amount of WEEE after China with the generation rate of 6.9 MT/year and per capita generation around 19-20 kg/person/year (Shittu, Williams, and Shaw 2021, 549-563). This implies that with the increase in WEEE generation rate, toxic metals and other hazardous substances will be emitted more in the environment and at the same time, valuable resources will be consumed more which would increase the need to recycle and recover them (Zeng et al. 2016, 1347-1358). This issue was also highlighted in a report published by the California government to promote resource recovery and recycling techniques that protect public health and the environment (CalRecycle 2018).

In California, consumers buy more than 120 million electronic items annually with most of them upgrading their devices in only 18 months (CalRecycle 2018). This high consumption rate necessitates better options for future management of E-waste and continual improvement in E-waste recycling. California legislations has not given permission for recovery of materials that involves chemical processing in state hence it sends the waste to outer cities or countries in secondary markets. However, no other state has implemented a robust payment system like California. California has a framework for management of CEDs (covered electronic devices) wherein the financial responsibility is assigned to the state agencies whereas in (Extended Producer Responsibility) EPR framework, the responsibility lies with the producer/manufacturer. To overcome this challenge, California government established a mission to promote recycling and recovery of E-waste and fully implement an EPR approach in future. The report states that European Union has the WEEE Directive, which is the successful and proven scheme to collect and recycle E-waste and thereby California will ensure to implement it in the long run. Due to the established network, it may take some time to change the existing model of recycling CEDs but will address emerging technologies and propose enhancements to the actual program (CalRecycle 2018).

California does not have proper collection and recovery techniques as all electronic devices are not included in the collection mechanism (Kang and Schoenung 2006, 1672-1680).

All states, except California and Utah, in United States have implemented an EPR framework which is based on the circular economy principles and has become an urgent and important scheme for WEEE management (Forti, Vanessa et al. 2020, 120)

Circular Economy (CE) principles aim to eliminate waste and pollution, circulate resources, and regenerate nature, through improved design (Meloni, Souchet, and Sturges 2018, 17). In CE, the life-cycle of consumer electronic products is extended and kept in use for longer times, then efficiently remanufactured for repairing, refurbishing, reusing, recovering or recycling the valuable components from WEEE (Meloni, Souchet, and Sturges 2018, 17). An EPR Framework is also based on CE principles with a take-back coalition scheme i.e., taking back the waste products from consumer for recovery and recycling of materials, wherein the responsibility lies with the manufacturer/ producer to fund the collection and implement recycling of WEEE (Panchal, Singh, and Diwan 2021, 102264). EPR is one of the successful strategies to recover valuable metals from E-waste and to mitigate the future environmental and economic risks (Panchal, Singh, and Diwan 2021, 102264).

1.1 Environmental Pollution and Health Impacts

Bressanelli et al. (2020, 174-188) identifies the implementation of circular economy in WEEE industry as a big challenge today to gain socio-economic and environment benefits. The effects of material extraction and increased mining operations pose significant health and environmental impacts (Meloni, Souchet, and Sturges 2018, 17). Huge amounts of water and energy are used for mining and manufacturing of electronic devices and the demand of resources increases the chance of unsafe working conditions. Improper handling and recycling methods can also increase the public exposure to toxic chemicals and hazardous substances. However, at the same time, WEEE industry can utilize valuable materials as it has a substantial recovery economic potential with an estimation of ca. 55 Billion Euros (Bressanelli et al. 2020, 174-188). Unfortunately, only 20% of the total E-waste is collected and recycled. Handling the large amounts of E-waste becomes a daunting task for governments, industries, waste recyclers and retailers with the implementation of circular economy (Bressanelli et al. 2020, 174-188). This has been one of my findings where I have tried to find answers to understand challenges for stakeholders in adopting circular economy in E-waste management.

E-waste is composed of mix of materials like Cu, Ag, Au, Al, plastic, and heavy metals that can contaminate the environment when disposed. Depending on the age and the type of product, the material composition and its chemical nature varies, and this increases the danger of health risks and environment pollution if disposed without treatment. Recovery of precious metals from E-waste generally happens in developing countries due to the cheap labor available where they try to obtain incentives out of it. Due to the lack of standardized methods of recovery, the informal sector exposes itself to the large concentrations of flame retardants and heavy metals. According to the study done in Guiyu, a region in China which is the largest E-waste recycling site in the world, the results reported increased concentrations of polybrominated diphenyl ethers (PBDEs) up to 16,000 ng/g in the Nanyang River near Guiyu. This explained that the unprocessed E-waste contaminants affected the water quality and aquatic systems through leaching. The study also reported high concentrations of polychlorodibenzo-p-dioxins and polychlorinated biphenyls from air and soil samples respectively posing a serious health risk to the humans in Guiyu. The traces of dioxins were also found in hair, placenta and human milk signifying high risk to pregnant women and children (Robinson 2009, 183-191).

In such areas, communities burn the E-waste especially the cable wires to obtain copper without being aware about its consequences on the children. In many cases, it has produced the highest income for people thereby creating more secondary markets. However, there is a need to create appropriate channels for recovery of metals and with proper standardization. The major takeaway from these articles were that populations living in the areas with high rates of informal recycling were the most vulnerable to the health risks and environmental impacts (Torres, Guzmán, and Kuehr 2016).

1.2 E-waste and SDGs

Figure 1 SDGs that are related to E-waste. Source: (Forti et al. 2020, 120)

The 2030 Agenda for Sustainable Development was adopted in September 2015 by the United Nations and its member states. The agenda included 17 Sustainable Development Goals and 169 targets to end poverty, protect the planet and ensure prosperity in the world. E-waste management is also included in some SDGs and is highlighted in (Figure 1). It is related to SDG 3, to improve the public health and wellbeing, as E-waste contains many hazardous substances and toxic constituents. The global undocumented flow of E-waste contains 50 t of mercury and 71 kt of (brominated flame retardants) BFR plastics annually which can affect the public health when exposed. It is also related to SDG 6, clean water, and sanitation, as the E- waste if disposed improperly in the environment can merge with other water bodies and can impact the aquatic life which also relates to SDG 14, life below water. E-waste management is related to SDG 8, decent work and economic growth, as it promotes green jobs in refurbishment and recycling sectors and reduces economic losses by avoiding extraction of virgin raw materials (Forti et al. 2020, 120).

With the increased generation of E-waste, the general indicators are used to monitor the growth of E-waste through SDGs on domestic material consumption (SDGs 8.4.2 and 12.2.2) and material footprint (SDGs 8.4.1 and 12.1.1). The SDGs 11 and 12 and its targets have a direct relation with E-waste to improve collection and recycling rates, protect public health and environment, and reduce improper disposal of E-waste. The goals and targets are mentioned below (Forti et al. 2020, 120):

"Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable

Target 11.6 : By 2030, reduce the adverse per capita environmental impact of cities by paying special attention to air quality as well as municipal and other waste management.

Indicator 11.6.1 : Percentage of urban solid waste regularly collected and with adequate final discharge with regard to the total waste generated by the city.

Goal 12 : Ensure sustainable consumption and production patterns

Target 12.4 : By 2030, achieve the environmentally sound management of chemicals and all waste throughout the life cycle, in accordance with agreed-upon international frameworks, and significantly reduce their release into air, water, and soil in order to minimize their adverse impacts on human health and the environment.

Indicator 12.4.2 : Treatment of waste, generation of hazardous waste, and hazardous waste management, by type of treatment.

Target 12.5 : By 2030, substantially reduce waste generation through prevention, reduction, repair, recycling, and reuse.

Indicator 12.5.1 : National recycling rate and tons of material recycled." (Forti et al. 2020, 120)

1.3 Research Questions

Understanding the problems associated to the increased E-waste generation, I decided to do research in finding ways on how to manage this problem that can create a win-win situation for all stakeholders and protect the environment and public health. My research is focused on finding answers for the following question and sub questions.

1) How can California improve E waste recycling by adopting a circular economy approach through evaluation of economic potential and policy options ?
   a) Economic Analysis : How is the recovery and recycling of E-waste economically beneficial to the state of California?
   b) Policy Analysis and Comparative Analysis: What are the existing policies and regulations for E-waste recycling in California and how do they differ from Switzerland?
   c) Case Studies: How is California approaching the concept of circular economy for e-waste management?

This research reviews the economic potential of E-waste recycling and recovery in California through estimation of E-waste generation, collection, and recycled rate. I expect to find the content of recovery material present in an electronic item and its valuation to evaluate its economic potential. I anticipate that E-waste recycling could yield good profits and environment benefits if the valuable materials embedded in them are recovered at its best. E-waste recycling can help the industries to overcome supply chain risks, protect the health and safety of vulnerable workers in mining activities, reduce environmental impacts and contribute to sustainable resource management. Moreover, the research analyzes the current policies in California and identifies the status of policy actions implemented to increase recycling of E-waste. The policy analysis of California's E-waste recycling is followed by the comparison with Switzerland policies to identify differences in E-waste management programs. The research also examines the case studies on the best approaches of E-waste management in California based on circular economy principles. Finally, the identified gaps and observations help me provide management recommendations to improve recycling of E-waste in California.

1.4 Methodology

My research analysis starts with the overview of circular economy strategies applicable in the E-waste industry (Chapter 2). The chapter also reviews the recycling and recovery challenges in

California to understand the existing scenario and throws some highlight on integration of EPR framework in E-waste management followed by three main chapters (Chapter 3, 4 and 5).

Chapter 3 estimates E-waste generation, recycling, and economic potential of E-waste in California. This is done through Market Supply Method which includes gathering the data from CalRecycle department of electronic devices sold in California from 2010-2020. This has helped me in estimating the E-waste generation rate in California. Later, I gathered the collection rate and recycling rate of E-waste from CalRecycle and Department of Toxic Substances Control (DTSC) website. Then I found out the average lifespan of different electronic devices to quantify their recovery potential (Parajuly and Wenzel 2017, 272-285). After getting the recycling rate of electronic devices, the recovery economic potential was determined by studying the valuation of critical metals, rare earth metals, precious metals and other materials embedded in E-waste as per the current market conditions (Islam and Huda 2018, 48-75) (Zeng et al. 2016, 1347-1358) (Panchal, Singh, and Diwan 2021, 102264). To understand the valuation, the monetary value of metals is required hence I read few articles that mentions the prices and content of the secondary raw materials in each electronic item and estimates the increase in use of the raw materials by 2030 (Zeng et al. 2016, 1347-1358) (Parajuly and Wenzel 2017, 272-285). After determining the recovery economic potential of E-waste, I reviewed the costs associated to a Material Recovery Facility (MRF) in California that includes labor cost, transportation cost, processing cost, infrastructure cost, etc. and finally prepared the cost revenue model that includes the general inputs/parameters for the costs and revenue of MRF. (Kang and Schoenung 2006, 1672-1680).

Chapter 4 is a policy analysis of California's E-waste policies and regulations done through Systems Analysis framework to understand the current progress and status of policy actions (Siehr Stephanie 2020). This is followed by a Comparative Analysis to compare the policies and frameworks of E-waste recycling program in California with Switzerland. The reason to choose Switzerland is that it is the first country to implement formal WEEE EPR framework in European Union and that has the highest recycling rate (59%) in the world (Shittu, Williams, and Shaw 2021, 549-563). This helped me to identify the loopholes in California's regulatory context and analyze the pros and cons in both the regions. I have referred to government reports, documents, and websites (e.g., CalRecycle, DTSC) to study frameworks, legislations and rules for collection and recycling of E-waste in California (CalRecycle 2018). For Switzerland, there is sufficient data available that focuses on the Swiss Global E-waste Program, ORDEEE initiative and other methods to promote recycling of E-waste and EPR scheme (WIDMER, SCHLUEP, and DENZLER 2014).

Chapter 5 is the case studies wherein I referred to the work by Ellen McArthur Foundation to understand more about the business models and frameworks that is related to E-waste management. I have taken successful models of E-waste management based on the CE designs (Reuse, Recycle, Repair, Refurbish, Remanufacture or Recover) in California.

The mix of different methods of analysis helped me to examine multiple aspects of E-waste in California. I have also tried to include qualitative data collected through expert interviews. For interviews, I approached university alumni a) Henintsoa Rakotoarisaona, MSEM Alumni 2021 Batch and b) Martin Cooper, MSEM 2020 Batch during Research Methods class to gain knowledge on E-waste issues and industrial trends. I approached experts from CalRecycle E-waste recycling department and coordinated with Matt Sheehan, Senior Environmental Scientist at CalRecycle Electronic Waste Recycling Program, who have helped provide detailed insights on E-waste data and its recycling challenges in California.

Chapter 2 : Overview of Circular Economy

2.1 Definition

As the Ellen McArthur Foundation states, a circular economy is a system where the economic growth is dissociated from the consumption of finite resources by utilizing the materials and components at their highest value and designing the waste out of the system. Different strategies can be applied to shift from cradle-to-grave approach to a cradle-to-cradle approach as shown in the circular economy diagram in (Figure 2) (Meloni, Souchet, and Sturges 2018, 17).

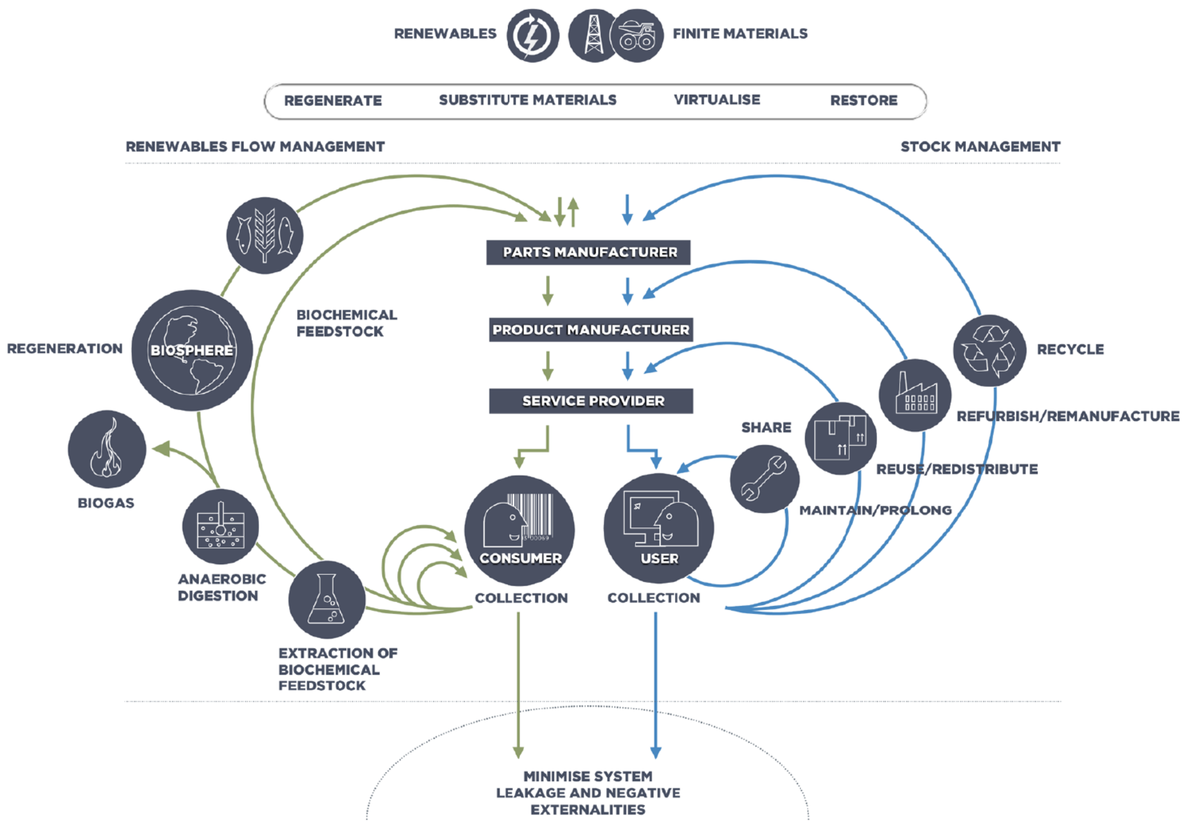

Figure 2 Circular Economy Diagram. Source (Meloni, Souchet, and Sturges 2018, 17)

