Data Science for Sustainability — Simulate a Circular Economy

Use data science to simulate the impact of a circular model on the CO2 emissions and water usage of a fast fashion retailer.

Samir Saci · Follow
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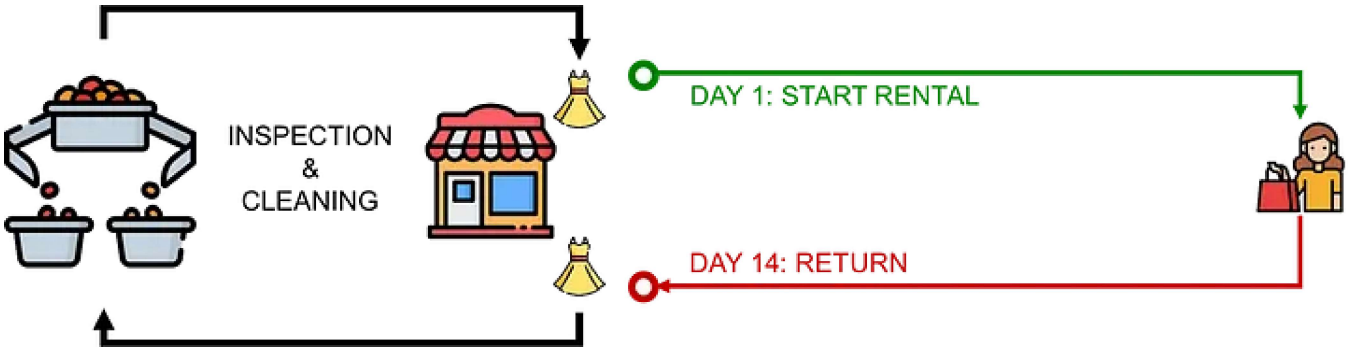
Rental Model — (Image by Author)

A circular economy is an economic model that aims to minimize waste and maximize resource efficiency.

It involves designing products and processes focusing on longevity, reuse and recycling.

Why not rent your dress instead of buying it?!

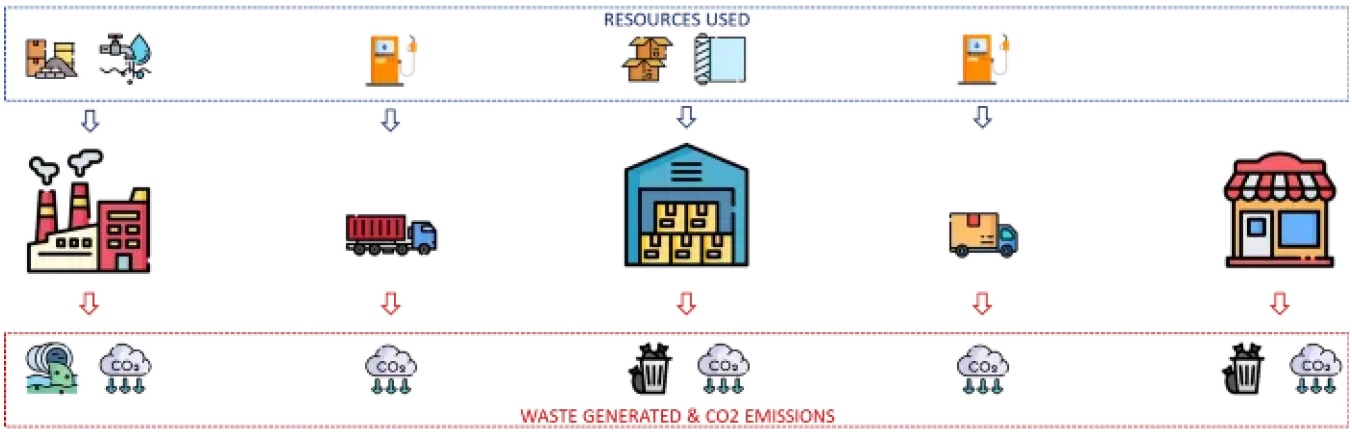
Several fashion retailers have implemented a **subscription model.**



Circular Rental Model — (Image by Author)

Customers pay a regular fee to access a product or service for **a specific period.**

The objective is to reduce the environmental impact along products' life cycles.



Product Life Cycle — (Image by Author)

Can you use data science to estimate the emissions reduction of an experimental rental model?

As a Data Scientist in the Supply Chain Department, you can build simulation models to assess the effectiveness of these initiatives.