2.2 Circular Economy Strategies

The inner and outer loops of the diagram state the following strategies for achieving circularity in E-waste management (Meloni, Souchet, and Sturges 2018, 17) :

a) Design : The design of products shall be made in a way to increase the ease of repairing and refurbishing devices. Changes in design can help recyclers or users to disassemble devices to a certain extent thereby extending the longevity of products. Some companies have already taken initiatives like Fairphone designs phones that can be easily disassembled and repaired. They provide instruction manuals of spare parts so that users can easily repair them. Apple too has allotted technicians for repairing and refurbishing the iPhone devices in their centers (Meloni, Souchet, and Sturges 2018, 17).

b) User willingness : According to the survey, major barrier for promoting circular electronic products is that users do not have knowledge about the availability of refurbished devices which reduces their market at the first place (Milovantseva and Saphores 2013, 8-16). While some users sense risk and have false impressions for refurbished devices. If these fallacies are cleared, more than 50% of the users would willingly buy refurbished or used devices. Also, increasing the transparency and certified guarantees would help overcome these challenges as users will be assured about the quality of device (Meloni, Souchet, and Sturges 2018, 17).

c) Refurbishment : Refurbishing means reusing the functional parts from the discarded products, to restore the damaged products or create new products that has the same function (Suppipat and Hu 2022). Nowadays companies have started investing in refurbishment technologies to reuse few parts and increase their longevity by selling it in attractive designs. Example, Cisco- certified refurbishment systems, refurbished smartphones sold by Telga communications company (Suppipat and Hu 2022).

d) Dematerialization : It is defined as minimal usage of resources to operate the same task but with changes in model. Dematerialization may include operating digitally or using fewer physical materials for production (Suppipat and Hu 2022). As per the research, consumers generally give more preference to the data stored in the devices than the devices itself (Meloni, Souchet, and Sturges 2018, 17). The best example for this is the cloud computing where it does not matter whether it's a smartphone, tablet or a laptop, the storage space in the cloud and the services provided helps in better utilization of resources (Meloni, Souchet, and Sturges 2018, 17). Another successful example is Amazon Kindle application that dematerialized the use of physical books to reduce the consumption of paper.

e) Reuse and Repair : Reusing the products or its parts for the same or other function helps in extending their lifespan. When the user discards the electronic device or it is broken down, its parts like modems, screens, batteries, body can be repaired and reused again to retain its value (Meloni, Souchet, and Sturges 2018, 17). In such a way, its application can be transferred from high performance products to low performance products thereby minimizing the need for virgin raw materials. However, the barriers to reuse such products are rapid innovation in technologies and lack of specific standards (Suppipat and Hu 2022). These can be overcome by gaining knowledge on the limitations of reuse in different applications and accordingly take decisions.

f) Recovery and recycling : To bring the circularity in electronics waste industry, recycling the discarded products and recovering materials from them are the key strategies. The secondary raw materials derived from the recycling and recovery of electronic devices can help reduce the dependence on primary resources. Compared to the production of aluminum and copper from the mines, recycling would save the energy up to 95% and 85% respectively (Işıldar et al. 2018, 296-312). Due to the precious and valuable metals embedded in them, E-waste has a high economic potential which can be utilized through recovery technologies like pyrometallurgy, hydrometallurgy, biometallurgy and other electrochemical processes. If the electronic devices are designed with improved recycling content and good quality of materials, the recovery and recycling of E-waste would yield high profits (Meloni, Souchet, and Sturges 2018, 17).

g) Reverse logistics : The term itself implies that it is opposite to the traditional forward logistics system where the products after use are returned to the retailer or recycler to enable circular economy principles and the responsibility lies with the producer. There are successful models and frameworks applied by governments and companies like product take-back programs or EPR Framework that has proved as a successful framework in European Union WEEE Directive for E-waste management. Example, 17000 tonnes of ink and toner cartridges were collected by Hewlett Packard (HP) through take-back program in 2016 (Meloni, Souchet, and Sturges 2018, 17). The main issues highlighted in this strategy are providing incentives to the consumers who return the electronic devices, the management of the whole process and the legislative barriers (Meloni, Souchet, and Sturges 2018, 17).

h) Green Labelling : This is a strategy to share the information as much as it is possible to increase recycling and recovery rates. Labelling the products that displays its material details, recovery potential and other specifications can help the recyclers to retain its highest value in addition to time and energy savings . It can be also termed as material passports, which can be scanned given the authorization to reduce the risk of data flow (Meloni, Souchet, and Sturges 2018, 17).

i) Business models : The circular business models aim to close the resources loop by maintaining the product integrity, modifying the designs, making new relationships with users, creating new experiences with products and offering shared services. These models promote waste minimization and sustainable resource consumption (Suppipat and Hu 2022). Circular business models are quite adapting in nature as the ownership lies with the manufacturer who can customize the services based on the customer's changing needs such as AirBnB, where owner of the house can provide rental rooms based on the customer requirements thereby reducing the resources to build hotels.

These strategies fit in different life cycle phases of an electronic product. The product lifecycle can be divided into 3 phases – a) Initial life b) Middle life and c) End of life (Figure 3). Initial life is when the raw materials are excavated and used for manufacturing of electronic products into different designs. The middle life is when the product is bought by the consumer, and it is in use till the end-of-life phase. This phase also includes extending the lifespan of product through maintenance and repairs. The end-of-life phase is when product is collected for reuse, recycle, recover, remanufacture, refurbish or disposal (Esmaeilian et al. 2018, 177-195).

The scope of my research is mainly focused on the end-of-life phase because few materials embedded in electronic products are categorized as hazardous waste thereby, it becomes necessary to collect them and properly handle them to reduce environmental issues (Nowakowski and Mrówczyńska 2018, 93-107).

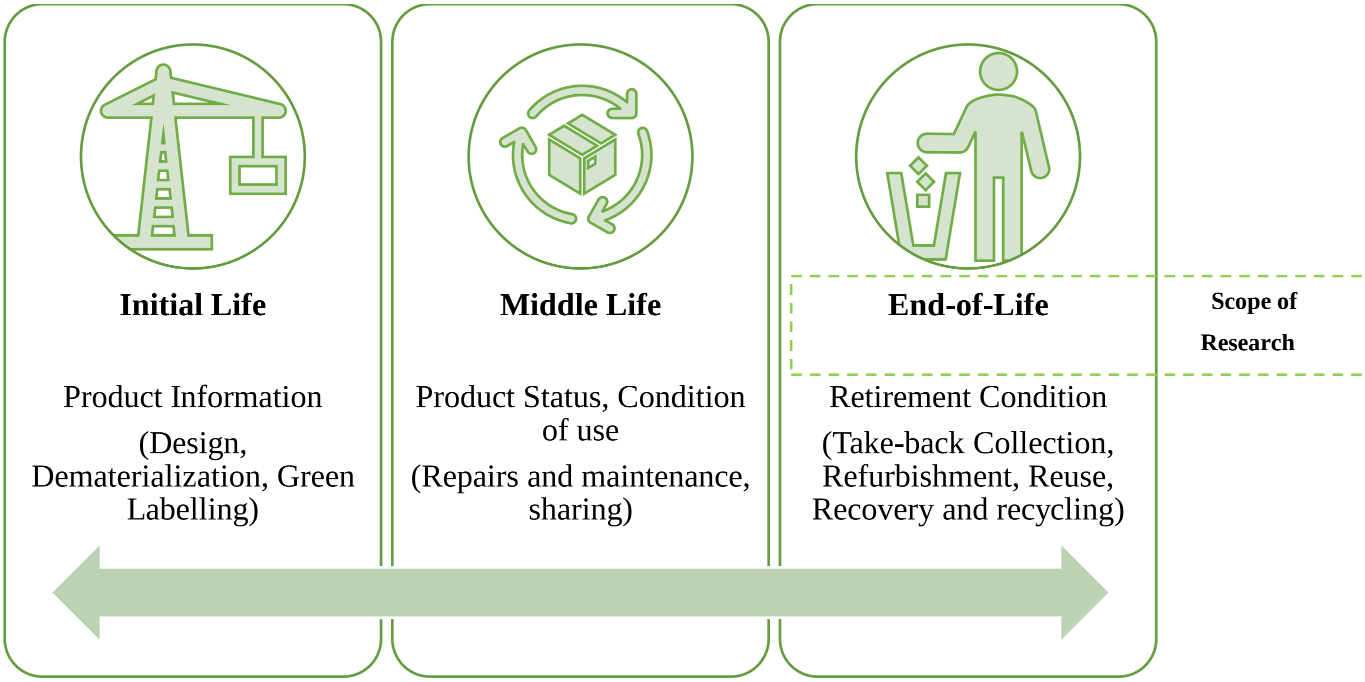

Figure 3 Three phases of product lifecycle with their respective circular strategies. Adapted and modified from (Esmaeilian et al. 2018, 177-195)

Bressanelli et al. (2020, 174-188) explains the current trends of how CE can be implemented in WEEE industry where the maximum focus has been given for exploring ways to increase economic advantages for supply chain through Recycle and Recover techniques. The literature is based on CE ‘4R’ scheme (Reduce, Reuse, Recycle and Remanufacture). The ‘Reduce’ strategies implies to reduce consumption of resources when using electronic products (e.g., energy-efficient refrigerators) or using Servitized models like sharing the devices. The ‘Reuse’ strategies focus on extending the life cycle of electronic products through repairing, maintaining, and changing product designs such as reusing mobile phones after repairing instead of disposing them. The ‘Recycle’ strategies include reprocessing of materials to produce new products and reduce dependence on virgin resources such as recycling shampoo bottles to make colorful beads. The ‘Remanufacture’ strategy follows a series of 5 steps: disassembly, cleaning, inspection, and sorting, reconditioning and reassembly. Remanufacturing products help to tap new markets and increase recovery and recycling potential. These findings can help me provide recommendations on specific strategies or combination of strategies for improving E-waste management in California.

2.3 Integration of EPR Framework

EPR gained its importance in Europe after it was introduced by Germany, Sweden, and France in the 1990s to control increased amounts of waste and soon was implemented in various EU Member States (Ahlers et al. 2021, 127-129). In 2003, European Union implemented the WEEE Directive and defined EPR Framework as giving the producers physical and financial responsibility to handle the take-back collection, recycling and recovering WEEE. This encouraged the producers to design circular products to achieve high recycling rates and economic benefits (Mayers, France, and Cowell 2005, 169-189). European Commission confirmed the adoption of EPR as an international policy as the framework promotes recycling, reuse, and recovery of waste. Also, it has served as an important tool in transitioning towards circular economy (Ahlers et al. 2021, 127-129). The four principal goals of EPR, according to the OECD, are (Khetriwal, Kraeuchi, and Widmer 2009, 153-165):

1. Source reduction (natural resource conservation/materials conservation).
2. Waste prevention.
3. Design of more environmentally compatible products.
4. Closure of material loops to promote sustainable development.

Generally, EPR implementation varies in different EU Member States and countries because of the geographical area, legislative complexity, number of Producer Responsibility Organizations (PROs) existing in the market and their nature (private or non-profit organizations) and type of ownership. Due to this, the performance of EPR schemes varies vastly in different areas and to control this diversity, European Commission revised the Waste Framework Directive in 2018 categorizing different waste streams and their specific targets (Ahlers et al. 2021, 127-129).

Type of EPR approach	Types of tools	Examples of EPR applied
Product take back programs	Mandatory take back	Packaging (Germany)
	Voluntary or negotiated take back programs	Packaging (Netherlands, Norway)
Regulatory approaches	Minimum product standards	EEE, Batteries
	Prohibitions of certain hazardous materials or products.	Cadmium in Batteries (Sweden)
	Disposal bans	EEE in landfills (Switzerland)
	Mandated recycling	Packaging (Germany, Sweden, Austria)
Voluntary industry practices	Voluntary codes of practice	Transport packaging (Denmark)
	Public/private paservicizingrtnerships	
	Leasing, "servicizing", labelling	Photocopiers, vehicles
Economic instruments	Deposit-refund schemes	Beverage packaging (Korea, Canada)
	Advance recycling fees	EEE (Switzerland, Sweden)
	Fees on disposal	EEE (Japan)
	Material taxes/Subsidies	

Figure 4 Different EPR approaches applied in different countries. Source : (Khetriwal, Kraeuchi, and Widmer 2009, 153-165)

Torres et al. (2016) mentions in its analysis that success of implementing EPR schemes in cities or countries depends mainly on the socio-economic conditions and transportation modes. The results explain that with the increase of PROs, productivity and innovation increases with an intention to gain the economic benefits and brand value. It also helps in decreasing the waste management costs because the increase in competition amongst PROs can influence the market prices. It also explains that the presence of a coordinating body is a key solution to many challenges which manages the whole waste management system and monitors the illegal exports and informal disposal of WEEE.

Role of Stakeholders:

1) Producer or manufacturer : It means any legal person irrespective of their selling methods who puts on market, sells, or manufactures with his own brand, the electrical and electronic equipment (EEE) (WEEE 2012, 38). The role of producer is to design the products that help in waste minimization, collect by establishing systems that are easily accessible by citizens or outsource it, spreading the awareness about its treatment techniques, treating responsibly at their end-of-life phase and mitigate environment pollution (Torres, Guzmán, and Kuehr 2016).

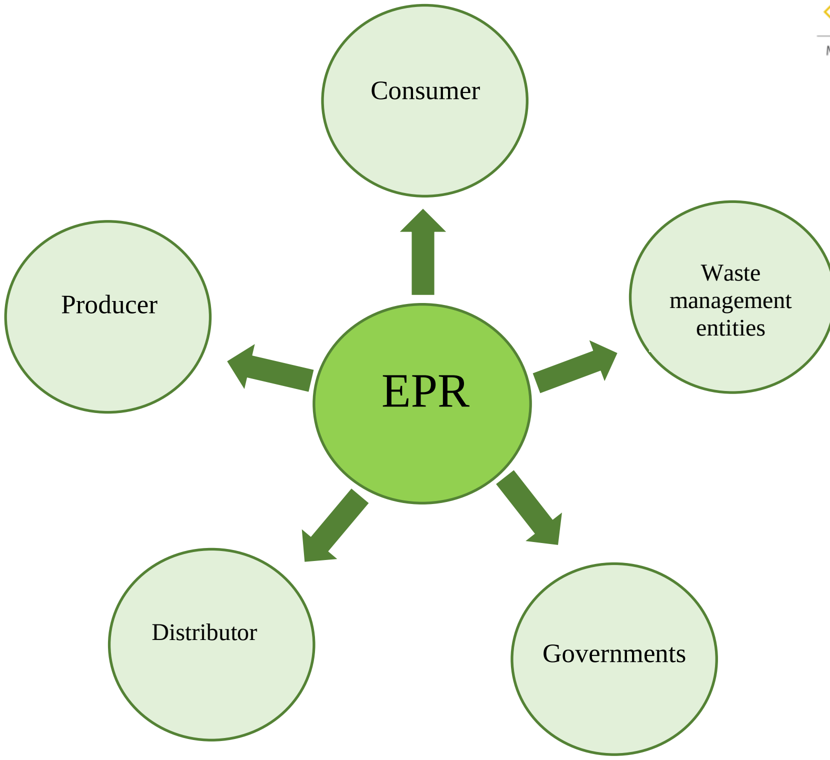

Figure 5 Stakeholders involved in EPR Framework. Adapted and modified from (Torres, Guzmán, and Kuehr 2016)

2) Consumer or users : Consumers are the ones that purchase the EEE and use it for fulfilling their purpose. The role of consumers is to try different techniques for extending the life cycle of products and keep it in use for as long as they can before final disposal. They can learn more about the upcoming technologies and repair/refurbishment centers to take proactive actions towards circular economy (Torres, Guzmán, and Kuehr 2016).
3) Waste management entities : These entities play the crucial role in the framework. They play the role of collection, sorting, disassembly, processing and treating the WEEE. It is important for waste management entities to do the risk assessment of different operations that involve physical and chemical hazards while recycling and recovering the waste. Hence, implementation of proper disposal techniques and standardization is necessary in the waste facilities to protect the health of workers. Also, inspections and site audits are organized to identify risks and verify compliance to standard operating procedures (Torres, Guzmán, and Kuehr 2016).
4) National and municipal Governments : The administration department plays an important role in regulating the EPR Framework. The government shall enforce the policies and laws to authorize PROs in the area and propose specific targets. They should consider

spreading awareness to the citizens through campaigns and education to discard E-waste separately and drop at collection points. They should also enforce punishments if not complied with the laws and oversee the illegal import and export of WEEE parts. The government is a coordinating body that binds all the stakeholders involved in the framework and manages the financial and administrative system of the state or country (Torres, Guzmán, and Kuehr 2016).

5) Distributor : It means any legal person or entity who manages the distribution of EEE and makes it available in the market (WEEE 2012, 38). The role of distributor in the market is to find criteria to select authorized importers and exporters of EEE and strategize the location of collection points for receiving bulk volumes of WEEE (Torres, Guzmán, and Kuehr 2016).

Chapter 3: California E-waste Recycling- Estimated Economic Potential

Few studies were referred to answer my question "How much content of valuable metals does E-waste or WEEE have such that they can be sustainably recovered from urban mining ?" To answer this, Zeng et al. (2016, 1347-1358) studied the recycling potential of 'New WEEE' in China, being the largest producer of E-waste with an annual increase rate of 25.7%. The article explains about the new categories of WEEE that were added in China's WEEE regulations leading to an increased control strategy for e-waste management. The results in the article stated that after reaching the end-of-life phase, electronic devices have huge quantities of valuable resources embedded in them. It also indicated that the quantities of valuable materials in WEEE is continuously increasing since 2010 and is further expected to grow. From Figure 6 A), it can be inferred that the average of WEEE recycling potential increased from US$ 16 billion in 2010 to US$ 42 Billion in 2020 to an estimated US$ 73.4 Billion by 2030. Figure 6 B) determines the increase in embedded amounts of Copper (Cu), Aluminum (Al), Iron (Fe), Plastics, Gold (Au), Silver (Ag), Palladium (Pd), Indium (In), Cobalt (Co) and total rare earths (including Nd, Y, and Eu) in WEEE from 2010 to 2030. It also indicates that precious metals (Au, Ag, Pd, In, Co) and Copper (Cu) have the major recovery economic potential of all the materials. This finding helped me to understand composition of valuable metals in E-waste and the increasing economic shares of specific metals.

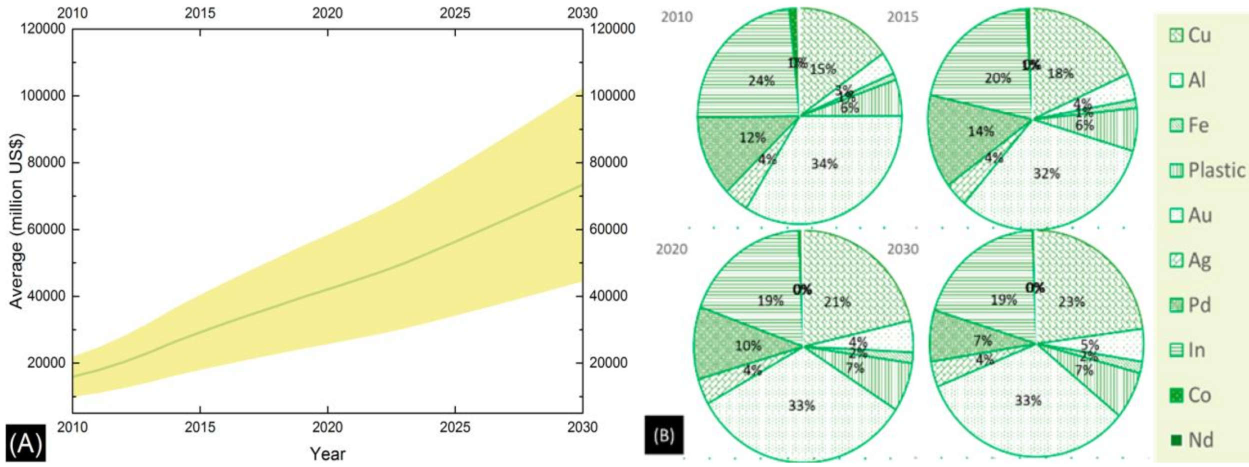

Figure 6 Economic potential of WEEE recycling: A) Change in economic value of total WEEE from 2010 to 2030 B) Variation of economic shares of materials embedded in WEEE from 2010 to 2030. Source: (Zeng et al. 2016, 1347-1358)

From the above figure, it can be said that the E-waste or WEEE has a high economic potential hence this finding made me curious to find out the recovery economic potential of electronic waste for the state of California. The analysis is divided into 3 steps : a) Estimating the E-waste generation in California b) Quantification of secondary materials embedded in E-waste and c) Evaluating the recovery economic potential of E-waste. These steps are followed by cost revenue model of MRF in California to estimate the associated costs and revenues.

3.1 Estimation of E-waste generation in California

The methodological framework is followed based on the study done for finding economic potential for E-waste in India (Panchal, Singh, and Diwan 2021, 102264). The methodology starts with getting the data on how much E-waste has been generated in California from the years 2015-2021. The framework is modified based on the availability of data as mentioned below in (Figure 7).

Note: In the analysis, the terms E-waste and CEW are equivalent because California's E-waste recycling program only covers covered electronic devices hence the waste is called as Covered Electronic Waste. To avoid confusion, I have used E-waste instead of CEW however, at some places where the acronyms could not be replaced, I have used CEW. Likewise, CEDs are also equivalent to electronic devices or equipment.

A covered electronic device (CED) is defined as a video display device having a screen of diagonal length greater than four inches and is found to exhibit the hazardous waste characteristic of toxicity when discarded (DTSC 2022). A CED can be of two types : a) Cathode Ray Tube (CRT) device and b) non-CRT device depending on the presence of cathode ray tubes. The older TVs and monitors used to have CRT glass installed in it which make them more hazardous due to lead and heavier by weight due to glass (Kang and Schoenung 2006, 1672-1680).

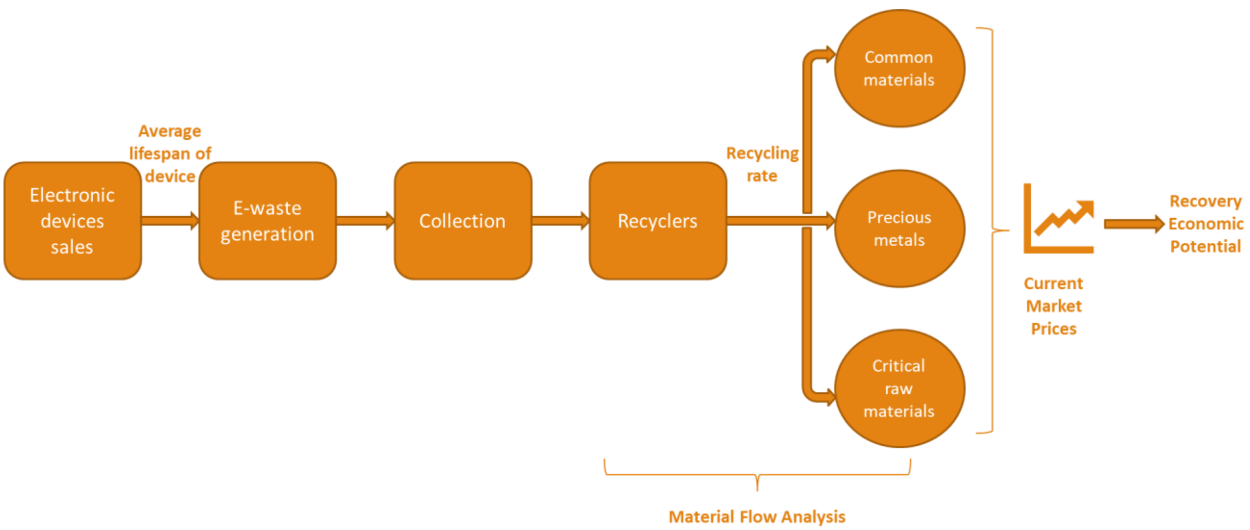

Figure 7 Methodological framework for evaluating recovery economic potential of E-waste. Adapted and modified from (Panchal, Singh, and Diwan 2021, 102264)

The CEDs sales in the market for each category is collected from CalRecycle department for the years 2010-2020 (Table 1). The sales represented the units of CEDs sold directly to consumers in the given year and within the geographical boundary of California. Since the sales data is gathered directly from manufacturers, it is assumed that the imports and exports of CEDs are not included in the analysis. The CEDs sold include both CRT devices (TV and monitors) and non-CRT devices (laptops, monitors, TVs, and DVD). The data is not complete for the E-waste collected and recycled in 2021, because the cycle starts from the month of June/July so the fourth quarter data still needs to be updated by CalRecycle department.

Table 1 Sales of Covered Electronic Devices in California 2010-2020. Source: Compiled by Author, data from CalRecycle E-waste department

Sales Year	Laptop/Tablet	Monitors	TV	DVD	Totals
2010	4007848	2991632	2998978	135462	10133920
2011	5244959	3860308	2012785	228530	11346582
2012	8778596	5087997	8544668	3843	22415104
2013	5583725	5303744	9863264	89961	20840694
2014	7961724	2127161	2493497	63317	12645699
2015	11726855	4666526	15827868	626600	32847849
2016	8854788	2690898	14572128	14106	26131920
2017	11425358	4453287	16219127	419425	32517197
2018	11843677	4706027	17242428	562734	34354866
2019	8118100	3442598	11584904	674669	23820271
2020	14088557	6322447	17474627	1031605	38917236

There are different equations been studied to estimate E-waste generation which are mentioned in the Global E-waste Monitor Report published by United Nations University (Forti et al. 2020, 120). Based on the data availability and ease of convenience, I have applied the Market Supply model, which is the simplest version of the models for estimating E-waste generation (Wang et al. 2013, 2397-2407). According to the model, E-waste generated in the year n is considered as a pure delay from the sales of devices in one historical year. This means that when an electronic device is put on market by the manufacturer it is sold to the consumer at that time and becomes eligible for waste in one year (Wang et al. 2013, 2397-2407).

$W(n) = POM\ (n - L^{avg})$; where, ………………………………………………………… (1)

W(n) = E-waste generation in the year n

POM = Devices sold/put on market in the historical year

L^{avg} = Average lifespan of device

The data on average lifespan of electronic devices except DVD players is taken from the website of Global Electronics Cycle that manages the EPEAT ecolabel and calculates the environment benefits for purchasing electronic devices (Global Electronic Council 2021). The average lifespan of DVD players is taken from (Tansel 2017, 35-45). The assumption made here is that the product lifespan will remain constant for six years.

Table 2 Average weight and lifespan of covered electronic devices

HS Code[g]	**Categories of device**	**Average weight (kg/unit)[c,d,e,f]**	**Average life (year)[a,b]**
0303	Laptop/ tablet	1.26	4
0308	CRT Monitors	15.01	6
0407	CRT TV	40	6
0404	DVD	2.98	6
0309	Non-CRT Monitors	5.07	6
0408	Non-CRT TVs	1.62	6

Notes: (a) (Global Electronic Council 2021) , (b): (Tansel 2017, 35-45) , (c): (Cucchiella et al. 2015, 263-272) , (d): (Parajuly and Wenzel 2017, 272-285) , (e): (Panchal, Singh, and Diwan 2021, 102264) , (f): (Hazardous Material Laboratory 2004) , (g): (Forti, V., Balde, and Kuehr 2018)

The average weight of devices is calculated based on the material composition of common base materials, precious metals, and critical rare earths. Each device's material composition is different and hence their average weights would differ accordingly. With the technological advancement, the devices are becoming more lightweight and hence their average weight is decreasing. It is also observed in (Table 2) that the average weight is different for CRT and non-CRT devices, CRT devices being heavier than non-CRT devices. CalRecycle has observed in their data patterns, that the weight of non-CRT waste exceeded 2% in 2013 for the first time and has reached up to 51% in the year 2021 based on the January to September 2021 data (CalRecycle 2022, 9). It can be also seen from (Figure 8) that the use of CRT devices keeps declining year by year whereas the use of non-CRT devices like light emitting diode (LED), organic light emitting diode (OLED) and liquid crystal display (LCD) technologies are increasing annually.

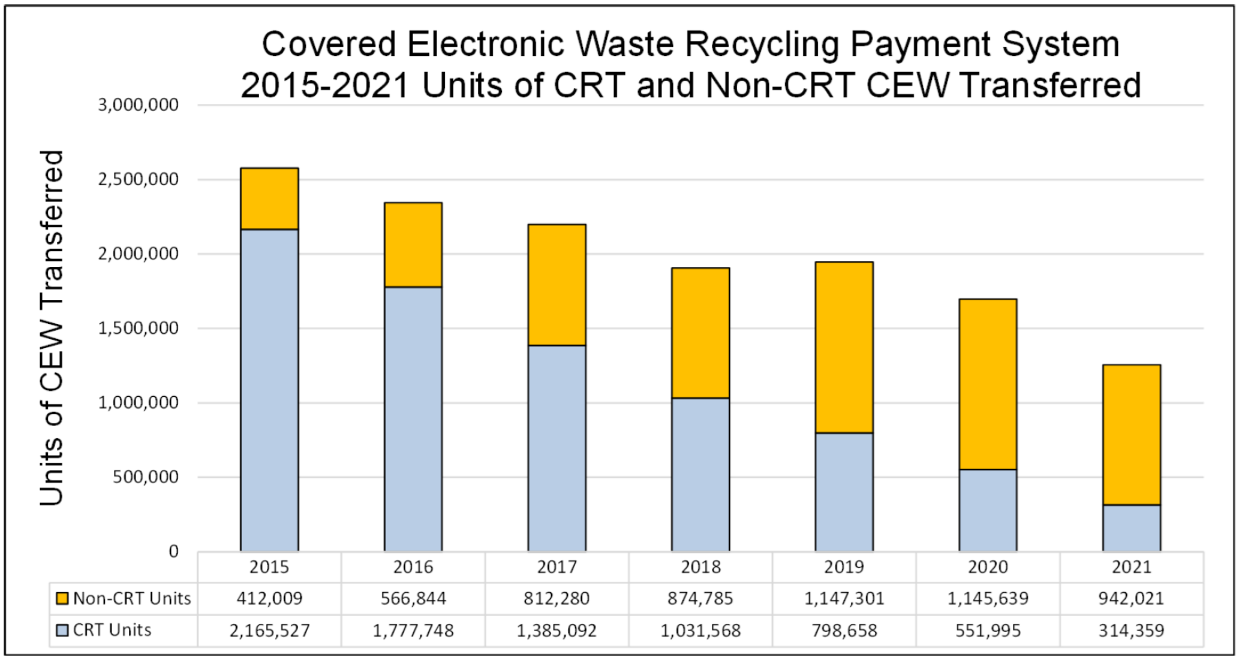

Figure 8 Number of CRT and non-CRT CEW recycled from 2015-2021 Source: (CalRecycle 2022, 9)

The figure (Figure 9) shows the graphical representation of CEW claimed for payment from 2010-2021 in California. It can be interpreted from the graph that in 2010, E-waste was mainly comprised of CRT devices however, year by year its ratio kept decreasing whereas the non-CRT devices started entering the waste stream from 2013 and reached the same amount as CRT devices in 2021. The graph also explains that CRT devices though consisted of only TVs and monitors were quite heavy as compared to non-CRT devices that consisted of laptops, TVs, monitors and DVD players.