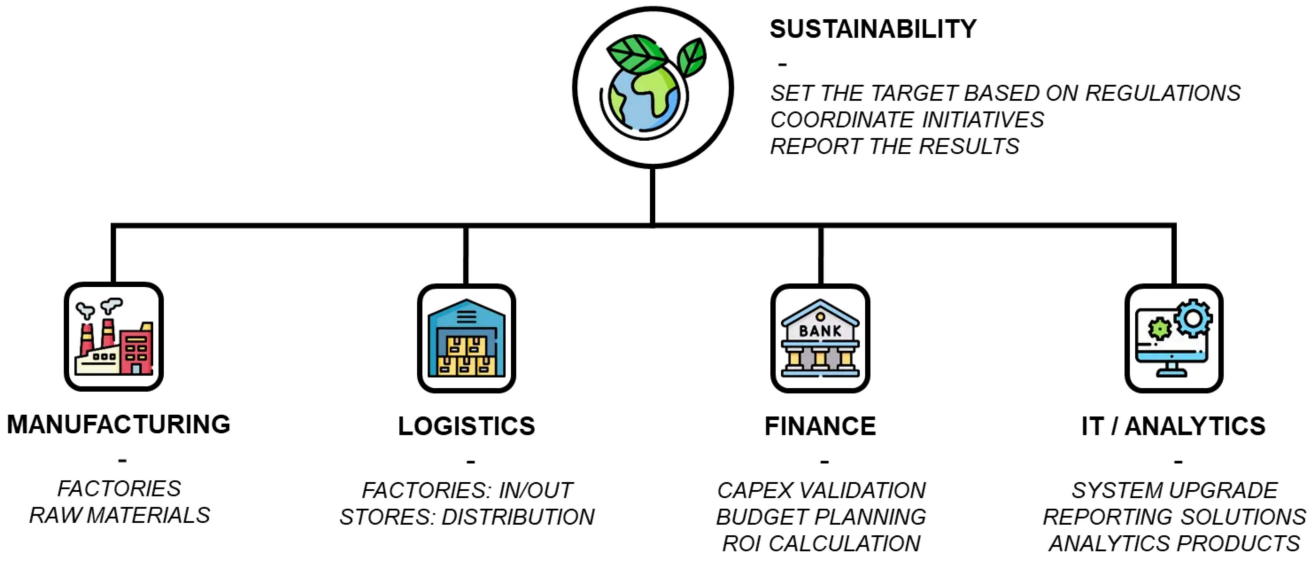
In this article, we will estimate the environmental impacts of implementing a rental model with **400 items** for a **fashion retailer**.

Circular Rental Models for Fast Fashion

Support the Decarbonization of your Supply Chain

You are the **Data Science Manager** in the Supply Chain department of an international **clothing group** with stores worldwide.

To support the United Nations Sustainable Development Goals, the company has committed to reducing its environmental footprint.



Project Team for the Sustainability Roadmap — (Image by Author)

Therefore, your colleagues from the **sustainability department** prepared a **roadmap** for carbon footprint reduction by 2030 involving several departments.

Among the initiatives, it has been decided to experiment with a circular economy model in **10 stores.**

If you are not familiar with the concept of circular, have a look at this article:

Data Science to Implement a Circular Economy

How can you use Data Science to support a Fast Fashion Retailer in Implementing a Circular Economy?

towardsdatascience.com

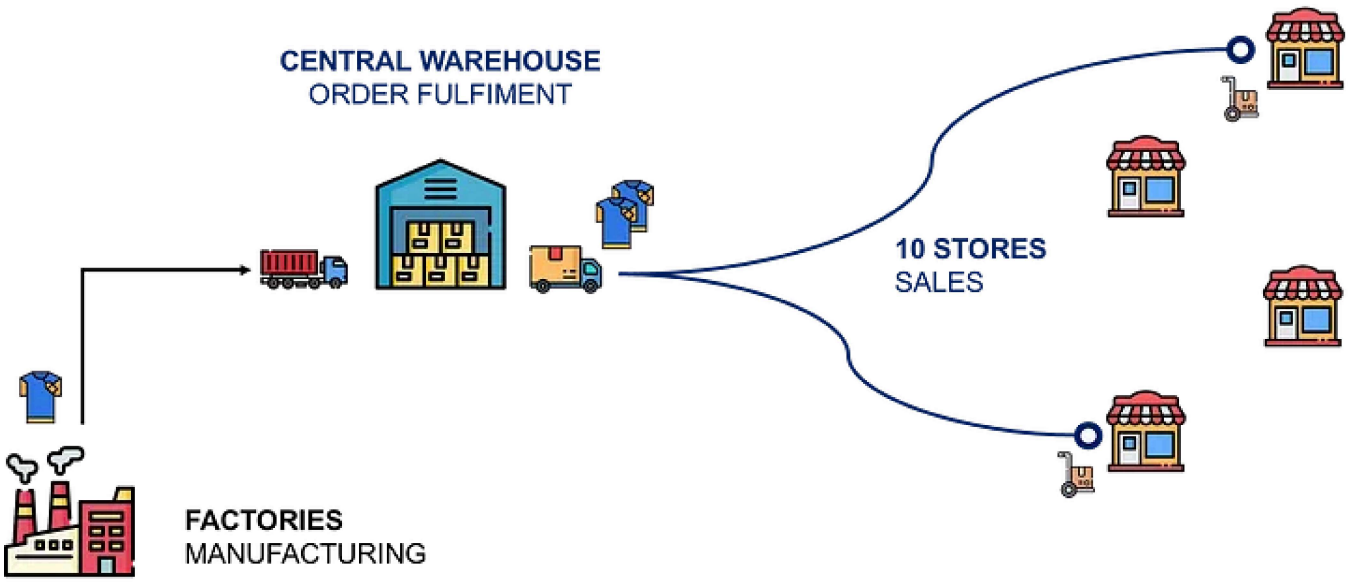
These locations will propose a **rental subscription model** to their customers for a limited scope of 400 items.