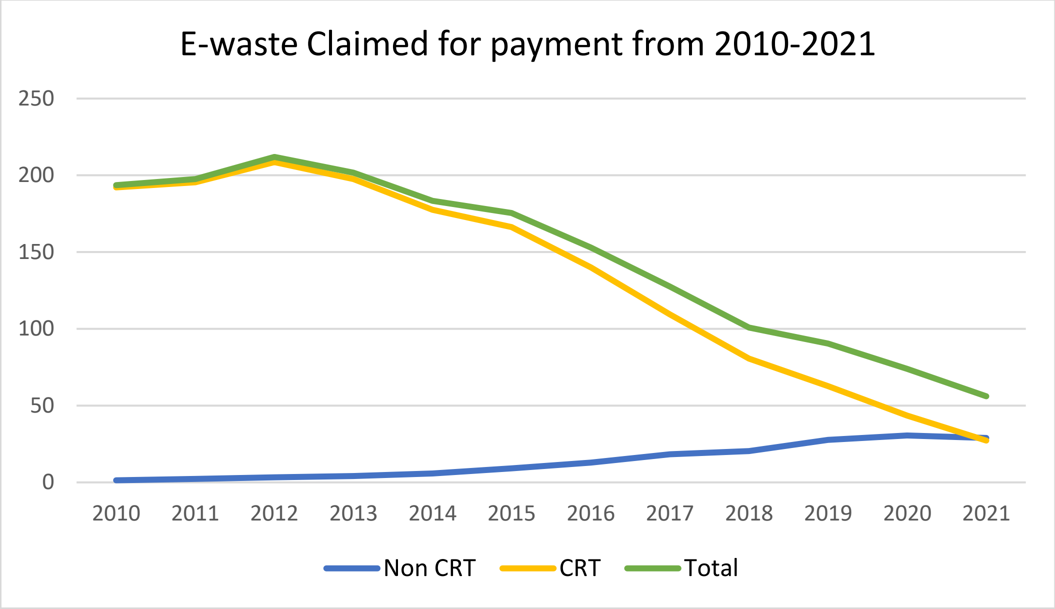

Figure 9 Weight of CRT , non-CRT and total E-waste collected and recycled from 2010-2021 in California. Source: Author and data taken from (CalRecycle 2022, 9)

Note: CalRecycle does not have data on how many CRT units and non-CRT units are sold every year. The units sold are based on the electronic device category. However, for E-waste collected and recycled, data is provided on how many CRT and non-CRT units are transferred but they do not have data on how many individual categories of CRT and non-CRT units are transferred. The definition of transferred is number of CRT or non-CRT units collected, sent to a recycler, and dismantled. The problem can be simplified as shown in (Figure 10).

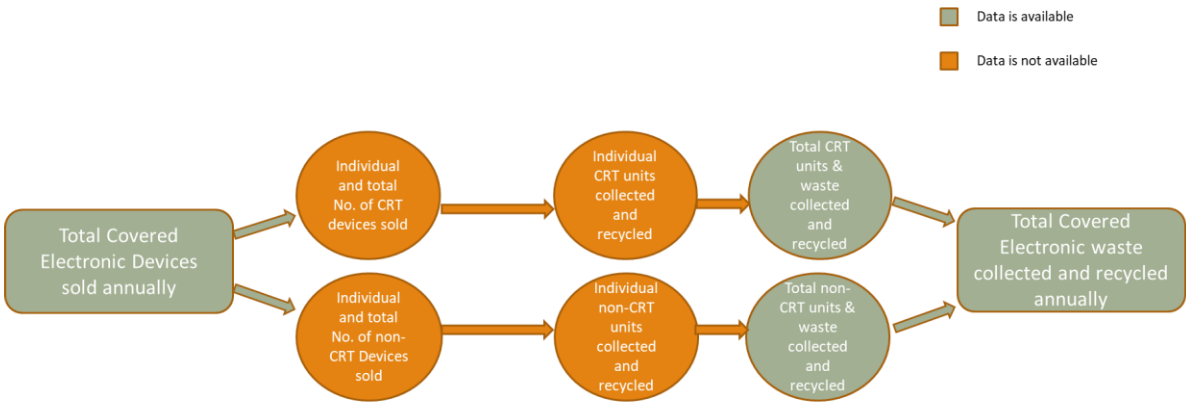

Figure 10 Diagrammatic version for availability and non-availability of data. Source: Author

Hence to overcome this issue, I applied the same ratio of CRT and non-CRT units collected and recycled to the CRT and non-CRT devices sold as shown below in (Figure 11). CalRecycle started collecting data on the ratio of units from the year 2015 when the E-waste was bifurcated into CRT and non-CRT waste to charge separate fees. During the analysis, the ratio for CRT and non-CRT units sold is applied in case of TVs and monitors only, because Laptops and DVD players are always categorized as non-CRT devices hence their characteristics would remain same throughout.

Year to Year CRT vs Non-CRT Unit Comparison (based on claim reporting month)*

2015 units transferred: 2.6M total, 2.2M CRT (84%), 0.4M Non-CRT (16%)
2016 units transferred: 2.3M total, 1.7M CRT (76%), 0.6M Non-CRT (24%)
2017 units transferred: 2.1M total, 1.3M CRT (63%), 0.8M Non-CRT (37%)
2018 units transferred: 1.9M total, 1.0M CRT (54%), 0.9M Non-CRT (46%)
2019 units transferred: 1.9M total, 0.8M CRT (41%), 1.1M Non-CRT (59%)
2020 units transferred: 1.7M total, 0.6M CRT (33%), 1.1M Non-CRT (67%)
2021 units transferred: 1.3M total, 0.3M CRT (25%), 0.9M Non-CRT (75%)

*Unit type (CRT or non-CRT) data only available/complete for 2015 reporting months and after.

Figure 11 Percentage of CRT and Non-CRT collected and recycled from 2015-2021. Source: (CalRecycle 2022, 9)

Putting all data in the equation (1), the estimation of E-waste generation is calculated for the years 2016-2021. The calculations can be explained with an example of CRT TV and non-CRT TV. For CRT TV, the E-waste generation in the year 2016 can be calculated as :

W(n) in M Pounds = POM(2016-6) x Average weight of unit x Ratio for TV and monitors

W(2016) M Pounds = 2998978 (units) * 40 (kg/unit) * 0.76 * 2.205(pound/kg) / 10^6 = **201.03**

For Non-CRT TV, the E-waste generation in the year 2016 can be calculated as :

W(2016) M Pounds = 2998978 (units) * 1.62 (kg/unit) * 0.24 * 2.205(pound/kg) / 10^6 = **2.57**

Table 3 Estimation of total E-waste generation in California from 2016-2021. Source: Author

Category	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Laptop/Tablet	24.39	15.51	22.12	32.58	24.60	31.74
CRT Monitors	75.25	80.49	90.93	71.97	23.23	38.61
CRT TV	201.03	111.84	406.97	356.68	72.58	349.00
DVD	0.89	1.50	0.03	0.59	0.42	4.12
Non-CRT Monitors	8.03	15.97	26.17	34.98	15.93	39.13
Non-CRT TV	2.57	0.00	14.04	20.79	5.97	42.40
Total (MPounds)	312.16	225.32	560.25	517.59	142.73	505.01

The (Table 3) shows the estimation of total E-waste generation of covered electronic devices in California from 2016-2021. It shows that maximum categories of E-waste had a sudden decrease in their figures during the years 2017 and 2020 which seems different from their usual growth line. The figures show an alternative increase and decrease of E-waste generation which is explained in the further sections.

3.2 Quantification of secondary raw materials (SRM) embedded in E-waste

Material flow analysis is used to quantify the average weights of secondary raw materials embedded in each E-waste category, as shown in (Appendix 1). The secondary raw materials are divided into 3 categories: common base materials, precious metals, and critical rare earths (Cucchiella et al. 2015, 263-272).

Since the data are not available on non-CRT devices collected and recycled, the analysis is limited to only CRT devices, which include CRT TVs and CRT Monitors. The recovery economic potential of CRT devices is evaluated for the year 2021 only, because it required heavy calculations to estimate for previous years and limited time was available for research. Using the weights of materials in CRT TVs and CRT Monitors from Appendix 1, the quantification of SRM embedded in both devices is done using the following equation:

$SRM_j = \sum_i N_i W_{ij}$; ……………………………………………………………….(2)

Where, SRM_j = Quantity of SRM, j available for recycling in the year 2021 (g)

N_i = Number of units of CRT device, i collected in the year 2021

W_{ij} = Average weight of SRM, j in given CRT device, i (g/unit)

As mentioned before, CalRecycle does not have data on how many individual CRT and non-CRT devices are collected and recycled each year, but the total amount of electronic devices collected and recycled is known. This is the reason for excluding non-CRT devices from the scope of analysis, because it is possible only for CRT devices to find out individual device units collected and recycled in 2021 through elimination and substitution method. I applied the back-casting approach for calculating the CRT device individual units. The available data helped me derive two equations (3) and (4), and there are two variables – TV and monitors in CRT devices which made it possible to solve them. However, in case of non-CRT devices, there are four variables – laptops, TVs, Monitors and DVDs, which require four equations. Hence, due to the ack of data it was removed from the scope of analysis.

$X + Y = 314359$…………………………………………………………….(3)

$40X + 15Y = \frac{27223000}{2.205} = 12346032$…………………………………………………….(4)

Where, X = No. of CRT TVs transferred= 305226 units

And Y = No. of CRT Monitors transferred = 9133 units

Using the weights from (Appendix 1) and multiplying with the results obtained from equations (3) and (4), the quantity of SRM that is available for recovery and recycling in the year 2021 was calculated (Appendix 2). The SRM available for recovery and recycling can be exploited at its maximum level with high efficiencies.

3.3 Recovery economic potential of SRM in CRT electronic waste

The recovery economic potential (REP) means how much worth the secondary resources are if they are recycled and recovered from the e-waste. The potential varies in different regions and countries because it depends on many external factors that play an important role in understanding the feasibility of material recovery. The factors include changes in policy and regulations, technologies to recover and recycle materials, continuous supply of discarded electronics by consumers for recycling and markets for recovered materials (Kang and Schoenung 2006, 1672-1680).

The quantity of SRM obtained from equation (2) is multiplied with the recycling rate of metals and the average market prices of metal for the year 2021. The recycling rate is explained as the quantity of material that can be utilized after recycling the device. It is assumed that the recycling rate will remain constant for six years that are considered in analysis. Since the market prices are taken based on 99.99% purity of materials it is assumed that with different levels of purity, market price of materials shall remain constant. The equation to evaluate REP is as follows:

$$REP_j = SRM_j R_j P_j \qquad (5)$$

Where, REP_j = Recovery economic potential of material, j (USD)

SRM_j = Total quantity of SRM, j available for recycling in the year 2021 of all CRT devices (pound)

R_j = Recycling rate of material, j (%)

P_j = Average market price of material, j for the year 2021 (USD/ pound)

The estimated recovery economic potential of secondary resources in CRT electronic waste is 0.31 billion dollars for the year 2021 (Appendix 2). The top five high potential recovery materials are copper, glass, lead, plastics and silver (Table 4).

Table 4 High recovery potential materials in CRT electronic waste

Type of material	Material wt. in CRT TVs (tons)	Material wt. in CRT Monitors (tons)	Total material wt.in CRT E-waste (tons)	Avg. market price of material ($/ ton)	Recycling rate of material (%)	Recovery economic potential of material (USD)
Copper	220	10	230	8480	0.5	974416
Glass	5291	69	5360	200	0.95	1018431
Lead	443	5	448	2420	0.68	736429
Plastics	2939	25	2964	2600	0.25	1926862
Silver	701	0	701	742040	0.58	301722439

The data in (Table 5) shows the estimation of E-waste generated per capita derived from the above analysis and calculations. The population dynamics were sourced from U.S. Census Bureau for the years 2016-2021. The E-waste collected and recycled is the data sourced from CalRecycle report (CalRecycle 2022, 9). The recycling rate is the measure of quantity of E-waste collected and recycled out of the generated amounts.

Table 5 E-waste statistics estimation based on data analysis. Source: Author

Year	**Ewaste generated (M pounds)**	**E-waste collected and recycled (M Pounds)**	**Collection and recycling rate**	**E-waste generated (kg/per capita)**
2016	312.16	153	49%	3.61

2017	225.32	127.58	57%	2.60
2018	560.25	100.94	18%	6.44
2019	517.59	90.31	17%	5.94
2020	142.73	73.94	52%	1.64
2021	505.01	56.08	11%	5.84

It can be observed from the (Table 5) that E-waste generated per capita has increased since the year 2016 with an average generation rate of 4.34 kg / per capita. The years 2017 and 2020 had the lowest generation rate of 2.69 kg/capita and 1.64 kg/ per capita respectively. The reason for 2017 can be explained due to the shortage of main electronic components in 2011 due to the recession effect. The Great Recession occurred from 2008-09 which made difficult for manufacturers to respond to the improving demand in 2011 (Pradhan Georgina 2010). The lowest generation rate in the year 2020 implies that the TVs, monitors, and DVD players sold in 2014 were decreased compared to previous years. The decrease in sales of 2014 can be because of external factors like shifting of market towards cheap smartphones and tablets, and advanced technologies entering in the market which were replacing the old TVs and monitors (Wolverton Troy 2014).

It can be also observed that the E-waste collected and recycled is decreasing at an average rate of 18% from 2016-2021. I learnt from the interviews with CalRecycle that due to the increase in non-CRT devices and decrease of CRT devices, the weight of CEW collected and recycled was reflected less. The fees are paid to the recyclers based on the weight of E-waste recycled and since the weight of non-CRT devices is less, the documented weight flows kept decreasing year by year. It was also learnt from the interviews that during the years 2020-2021 the COVID restrictions made difficult to collect and recycle E-waste in a usual way. This altogether resulted in a sharp decrease of E-waste recycled amounts. The E-waste collection and recycling rate is quite low during 2018, 2019 an 2021 due to the huge difference between generation and recycled amounts created by continuous decrease in E-waste recycled amounts.

3.4 Cost Revenue Model of Material Recovery Facility

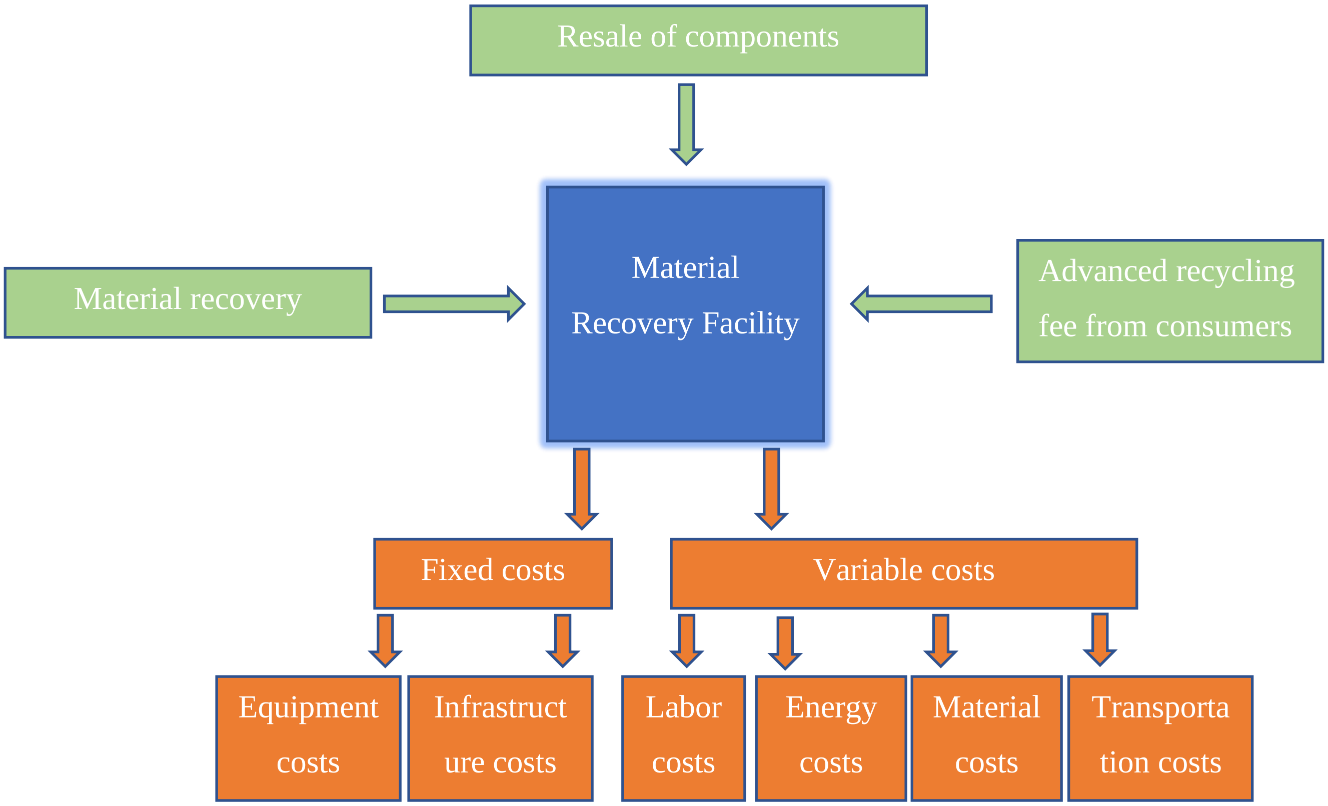

Figure 12 Cost revenue model of Material Recovery Facility in California. Source: *(Kang and Schoenung 2006, 1672-1680)*

a) Fixed costs:

MRF Equipment cost recovery life (years)	6
Operating time (days/year)	240[a]
Price for buying space ($/m^2/month)	19.62[b]

b) Variable costs:

Labor wage ($/ h)	N (14.0, 1)[c]
Price of electricity (industry sector) ($/kWh)	N(0.14, 0.02)[d]
Treatment volume (tons/year)	2500[a]
CRT Treatment amount (kg)	15
Landfill tipping fee ($/ kg)	N (4.7, 1)[e]

General inputs for MRF revenues:

Resale price for board ($/ kg) N (1, 0.5)[a]

Rebate for working monitor ($/ unit) N (3.5, 1.5)[a]

ARF charged for CRT monitor (17 in) ($/ unit) $5

Resale price for CRT Monitor ($/unit) N (25, 15)[f]

Material recovery for CRT Monitor ($/ unit) N(21, 5)

Sources: (a): (Kang and Schoenung 2006, 1672-1680) , (b): (Industrial Pricing 2021) , (c): (Labor wages 2021), (d): (Electricity charges 2022), (e): (Landfill fees 2022), (f): (CRT Prices) . The remaining data are taken from the above analysis of recovery economic potential.

Cost of one unit operation = equipment + infrastructure + labor + energy + materials + transportation

Total cost = $\sum cost\ of\ one\ unit\ operation$

Total Revenue = resale of materials + ARF charged to consumers + material recovery

Net Profit = Total Revenue – Total Cost

Analysis of results: The diagram represents green colored boxes as revenue inputs and orange-colored boxes as cost inputs of MRF. The fixed costs include MRF equipment cost recovery life, which is six years since the time to recover full cost of equipment will be the time taken when CRT TVs shall be discarded during the end of its life. All other inputs are self-explanatory. By feeding the accurate data of inputs, the net profit can be calculated by subtracting total cost from total revenue. It is not expected that for every MRF it can lead to profits. The earnings shall be dependent on many factors like the demand for secondary markets, labor availability, renewable electricity supply, availability of land and operational efficiencies. Hence, it may vary from region to region.

Chapter 4: Policy Analysis of E-waste Management in California

The policy analysis reviews the various bills passed and enforced by California government to avoid the illegal disposal and manage the collection and recycling of E-waste, batteries, cell phones and CRT panel glass. It also reviews the current, past, and proposed E-waste regulations enforced by CalRecycle to improve the E-waste recycling in California. The California's proposed Futures Project highlights the objectives, goals, challenges, and recommendations for continual improvement in E-waste recycling and evaluates the options of adopting programmatic model i.e., EPR approach or a product stewardship program or a hybrid version of current E-waste recycling program. A comparative analysis with Switzerland E-waste recycling program is done to understand its policies and frameworks and identify the loopholes that can help improve California's E-waste recycling program.

4.1 Background

In California, the management of E-waste is regulated by Department of Toxic Substances Control (DTSC) through the Electronic Waste Recycling Act of 2003 and is managed by Department of Resources Recycling and Recovery (CalRecycle) through Covered Electronic Waste Recycling Program. The role of CalRecycle is to provide payments for the claimed CEW to the approved collectors and recyclers to balance the net costs reported for collecting, recycling, processing and recovery activities. The role of DTSC is to protect public health and environment by regulating the collection of CEDs by collectors and dismantling activities by recyclers, through annual facility inspections. DTSC regulates and limits the concentration of hazardous materials in electronic devices by complying with the European Union's Restriction of Hazardous Substances (RoHS) Directive. CDTFA manages the funding of CEW recycling program through Electronic Waste Recovery and Recycling Account (CalRecycle 2022, 9). The role of California Office of Administrative Law is to monitor the compliance of regulations proposed by state agencies with the standards described in California's Administrative Procedure Act (APA) to publish in California Code of Regulations. The OAL is also responsible to oversee whether the agency regulations are valid, necessary, and accessible by the public (OAL California 2022).

California has passed the following bills regarding the recycling of various electronic devices:

- Electronic Waste Recycling Act of 2003 (SB 20): The California Legislature enacted the Electronic Waste Recycling Act of 2003 (SB 20, Sher, Chapter 526) in response to the increasing volumes of electronic waste and managing the costs of properly collecting and recycling them. The intent of this act is to avoid illegal dumping of waste monitors and TVs, provide zero cost recycling solutions to the consumers, manage the funding of E-waste recycling and reduce the quantities of hazardous materials found in covered electronic devices (CalRecycle 2022, 9).

- Cell Phone Recycling Act of 2004 (AB 2901): The law requires the retailers to take back the used cell phones and provide the mechanism to reuse, recycle and properly dispose them at zero cost to the consumers. The intent of this act is to reduce the illegal disposal of toxic materials present in the cell phones like arsenic, lithium, cobalt, and lead in the environment and promote waste reduction (Pavley 2004).

- Rechargeable Battery Recycling Act of 2006 (AB 1125): The law requires the retailers to take back the used rechargeable batteries and provide the mechanism to reuse, recycle and properly dispose them at zero cost to the consumers. The intent of this act is to reduce the illegal disposal of toxic materials present in the rechargeable batteries like mercury, cadmium, lead, nickel, and other heavy metals in the environment. The Act defines rechargeable batteries as a "small, nonvehicular, rechargeable nickel-cadmium, nickel metal hydride, lithium ion, or sealed lead-acid battery, or a battery pack containing these types of batteries." (Pavley 2005).

- CRT Panel Glass Recycling of 2017 (AB 1419): The law iss passed to exempt the CRT glass from the DTSC's hazardous waste regulations if it follows the set of requirements mentioned in California Code of Regulations, Title 22, Division 4.5, Chapter 23 and recycle the CRT panel glass without the phosphor. CRT is found in the old electronic devices like monitors and televisions known as CRT devices, where the CRT and other components are composed of heavy metals and thereby considered as a hazardous waste (DTSC 2021a). With the launch of LCDs and LEDs in the market, the use of CRT devices has been reduced in the last years thereby stockpiling in the recycling facilities. Hence the law allows to recycle and utilize the CRT panel glass without the phosphor that is safe for the public health and the environment (Guyen).

4.2 Regulations

Past Regulations: The electronic waste consists of hazardous materials like heavy metals and can harm the public and environment if disposed improperly. Hence the electronic waste is either regulated by the federal government through RCRA (Resource Conservation and Recovery Act) or through state hazardous waste laws (Health and Safety Code), or both (CalRecycle Regulations 2022). With market fluctuations and quick updates in electronic devices, the current regulations and policies require amendments for managing the e-waste in future. The past regulations that got approved by the Office of Administrative Law include (CalRecycle 2022, 9):

- Giving legal options and addressing changes to recycle CRTs/CRT glass due to the fluctuating market conditions in 2018
- Amending regulations of the CEW Recycling Program in 2018
- Allowing local governments to designate an approved collector on their behalf to offer CEW collection services in 2020
- Bifurcating the recovery and recycling payment rates of CRT and non-CRT E-waste in 2021
- Amending the E-waste recycling payment fees depending on the screen size in 2021

Recent Regulation: According to the California Code of Regulations, Title 22, Division 4.5, Chapter 10, Section 66260.201 and Chapter 11, Appendix X, the current list of CEDs covered under the CEW Recycling Program include the following 9 categories (DTSC 2022).

1. Cathode ray tube containing devices
2. Cathode ray tubes (CRTs)

3. Computer monitors containing CRTs
4. Laptop computers with liquid crystal display (LCD)
5. LCD containing desktop monitors
6. Televisions containing CRTs
7. Televisions containing LCD screens
8. Plasma televisions
9. Portable DVD players with LCD screens

However, an emergency rulemaking was submitted on December 9, 2021, to include the new devices and amend the current list of devices as the volume of non-CRT E-waste is increasing and reached the rate of 51% of the total E-waste claimed by September 2021 (CalRecycle 2022, 9). On December 20,2021 the recommendation to amend the list of CEDs was approved by the Office of Administrative Law (OAL). It led to the addition of 6 new categories of CEDs namely the OLED and LCD devices as mentioned below (DTSC 2022):

1. OLED-containing televisions.
2. OLED-containing laptop computers.
3. OLED-containing tablets.
4. OLED-containing desktop monitors.
5. LCD-containing tablets; and
6. LCD-containing smart displays.

From July 1, 2022, consumers will pay the E-waste recycling fee while purchasing these devices from retail stores and when these devices become E-waste, they will be collected and claimed by approved collectors and recyclers for recycling and recovery payments under CEW Recycling Program (DTSC 2022).

4.3 Covered Electronic Waste Recycling Program

According to the report (CalRecycle 2018), the CEW Recycling Program has been a great success in E-waste management as it successfully collected and recycled over 2.5 billion pounds of covered electronic waste generated in the state since January 2005 till September 2021. The program provided no cost collection and recycling opportunities to the consumers in the State and developed a strong network of collectors and recyclers spread out in more than 400 locations, reducing the burden on businesses and local authorities to manage these wastes (Figure 13). Manufacturers are subject to inform retailers on what products the recycling fee needs to be charged. Consumers are required to pay a fee known as Advanced Recycling Fee (ARF) on all Covered Electronic Devices (CEDs) at the time of retail purchase (from approximately 11,500 retailers) (CalRecycle 2018). As per the survey (Nixon and Saphores 2007, 547-559) , Californians explain the willingness to drop off electronic waste at recycling centers or being offered the pickup services. The survey also mentions that people explain willingness to pay 1% ARF to get rid of E waste which means people are aware and want to take this issue seriously. As of September 2021, there are 303 approved collectors and 19 approved recyclers in California. Retailers collect the fees from consumers and then remit the fees to CDTFA (Department of Tax and Fee Administration) excluding 3% administrative costs. CDTFA uses that fee to fund CalRecycle and DTSC activities through Electronic Recovery and Recycling Account. The responsibility of CalRecycle under SB 20 is to oversee the Covered Electronic Waste (CEW) Fee and Payment system (CalRecycle 2022, 9).

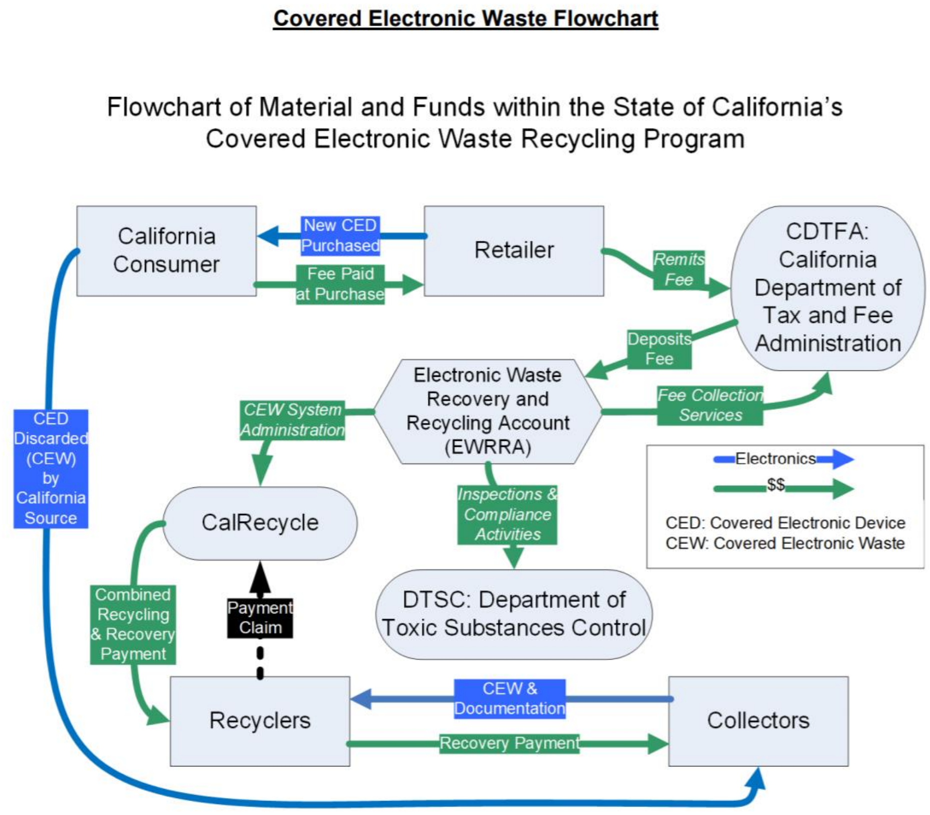

Figure 13 Framework of CEW Recycling Payment Program Source: (CalRecycle 2022, 9)

The scope of CalRecycle's CEW fee and payment program only covers CEDs (i.e., video display devices with screen sizes larger than four inches) because the state considers these products hazardous and bans their illegal disposal in landfills. The payment fees are revised based on the market conditions and retail sales of electronic devices in California. The following table (Table 6) shows the payment rates for video display devices of different screen sizes from the year 2005-2021. As of September 2021, the annual total revenue from CEW Recycling Fees was $94M for FY 2019/20, $40M for FY 2020/21 and $64M for FY 2021/22. The reason for the reduction in revenue from 2019-2021 is the COVID restrictions implemented in the state which made it difficult for collectors and recyclers to collect and recycle CEW without making contact. For CRT CEW, the combined recovery and recycling payment is $0.66 per pound, for non-CRT CEW it is $0.87 per pound and the recovery rate for collectors is $0.26 per pound (CalRecycle 2022, 9).

Table 6 Recycling payment fees paid by consumers during purchase of CEDs in California from 2015-2020 Source: (*CEW Fees*)

Categories	2005 to 2008	2009 to 2010	2011 to 2012	2013 to 2016	2017 to 2019	January 1, 2020 Forward
More than four inches but less than 15 inches	$6	$8	$6	$3	$5	$4
At least 15 inches but less than 35 inches	$8	$16	$8	$4	$6	$5
35 inches or more	$10	$25	$10	$5	$7	$6

Limitations and challenges of CEW Recycling Program- Apart from the video display devices mentioned in the current regulations, CEW recycling Program does not cover many other electronic devices like batteries and lamps. Even today, not all hazardous E-waste is managed properly. Heavy CRTs bring more profits due to the high intrinsic scrap value but with the increase in technologies and lightweight concepts, the volumes of non-CRT electronic devices are increasing. Since the payments are claimed based on the weight of E-waste recycled, CalRecycle often ends up paying less to the collectors and recyclers for the same amounts of non-CRT E-waste. This altogether adds the burden on recyclers because non-CRT E-waste being light weighted have less intrinsic scrap value, more expensive to manage and requires special handling for certain components. The infrastructure for recovering E-waste has been established to recover various constituents, but it is not directly funded by CEW Recycling Program.

Cell Phones

In United States, 97% of the adults own a cellphone in which 87% of them own the smartphone. This necessitates the recycling and recovery of the used cell phones to reduce the mining of new resources and additional oil to make plastic. Cell Phones contain toxic metals like arsenic, lead, lithium, and cobalt in its internal components however, they also contain valuable metals like gold, palladium and silver (Figure 14). To reduce the disposal of toxic elements in the environment, DTSC conducts monitoring and testing of the samples in laboratory and ensures their proper disposal. Since the plastic represents a major part of the cell phones, 80% of the discarded cell phones can be recycled and reused (DTSC 2021b).

Figure 14 Weight of valuable metals in discarded cell phones Source: *(DTSC 2021)*

In California, Cell Phone Recycling Program is implemented to take back and recycle the used cell phones. As of July 1, 2006, the retailer is required to comply with the Cell Phone Recycling Act of 2004 and publicize the information of recycling opportunities to the consumers (Pavley 2004).

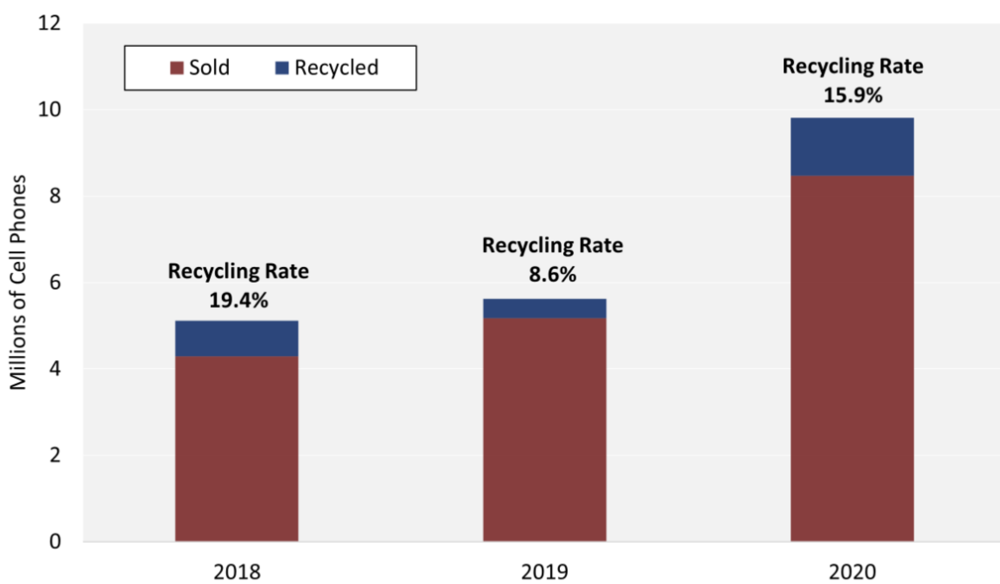

Figure 15 Number of cell phones sold and recycled in California from 2018-2020 Source: *(DTSC 2021)*

As per the results shown on DTSC website, during the year 2020, the estimated sales of cell phones throughout California were 8.47 million and the cell phones that were reported as recycled were 1.34 million achieving the recycling rate of 15.9% (Figure 15). The limitations of the data are that California does not require manufacturers to report the cell phones that are sold throughout California, nor it requires collectors to report the number of cell phones that are collected for recycling hence not producing the accurate results (DTSC 2021).

Batteries

Most of the electronic devices possess batteries as battery is an integral part of an electronic device to complete the circuit. However, batteries also contain toxic materials like mercury, cadmium, nickel and lead that can affect the public health and environment. To overcome this challenge, California passed the Rechargeable Batteries Recycling Act in 2005 to return, recycle and ensure safe disposal of used rechargeable batteries (Pavley 2005).

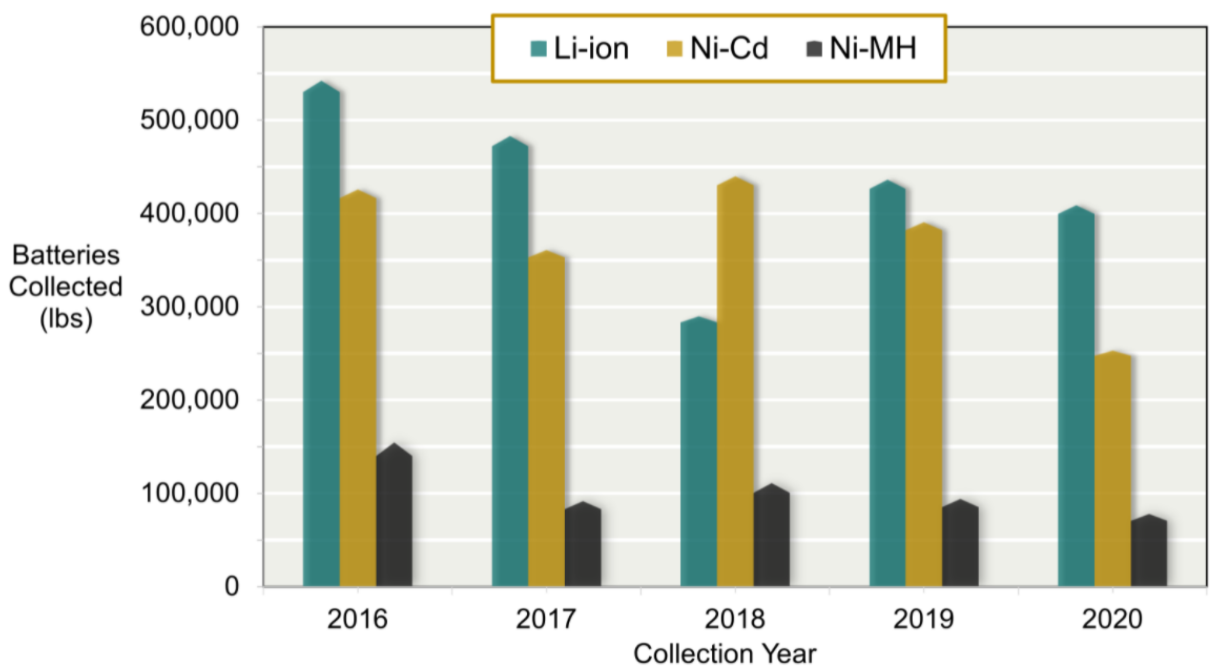

Figure 16 Rechargeable batteries collected by weight for recycling in California from 2016-2020 Source: (DTSC 2021c)

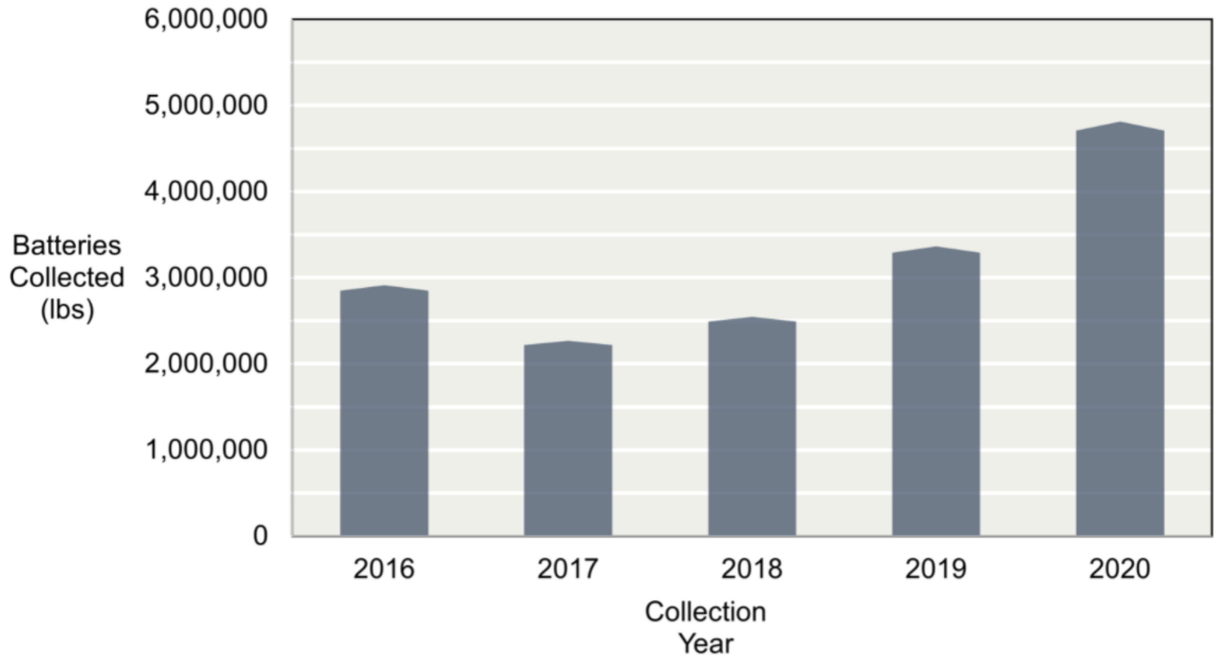

Figure 17 Small sealed lead acid batteries collected for recycling in California from 2016-2020 Source: (DTSC 2021)

In the year 2020, the quantities of rechargeable batteries collected by weight for recycling were : 408,823 lbs. of lithium-ion batteries (Li-ion), 252,969 lbs. of nickel cadmium batteries (Ni-Cd), 77,766 lbs. of nickel metal hydride batteries (Ni-MH) and 4,810,578 lbs. of small, sealed lead acid batteries (SS Lead Acid). From the (Figure 16), we can say that the collection of Li-ion, Ni-Cd and Ni-MH batteries reduced in 2020 as compared to the year 2016. However, (Figure 17) shows the increase of lead acid batteries collected in the year 2020 as compared to the year 2016. There are many reasons that can explain the change. First, the use of technologies that include Ni-Cd and Ni-MH batteries are reduced like cordless phones, old mobile phones, two-way radios, etc and the use of lead acid batteries is increased in technologies like mobility scooters and power backup systems. However, the Li-ion batteries is found in most of the rechargeable products today. Therefore, second reason can be the data limitations mentioned on the DTSC website as California law does not require collectors and recyclers to report the rechargeable batteries collected and few battery handlers do not track the origin of batteries. Also, the batteries obtained from the CEW is managed separately and may represent the huge portion of total batteries sold (DTSC 2021).

4.4 Policy Framework : Systems Analysis

The analysis is done based on the Systems Analysis framework taught by Professor Stephanie Siehr during "Environmental Policy: Design and Implementation" course at University of San Francisco (Siehr Stephanie 2020). The framework is referred to the lecture notes taken from the published materials (United Frontline Table 2020) (Vig and Kraft 2019).

Environmental issue: Several constituents in the electronic devices exhibit the hazardous waste characteristic of toxicity when disposed. Consumers purchase more than 120 million electronic devices in California every year and if the electronic waste is disposed improperly, it would harm the public health and environment. Electronic Recycling Act of 2003 was passed to oversee the funding for collection and recycling of certain electronic wastes through CEW Recycling Program. Though it has been a success in the past, current approaches would not remain effective in the future with the increased automation and technological changes in electronics industry. SB 20 needs to be updated to address the future challenges and ensure the continuous success (CalRecycle 2018).

Policy description: CalRecycle undertook the Futures Project in March 2016 to evaluate the future options for E-waste management in California by examining current scenarios, prioritizing resource recovery, and emphasizing waste reduction, reuse, and recycling through an EPR approach. The objectives are mentioned in the report (CalRecycle 2018) as CalRecycle's policy to support a robust collection and processing infrastructure and enhance the current CEW Recycling Program.

Scope of the policy: The policy is applicable for all the electronic products that are and/or will be included in the revised electronic waste definition of SB 20 like the European Union's WEEE directive definition. As compared to the current CEW Recycling program applicable only for the Covered electronic devices, the Futures Project will address new electronic devices and emerging technologies like solar panels and electric vehicle batteries.

Scale: The scale of the policy is limited to the state of California because SB 20 has tasked CalRecycle to administer CEW Recycling Program which is a statewide program for e-waste management.

Rate: The Futures Project is quite a long-term project as the objectives mentioned in the report will remain as an ongoing process involving various stakeholders and their participation during the workshops. One of the objectives is to add more products in the definition of covered electronic devices and the regulation was passed and got approved in December 2021 to add six new categories of electronic devices in the E-waste category.

Duration: It is an ongoing project that will amend the current CEW Recycling Program to address new issues in the future and ensure continual success for e-waste management.

Key participants: The key participants include the general public, CalRecycle, DTSC, E-waste experts from various interest groups, state, federal and state government officials, manufacturers, recyclers, retailers, environment organizations and repair organizations. CalRecycle has also organized workshops, discussions and notice to common public for incorporating feedback from all stakeholders.

Stage of the policy process: According to the 5-stage policy process from the government perspective (Vig and Kraft 2019), it is at the 'Policy Implementation' stage where new rulemakings and programs are being put in place through administrative decisions and involvement of stakeholders to implement all the recommendations.

Policy goals and strategies: The goals of the Futures Project are to retain the SB 20's goals, which includes maintaining free and convenient collection opportunities, encouraging environmentally sound design, maximizing efficient recovery of materials, responsibly managing hazardous materials, providing safe working environments, encouraging reuse and addressing illegal dumping of hazardous materials. It also includes developing strategies for fully transitioning towards an EPR approach in California. The adoption of CalRecycle's policy for the future e-waste management includes nine objectives:

1) Add more products to the list of CEDs
2) Increase awareness and public outreach
3) Strengthen and increase manufacturer responsibilities
4) Provide economic incentives for repair and reuse of electronic devices
5) Establish new market development programs like grants and loans

6) Initiate new research activities
7) Streamline submittal of claim documents
8) Secure authority to adjust payment rates every year
9) Change fee collection by Department of Tax and Fee Administration (DTFA, formerly the Board of Equalization) from retailer to manufacturer level

Equity and Environmental Justice: The policy includes following components for providing equitable justice to the public and environment:

- Entities covered: Households, schools, businesses, government entities, non-profit organizations
- Distributive Justice: The current program has been a success in distributing the incomes to collectors and recyclers based on the weight of E-waste claimed to CalRecycle department. However, due to the dynamics in the market, the policy aims to develop new grant and loan programs for effective collection and management of E-waste. It shall provide economic incentives to the non-profit repair and reuse organizations, bonus for the environmentally sound designs and funding the collection and recycling activities.
- Procedural Justice: All the documents including statistics, reports, facts and figures are posted on the CalRecycle website and can be accessed anytime.
- Interactional Justice: The policy design stage involved many small group and large group discussions during workshops and presentations. Stakeholders who were not able to attend the meeting were given an option to attend via conference calls. The rulemaking involved administrative decisions after public hearings and public notice was given to incorporate their feedbacks. The policy aims to increase the awareness amongst the consumers through public outreach campaigns and awareness sessions in schools for teaching the concepts of e-waste management.
- Restorative Justice: The policy aims to protect public health and environment. With the addition of new electronic devices in CEDs list, the hazardous materials disposition will be reduced in the environment. The current program has succeeded in reducing burden on local jurisdictions and businesses to manage e-waste and offers zero cost collection opportunities to the consumers.

Policy Actions: The policy actions for fulfilling nine strategies are:

Table 7 Status of policy actions. Source: Author and data taken from (CalRecycle 2018)

Sr. No.	Strategies	Future Actions	Status
1	Add products to definition of CED	Amend SB 20 to adopt the WEEE Directive definition of European Union that will include all the electronic and electrical equipments.	The amendment has not still happened. It was discussed during workshops in 2017 and was decided to start with products containing batteries and lamps but it has not happened yet. Recently, six new electronic devices are added to the list of CEDs that exhibit characteristics of hazardous waste.
2	Increase public education and outreach	Legislation for some elements (e.g., mandating point-of-purchase consumer education), although there is existing authority for general education and outreach	The concepts of e-waste management are to be added in statewide kindergarten through 12th-grade education. The initiatives on outreach programs and awareness campaigns are posted on the CalRecycle website. Best Buy stores have started publicizing and placing E-waste bins for collecting the used E-waste (Best Buy 2022).
3.	Strengthen and increase manufacturer responsibilities	Legislation for concepts like product passports, enhancing durability, offering base-level warranty and guarantee.	CalRecycle has discussed the details and strategies to implement EPR approach where the responsibility will be of

		However, existing authority permits enforcing the submittal of compliant annual reports.	manufacturers to fund and manage the E-waste collection and recycling. The manufacturers have started taking initiatives for free recycling of their products however the EPR approach is still in the decision stage.
4.	Provide incentives for repair and reuse of electronic devices	Existing authority for concepts like facilitating partnerships with repair and reuse organizations, research for incentives; additional spending authority required to apply modulated fees for encouraging product longevity.	California introduced 'Right-to-repair' legislation in 2019 and CalRecycle aims to partner with repair and reuse organizations like iFixit, Fixit Clinics and the Repair Association (iFixit 2022). The additional spending authority has not been decided yet.
5.	Establish new market development programs	Legislation for concepts like low-interest loan for recycling and processing, research into new methods for tracking material flow, infrastructure development, domestic processing of non-hazardous waste; existing authority (CalRecycle) for Electronic Product Environmental Assessment Tool (EPEAT) promotion	Loans and grants are provided by California Office of Small Business Advocate to the recyclers and businesses that are into recycling manufacturing and reuse through Reuse Grant Program and Recycling Market Development Zone Loan Program. However, recycling of E-waste is still not included in their eligibility criteria (CalRecycle Loans). There are

			no legislations in process for the EPEAT guidelines promotion.
6.	Initiate new research activities	Legislation for research on concepts like material recovery feasibility, recycling technologies, E-waste data for quantities available for recycling, anticipated lifespan of products, raw materials available in e-waste stream; additional expenditure authority might be needed for contracts	No legislation in place.
7	Streamline submittal of claim documents	CalRecycle would be requiring administrative and regulatory action to reduce burden on reporting requirements of claims	No regulatory action in place.
8	Secure authority to adjust payment rates every year	Requires legislation as CalRecycle is able to adjust payment rates every other year and not annually.	No legislation in place. The next workshop for recycling and recovery payment rate considerations is held on April 21, 2022, and the last workshop was on April 27, 2020.
9	Change fee collection by Department of Tax and Fee Administration	Requires legislation if an EPR approach or product stewardship program is implemented. Also, since there are 11500 retailers and	No legislation in place. Manufacturers are currently remitting the fee for used oil, carpet, and paint stewardship programs hence e-waste

	(CDTFA, formerly the Board of Equalization) from retailer to manufacturer level	only 360 manufacturers, changing fee collections would reduce burden on state resources.	stewardship program can be implemented if technical and management issues are addressed.

Other than the above nine actions, the future actions also include enhancing the fee and payment model, implementing the programmatic model based on EPR approach or product stewardship approach and addressing emerging technologies like solar panels and electric vehicle batteries. After multiple meetings and discussions, most stakeholders that include recyclers, collectors and manufacturers, preferred the option of enhancing the existing fee and payment system because it is a robust and proven system employing thousands of people. Also, some stakeholders do not believe in the success of EPR programs in other states. However, local governments want an EPR approach where the major responsibility will be laid on manufacturers and will reduce the state resources for administration and monitoring. Since the EPR programs implemented in other states is not comprehensive, CalRecycle passed the EPR checklist in June 2019 that includes the comprehensive EPR approach with all the details and key components. Without the consent of industry leaders, EPR approach would be difficult to implement hence the discussion is still going on. CalRecycle recommends that transitioning to a stewardship system can be implemented effectively and for transitioning to a full EPR approach, it needs more work with stakeholders and analyzing the ways.

4.5 Comparative Analysis: California and Switzerland

<u>Overview of Swiss E-waste Policies:</u> Switzerland and other European Union (EU) Member States are obligated to comply with EU WEEE and RoHS Directives. The European Union Council enforced WEEE Directive to protect the environment and public health by mitigating impacts of WEEE generation and by promoting sustainable resource consumption (WEEE 2012, 38). The RoHS Directive was enforced to restrict the use of hazardous substances in electrical and electronic equipment (EEE) as well as promoting proper recovery and disposal techniques of WEEE to protect public health and environment (RoHS Directive 2011). European Parliament

and Council extended the scope of Directive 2012/19/EU with a focus on Waste Electrical and Electronic Equipment (WEEE) and divided them into six main categories (WEEE 2012, 38).

1. Temperature exchange equipment
2. Screens, monitors, and equipment containing screens having a surface greater than 100 cm 2
3. Lamps
4. Large equipment
5. Small equipment
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)

Switzerland is the first country in the world that initiated a comprehensive system for WEEE management called the SENS, also known as Swiss Foundation for Waste Management (Shittu, Williams, and Shaw 2021, 549-563). It is based on the EPR scheme where the collection of WEEE is done by SENS on behalf of the manufacturers and retailers. Switzerland's recycling system is quite robust and successful since 1992. It is one of the leading countries in collection with 15 kg per capita collection rate achieved in 2011 (Figure 18).

Since 1992, the collection of WEEE has been done separately in Switzerland by producer responsibility organizations (PROs). The PROs are the not-for-profit and voluntary organizations formed through collaboration of manufacturers and importers. Before Ordinance on the Return, the Take-Back and Disposal of Electrical and Electronic Equipment (ORDEE) was enforced in 1988, these organizations were responsible for financing, collecting, transporting, and recycling WEEE properly. ORDEE set up the EPR scheme in Switzerland where the retailers are mandated to collect the used WEEE from consumers and then send them to recyclers. The good condition WEEE are sent for reuse to the recyclers for further treatment including sorting, decontamination, pre-processing and shredding processes. Recyclers get the incentives by producers for achieving higher efficiencies on behalf of high quality and quantity of secondary raw materials. Getting incentives would motivate the recyclers to increase efficiency of recycling processes which in effect is good for the environment too as the more the recycling of materials, lesser are chances of waste to get diverted to landfills and incinerators. It also reduces the expenses of producers and manufacturers by avoiding high penalty fees and taxes for disposal.

Another advantage is that it creates a competitive market for recyclers to improve the quality of recycling which is also a responsibility of PROs as they determine the recyclers and revise contracts based on the recycling and recovery rates set in the "Technical regulations on the recycling of electrical and electronic appliances" (Khetriwal, Kraeuchi, and Widmer 2009, 153-165) (Duygan and Meylan 2015, 98-109).

Since 2007, there are four PROs in Switzerland that manage all the WEEE products, namely:

1. SWICO Recycling Guarantee and SENS – Manage grey, brown, and white goods, including categories 1-5, 6 and 7 of EU WEEE Classification.
2. SLRS (Swiss Light Recycling Foundation) and INOBAT (Stakeholder Organization for Battery Disposal) – Manage lighting equipment and batteries respectively.

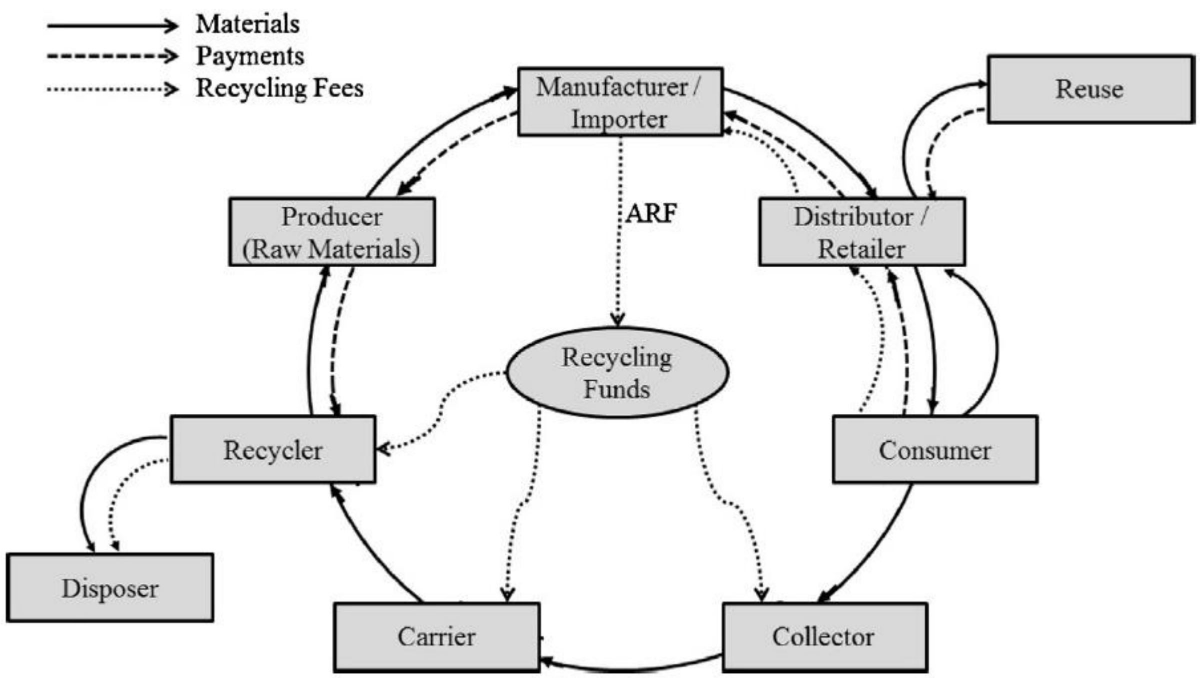

Figure 18 Switzerland WEEE Management system. Source: (Duygan and Meylan 2015, 98-109)

Table 8 Comparative analysis of Swiss and California E-waste management policies. Source: Author

Criteria	SWISS WEEE Management System	California CEW management system

Definition of E-waste	Includes all six categories of WEEE as per EU WEEE Directive definition consisting of all electronic and electrical equipment.	Includes ten types of covered electronic products listed under the E-waste category by DTSC.
Scope of E-waste	Includes domestic production and imports because majority of electronic devices are imported in Switzerland	Includes domestic production of CEDs which are laptops, TVs, monitors and portable DVD players.
Regulation/ legislation	Ordinance on the Return, Taking back and Disposal of Electrical and Electronic Equipment. (ORDEE)	Electronic Recycling Act of 2003
Regulatory Authority	Producer responsibility Organizations	CalRecycle and DTSC
Programmatic model	EPR approach	State run program
Financial management	Manufacturer/ importer PROs (SWICO, SENS)	CDTFA oversees and CalRecycle administers
Source of recycling fee	Consumer at the point-of-purchase	Consumer at the point-of-purchase
Funding mechanism	Advanced Recycling Fee	Advanced Recycling Fee
Physical responsibility	Manufacturer/ Importer PROs (SWICO, SENS)	DTSC
Collection authority	Retailers and distributors; designated collection points	Approved Collectors; designated collection points
Recycling permit	License of recycling is given by PROs	Permit given by DTSC
Material recovery permit	Most of the material recovery takes place outside Switzerland	DTSC does not allow chemical processing of hazardous waste for

	in smelter plants however, the recycling efficiencies are high in obtaining secondary raw materials.	material recovery hence it is exported to the secondary markets.
Data management	Empa, a bridge between PROs and keeps record of all data	Improper tracking mechanism. Tracks data only for E-waste collected and recycled.

4.6 Discussion

The Content of the Policy: Swiss EPR Policy is set by ORDEE legislation that clearly states out the responsibility and obligations of all the stakeholders involved. The role of stakeholders is mentioned in the figure below. According to the OECD, the definition of WEEE is clearly stated as ‘‘any appliance using an electric power supply that has reached its end-of life’’. Swiss legislation follows the same definition and has included all types of electronic and electrical appliances that are listed in EU WEEE Directive (Khetriwal, Kraeuchi, and Widmer 2009, 153-165). However, California currently covers only limited amounts of electronic devices for recycling and recovery (Figure 19). CalRecycle revises the list of CEDs based on the product market share and its demand in future generations. With the quick update in technologies and changes in lifestyle, the designs and structure of electronic devices is changing rapidly which makes difficult to track the waste generation. But the same scenario applies in Switzerland too hence I would recommend that the definition of E-waste must be amended soon in California. The figure shown (Figure 19) lists out the type of devices covered by the recycling program in different states of U.S.

Administration by Implementing Agencies: The most important part of Swiss E-waste management system is that it was not enforced by the government, it started way back in 1990 by the producers by taking back the IT equipment from the consumer. Later, it was supported by the other producers, and they altogether participated in the initiative taken by a voluntary organization S.E.N.S (Stiftung Entsorgung Schweiz) to collect and recycle refrigerators and freezers. Besides, the customer requests increased for taking back the old products irrespective of their brand, that is when producers approached SWICO (Swiss Association for Information, Communication and Organization Technology).

	State	Per Capita Rate	Computer	Laptop	Monitor	Tvs	Printer	FAX	Scanner	Keyboard Mouse	DVD player	VCR	Others	Monitors and TV comprise what percent of products collected?
1	Vermont	**7.7**	☑	☑	☑	☑	☑			☑				82%
2	Oregon	**6.9**	☑	☑	☑	☑								93%
3	Wisconsin	**6.83**	☑	☑	☑	☑	☑	☑		☑	☑	☑		73%
4	Minnesota	**6.62**	☑	☑	☑	☑	☑	☑		☑	☑			Not tracked
5	Washington	**6.30**	☑	☑	☑	☑								92%
6	Maine	**5.6**		☑	☑	☑	☑						Games Digital frames	95%
7	California	**5.54**		☑	☑	☑					☑ Port able			Not tracked
8	Rhode Island	**4.55**	☑	☑	☑	☑								Not tracked
9	New Jersey	**4.53**	☑	☑	☑	☑	☑							Not tracked
10	South Carolina	**3.92**	☑	☑	☑	☑	☑							Not tracked

Figure 19 What covered entities are included in the e-waste management program in California Source: (Electronics Take Back Coalition)

This gave birth to the recycling guarantee program in 1994. SENS had a wide range of electronic products because of the increase participation and seeing this momentum, ORDEE came into effect in 1998 and set the regulations to oversee and monitor the hazardous waste disposal (Tojo 2003).

Actor	Roles and responsibilities
Government	The federal government plays the role of an overseer, framing the basic guidelines and legislation. Cantonal authorities play a part in the overall control and monitoring in their capacity as the licensing authority for recyclers.
Manufacturers/Importers PROs (SWICO, SENS)	Importers carry the economic and physical responsibilities of their products. *Have the role of managing the day-to-day operations of the system, including setting the recycling fees, as well as licensing and auditing recyclers.*
Distributors & retailers	Bear a part of the physical and informational responsibility of the product. Are obligated to take back products in categories they have on sale, irrespective of whether the product was sold by them, or whether the consumer purchases a similar product as replacement. *Are responsible for clearly mentioning the amount of the ARF in the customer invoice.*
Consumers	Are responsible, and obligated by law, to return discarded appliances to retailers or designated collection points. *Bear the final financial responsibility through the recycling fee on new product purchases.*
Collection points (specifically designated locations)	*Collect all kinds of WEEE free of charge and ensure the safety of the disposed products to prevent pilferage or illegal exports.*
Recyclers	Must adhere to minimum standards on emissions and take adequate safety measures concerning employee health. Need authorisation to operate a recycling facility from the cantonal government, *as well as a license from the PROs.*

Figure 20 Role of stakeholders in Swiss WEEE management system Source: (Khetriwal, Kraeuchi, and Widmer 2009, 153-165)

The figure (Figure 20) explains the roles and responsibility of various stakeholders that are involved in Swiss WEEE management system. The collection of waste is done through retailers, designated collection points and direct collection by producers. There is no involvement of municipalities except that it keeps an eye on the activities to handle the situation when required. The retailers are obligated to accept the e-waste returned by consumers irrespective of type, model, and brand. They have options of either sending to a recycler or for reuse of devices through a carrier. The physical responsibility for collection of e-waste is of retailers, distributors, and transporters. The recyclers are given license by SENS and SWICO based on their quality of recycling. The bidding takes place every two years hence a particular area is allocated to a particular recycler for two years. The market is competitive hence recyclers try to gain their position by improving the quality of recycling and complying with the permit requirements. Canton government gives the permit of disposal to the recyclers but being a member of SWICO and SENS there are rare chances of non-compliance risks because of the stringent requirements set by these PROs (Tojo 2003).

The government do not organize the campaigns or awareness sessions. SWICO puts a brochure that is available at retail shops and on the websites of SWICO and SENS. When required, municipalities return the illegally dumped products to the collection points. However, the consumers are obligated to return E-waste and to not discard them in municipal waste stream. The final recycling fee is paid by consumer during the purchase of device and the rates are visible and added separately in the bill.

Most of the recycling takes place in Switzerland however few material recovery processes of metals like precious metals and critical earth metals happen outside Switzerland mostly in Sweden (Duygan and Meylan 2015, 98-109). The government tries to avoid the export of hazardous materials by recycling up to the maximum potential in Switzerland. As of 2019, (Forti et al. 2020, 120) the E-waste generated in Switzerland was 201 kt with a rate of 23.4 kg per capita. The e-waste that was documented to be collected and recycled was 123 kt in 2017.

The advanced recycling fee is paid by the consumers to retailer which in turn pays back to the producers during the purchase of equipment. Under SWICO, the ARF is handed over to the producer which he can either use it to pay recycler for recycling of its products that he has directly collected from consumers, or transfers into a common account managed by SWICO for financing the collection, recycling, and processing activities. The ARF collected by PROs is only used for the products currently collected (Tojo 2003).

The most crucial element of managing the system is data. Lack of data leads to the failure of the system. Switzerland was at front with managing the data by measuring and tracking them. Empa, Swiss Federal Laboratory for Materials Testing and Research, acts as a bridge between SWICO and SENS and keeps track of all recycling plants data.

The Commitment of the Implementers: Switzerland and few other countries were already following the EPR approach before WEEE Directive came into effect. This interprets that the producers were quite proactive in managing the e-waste and recycling them with highest efficiency. It can be also highlighted from their interviews when Mr. Bornand of SWICO says “it makes no sense to say that you are responsible and send the product somewhere. You must have a control.” S.E.N.S also is committed to its work describing it as “ to check the quality of the collection points, to secure that the equipment which has to be recycled is to be transported to our recycling facilities” and to “check the quality of recycling” (Tojo 2003).

The Support of Stakeholders: The producers are quite supportive and cooperative with the government. The group of producers that started this program included tech giants like Apple, Samsung who supported the small-scale recyclers too by getting more revenue from this system such that it can fund the free riders. The retailers did not get a chance to complaint the PROs in case of storing the returned electronic products in their facilities because consumers were given convenient options of dropping the products at collection points like railways.

The Nature of the Institutional Context : Most producers in Switzerland are members of SWICO and/or SENS hence deciding the fee structure and managing the e-waste becomes easier for them as they are aware of their products and market share.

Chapter 5: Case Studies - Adoption of CE Principles in California for E-waste Management

Circular economy initiatives in general are taken by government and businesses at the wide scale for different waste streams. Few major initiatives are listed below that gives a general idea on how California is adopting the principles of circular economy in E-waste management. The case studies have been divided based on the initiatives taken by different stakeholders in the EPR Framework.

Manufacturers:

Apple: Apple offers trade – in program to trade a new product by providing credit through gift cards and if not eligible for credit, it offers free recycling solution to get rid of old devices like computers, displays, and peripherals — cables, mice, keyboards, speakers, printers, scanners, media, hard drives, etc. Also, if the device is an iPhone, it sends it to a disassembly robot that efficiently recovers the secondary raw materials from the device. Apply has adopted CE principles throughout the value chain by using 2 times more recycled tungsten, critical materials, and cobalt in iPhone devices in 2021. It uses 100% recycled gold, rare earths and tin in devices making it more environmentally sound designed (Apple Trade-in 2022).

Dell: Dell offers almost the same type of service to the consumers. It allows consumers to enter details of an eligible electronic device irrespective of their brand to get instant credit. And then deliver through FedEx to get pre-paid debit card which can be used to buy Dell products. It has recovered more than 2.5 billion pounds of used electronics since 2007. They also give a free recycling option of any brand device during the purchase of a new Dell product (Dell 2022).

HP: HP offers the recycling and recover solutions too to the consumers. They clean the data for maintaining industrial standards and recycles the old devices for free. They also give the recovery benefit for the residuals in old devices. HP collects old devices for resale and recycles computer equipment, printing supplies, rechargeable batteries and other items, in more than 76 countries (HP 2022).

Many tech giants like Google offer free recycling options for its equivalent devices but some has an option of trade- in and some do not. Google offers free recycling option through a third-party recycler for eligible devices and also provides service of repair and replacements for extending the lifespan of products (Google 2022).

Retailers:

Best Buy: Best Buy being one of the major retailers of electronic products throughout the country, offers recycling solution for many products. They offer free recycling service for three items related to electronics, appliances, and fitness equipment per household per day to the California residents. They cover a large range of products and charge no drop off fees to the residents. As of 2022, they have collected over 2 billion pounds of electronic waste and appliances making them the biggest national retail collector of e-waste. They also offer service to calculate the trade- in value for the return of old device through Trade- in calculator. It helps consumers to be aware about the recover value of its device without going to different stores and asking them. They also offer service to collect large appliances from home through haul service and recycle them at provided charges (Best Buy 2022).

Staples: Staples offers free recycling options for electronics, ink and toner cartridges and batteries at all retail stores and accepts any other brand office technologies. They also run a B2B e-waste recycling program to easily recycle old electronics. In 2016, they collected 48.7 million pounds of electronics and ink and toner for recycling in North America (Staples 2018).

Office Depot: Office Depot has a different style of providing recycling solution. They provide $2 rewards per recycled cartridge to customers for recycling their old ink and toner cartridges. The customers can bring empty cartridges and recycle up to 10 in exchange of 10$ qualifying purchase. Since 2003, they have diverted over 65 million ink and toner cartridges from landfills (Office Depot 2022).

Recyclers:

There are 303 approved collectors and 19 approved recyclers in California that are enrolled in CEW Recycling program (CalRecycle 2022, 9). CalRecycle also offers a recycler and/or collector locator to search nearby recycling and collection sites in your area. Another organization that offers a locator tool is Call2Recycle. It shows the locations for recycling rechargeable batteries, single-use batteries, cellphones and E-bike batteries (Call2recycle 2022).

Green Citizen: One of the biggest recycler and environment service company in California is Green Citizen; headquarters located in Burlingame. They offer collection and recycling services for electronics, Styrofoam and solar panel recycling to businesses and residents. Since 2005, they have recycled 29,455,498 pounds of electronics (Green Citizen 2022). They also guide the consumers on how to shift towards using environment friendly products, find green jobs in environment sector, where to recycle and reuse their products through Green Directory and be aware about latest environmental affairs. They also have a platform named Green Store where they provide refurbished electronics for sale (Green Citizen 2022).

Voluntary organizations:

iFixit: California implemented the Right to Repair legislation in 2019 which gave a chance to the consumers to repair their devices if they are broken or scratched and extend the lifespan of electronic products. iFixit provides an online platform to offer repairing guides and parts for various electronic devices. It allows online users to post how-to repair videos and blogs on the website to help and teach everyone.

Fixit Clinic: Fixit Clinic works in the same way as iFixit. They have taken virtual repair initiatives through zoom classes where anybody can register and learn how to repair the device. They are also available on call 24x7 through Global Fixer Server. To have our device review by any repairer in the world, we can directly register and fill the form on their website. They also give customers an option to set up a local clinic in their area (Fixit Clinic 2021).

The Repair Association: The Repair Association is a limited community association that involves tech giants, investors, business owners and repair experts from various countries to learn and gain professional experience of repairing the electronic devices. It has a widespread network that conduct case studies, cover litigation fees, overseeing the legal documents and supporting the repair industry. One needs to select the type of membership to become a part of this association (The Repair Association 2022).

Governments and Institutions:

One of the biggest collaboration groups for Danish academics and innovators is Innovation Centre Denmark Silicon Valley which helps in collaborating with business partners, startups and research institutions who are taking big steps in circular economy. University of California is one of those institutions who are making plan to implement zero waste goal in their campuses. It provides a platform to connect with tech-giants Apple, Microsoft and Google who have taken initiatives to achieve circularity in their system. Also, the yearly Bay Area Greenbiz conference event is held named Circularity that gives opportunities to network, share ideas, and collaborate with innovators and partners in California (Denmark in Silicon Valley).

Implementing 'Take-Back' system is one of the main principles of circular economy, where we can consider public private partnership of E waste recycling programs. Spreading the awareness amongst the users to exchange the old item with a retailer like Best Buy and/or return waste to the recycler helps in overcoming the collection challenges. As per the Polluter Pays principle, consumers are supposed to pay fees to protect the environment, but they are also supposed to use the electronic items for longer use through repair and recycling techniques to save the environment.

Conclusions and Recommendations

The results explain that circular economy is the best approach to manage E-waste effectively in California. The results also explain that the E-waste generated has increased at an average rate of 59% from 2016-2021 however E-waste collected and recycled has decreased at an average rate of 18% from 2016-2021 due to the market fluctuations and new technologies.

The results from economic analysis states that the recovery economic potential of secondary resources in CRT E-waste is 0.31 billion dollars. The major potential materials found are copper, silver, glass, plastics, and lead. The CRT TVs and monitors used in analysis are composed of glass, lead and plastics in large quantities, hence those materials indicated as high recovery elements. The top five materials found have high potential to reduce the burden on imports or reduce the need to extract virgin raw materials thereby protecting the safety of workers and the environment (Panchal, Singh, and Diwan 2021, 102264).

The results from policy analysis states that California has a quite narrow list of E-waste categories included in the recycling program. It is also concluded that California's EPR policy is in the decision stage, funding programs are not in place and many objectives lack the regulatory actions. The financial and physical responsibility if handed over to the manufacturers, results in better management of E-waste because they are more aware about their products. The collaboration of manufacturers is highlighted as a strong point of Swiss recycling program because it allowed them to run programs at national level and gain environment and economic benefits. The analysis also states that creating a competitive market for recyclers yields high operational efficiencies. The results state that Advanced Recycling Fee taken from consumers is a successful approach to manage E-waste and can be continued in California.

The policy actions proposed by CalRecycle for future management of E-waste are in align with the European Union WEEE Directive and highlights main issues and key points that needs to be improved. However, most of it would be true if the actions are implemented soon and overcomes all challenges. For a full transition towards EPR approach, it is interpreted that more work needs to be done by manufacturers/producers to take responsibility and collaborate with each other for improving E-waste management in California. CalRecycle would act as a coordinating body to oversee all the activities however, manufacturers would be required to act on time by following the case study of Switzerland WEEE management system. The comparative analysis of CalRecycle E-waste recycling program with Switzerland WEEE management program identifies that major control of manufacturers/ importers have resulted to an increase in collection and recycling rates in Switzerland. The results also highlight that the incentives given to the recyclers and collectors based on their efficiency rates on behalf of high quantity and quality of E-waste recycled helped in increasing the recycling rate of E-waste in Switzerland. Switzerland has a strong data tracking mechanism to keep record of all data which is another area that California lacks in.

The initiatives highlighted in the Case Studies section of different organizations gives a brief overview on how manufacturers have started adopting the principles of circular economy.

The conclusion also says that only big companies are taking head starts in this approach and more initiatives needs to be done by small and medium sized electronic and electrical manufacturers to take the E-waste issue seriously.

Recommendations to CalRecycle

- Improve data tracking for electronic devices sold, E-waste generated, collected, recycled, reused, and kept in stocks. This can be done by creating proper data channels through a common platform or website and imposing regulations for mandatory reporting of data.
- Extend the funding and payment programs from dismantled CEW to include recovered, resold and reused electronic waste in the program.
- Encourage bidding of recyclers to create a competitive market and provide incentives to recyclers for achieving high efficiency rates based on quality as well as quantity of E-waste recycled.
- Include all electronic and electrical equipment in the E-waste category as per the European Union WEEE Directive.
- Improve data collection techniques for batteries, as the lack of data provides inaccurate results making it difficult to handle and dispose the batteries properly. To achieve high recycling rates, batteries should be included in the categories of electronic waste that can help in proper tracking of collected and recycled amounts.
- Create a common platform like PROs under CalRecycle to encourage enrollment of manufacturers by taking participating fees that can be used for funding the collection and recycling of -waste in California. The intangible benefits can be provided to improve the participation of manufacturers. Award manufacturers a compliance certificate for recycling their devices through formal recyclers and utilizing recovered materials in their facilities. This would reduce their dependence on virgin raw materials.
- Establish regulations for Material passports that can be labeled and scanned during purchase of devices.
- Provide research subsidies for recycling and recovery technologies to achieve higher operational efficiencies.

- Collaborate with DTSC to test the electronic devices and maintain a common data platform for E-waste generated, collected, and recycled amounts.
- Promote a circular economy through standardized frameworks and public-private partnerships.

Further research opportunities include:

- Gathering data on CEDs stocks, average weight and their lifespan distribution from reliable sources like consumer surveys, market surveys and site visits to recycling sites.
- Cross- checking data for errors by comparing with different models. This was not done considering the time constraints. It can be done by conducting the study for a particular year when all data variables are available and then estimating E-waste generation through applicable models to find out most reliable and accurate method for California.
- Considering import and export of electronic devices and electronic waste in the analysis to get accurate results.

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Appendices

Appendix 1 Average weight of secondary raw materials in each electronic device.

Category	Laptop[a]	CRT TV[b,d]	Non-CRT TV[b]	CRT Monitors[b]	Non-CRT Monitor[b]	DVD players[c]
Common base materials						
Al	18.9	67	-	242	130	241.5
Arsenic	-	-	-	-	-	-
Barium	-	-	-	1	-	-
Cadmium	-	0.2	-	-	-	-
Chromium	-	0.03	-	-	-	-
Cobalt	0.0107	-	-	-	-	-
Copper	71.82	656	824	952	-	44
Ferrite	-	-	-	483	-	-
Glass	-	15760	162	6845	590	-
Lead	-	1319	-	464	16	-
Mercury	-	-	-	-	0.001	-
Molybdenum	-	-	-	-	0.633	-
Plastics	201.6	8755	612	2481	1780	184
Steel/Iron	252	-	-	3322	2530	2237
Tin	-	32	18	20	24	-
Titanium	-	-	-	-	0.633	-
Tungsten	-	-	-	-	0.633	-
Vanadium	-	-	-	1	-	-
Zinc	-	8.6	-	-	-	-
Precious metals						
Gold	0.000032	-	0.11	0.31	0.2	-
Nickel	-	-	-	199	-	-

Silver	0.00019	2088	0.45	1.25	0.52	-
Critical raw materials						
Antimony	-	14	0.71	-	-	-
Cerium	-	-	0.005	-	0.001	-
Dysprosium	-	-	-	-	-	-
Europium	-	-	0.008	-	0.001	-
Gadolinium	-	-	0.001	-	0.001	-
Gallium	-	-	-	-	0.003	-
Indium	0.00014	-	0.003	-	0.079	-
Lanthanum	-	-	0.007	-	0.001	-
Palladium	0.000019	-	0.044	-	0.04	-
Platinum	-	-	-	-	-	-
Praseodymium	-	-	0.001	-	0.001	-
Terbium	-	-	0.002	-	0.001	-
Yttrium	-	-	0.11	1	0.016	-
Neodymium	0.00036	-	-	-	-	-
Tantalum	-	-	-	-	-	-
PCB	-	-	-	-	-	270
Other	716	11300	-	-	-	6.5
Total(g/unit)	1260	40000	1617	15013	5073	2983

Notes: (a): (Panchal, Singh, and Diwan 2021, 102264), (b): (Cucchiella et al. 2015, 263-272), (c): (Parajuly and Wenzel 2017, 272-285), (d): (Hazardous Material Laboratory 2004)

Appendix 2 Estimation of total recoverable materials and Recovery Economic Potential of CRT E- waste. Source: Author

Category	Material wt. in CRT TVs (lb)	Material wt. in CRT Monitors (lb)	Total material wt.in CRT	Avg. market price of	Recycling rate of	Recovery economic potential of material

			devices (lb)	material ($/ lb)	materia l (%)	
Al	44,990	4,862	49,853	1.22	0.6	36,492
Antimony	9,401	0	9,401	2.72	0.28	7,160
Arsenic	0	0	0		0.01	0
Barium	0	20	20	0.09	0	0
Cadmium	134	0	134	1.129		0
Cerium	0	0	0	0.9	0.01	0
Chromium	20	0	20	5.65	0.87	99
Cobalt	0	0	0	24.21	0.68	0
Copper	4,40,502	19128	4,59,630	4.24	0.5	9,74,416
Dysprosium	0	0	0			0
Europium	0	0	0	14.06	0.01	0
Ferrite	0	9,705	9,705	0.317		0
Gadolinium	0	0	0		0.01	0
Gallium	0	0	0	258.62	0.01	0
Gold	0	6	6	26,109.7 2	0.4	65,053
Glass	1,05,82,79 1	1,37,536	1,07,20,3 27	0.1	0.95	10,18,431
Indium	0	0	0	99.82	0.01	0
Lanthanum	0	0	0	0.9	0.01	0
Lead	8,85,704	9323	8,95,028	1.21	0.68	7,36,429
Mercury	0	0	0	0	0.6	0
Molybdenum	0	0	0	23	0.3	0
Neodymium	0	0	0	50	0.01	0
Nickel	0	3,998	3,998	8.3	0.63	20,908

Palladium	0	0	0	35,316.5	0.55	0
Platinum	0	0	0		0.55	0
Plastics	58,78,955	49,850	59,28,806	1.3	0.25	19,26,862
Praseodymium	0	0	0		0.01	0
Silver	14,02,086	25	14,02,111	371.02	0.58	30,17,22,439
Steel/Iron	0	66,749	66,749	0.21	0.9	12,615
Tantalum	0	0	0		0.01	0
Terbium	0	0	0	589.83	0.01	0
Tin	21,488	402	21,890	15.8	0.75	2,59,394
Titanium	0	0	0	1.9	0.9	0
Tungsten	0	0	0	8.5	0.66	0
Vanadium	0	20	20	15.4		0
Yttrium	0	20	20	17.24	0.01	3
Zinc	5,775	0	5,775	1.46	0.5	4,216
PCB	0	0	0			0
Other	75,87,915	0	75,87,915			0
			0			0
Total recovery economic potential of secondary resources in CRT E-waste in California 2021						**30,67,84,517**