Before implementing this additional service, logistics and sustainability teams requested your support to estimate the emissions cuts we can reach.

Operational Assumptions

The inventory at the store is managed by distribution planners using an ERP.

- Stores are replenished by a Central Warehouse
- Factories replenish the Central Warehouse



Distribution Network — (Image by Author)

For this simulation, I will use the model designed for the article about Green Inventory Management, considering the following assumptions:

- **365 days** of sales transactions in **10** locations
- **3,300 active SKUs** with **400 SKUs** included in the circular model
- Inventory Periodic Review Policy Rule: **2 days**

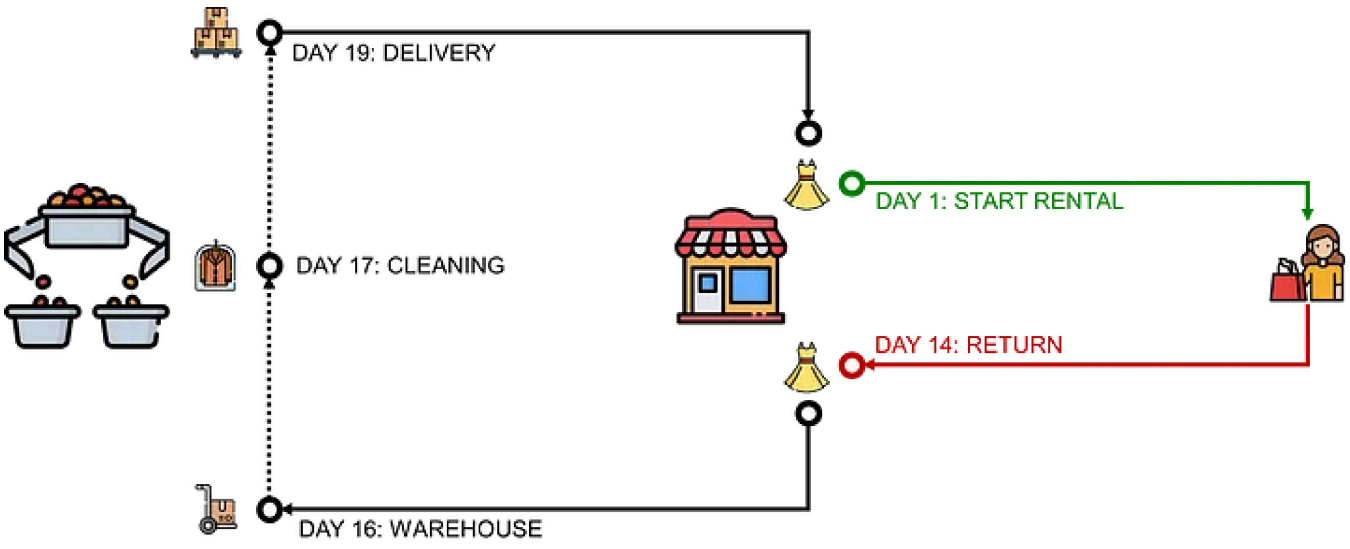
That means your stores are replenished every two days by the Central Warehouse.

Logistics Parameters — (Image by Author)

We will add the assumptions linked to the circular model

- Delivery Lead Time from Warehouse for Circular Items: **2 days**
- Cleaning & Inspection at Warehouse: **1 day**
- Return to Warehouse Lead Time: **2 days**

When an item is returned at the end of the rental period, it takes two days to ship it back to the warehouse.



Circular Process — (Image by Author)

Another day is needed to inspect and clean. And finally, it will be delivered back to a store after two additional days.

Now that we have introduced the assumptions, we can focus on the simulation.

Simulation Model of the Circular Model

The main parameter of our circular model will be the rental period.

> What is the optimal rental period to maximize the emissions reductions?

The objective is to test several rental periods to observe the impact on CO2 emissions and water usage reduction.

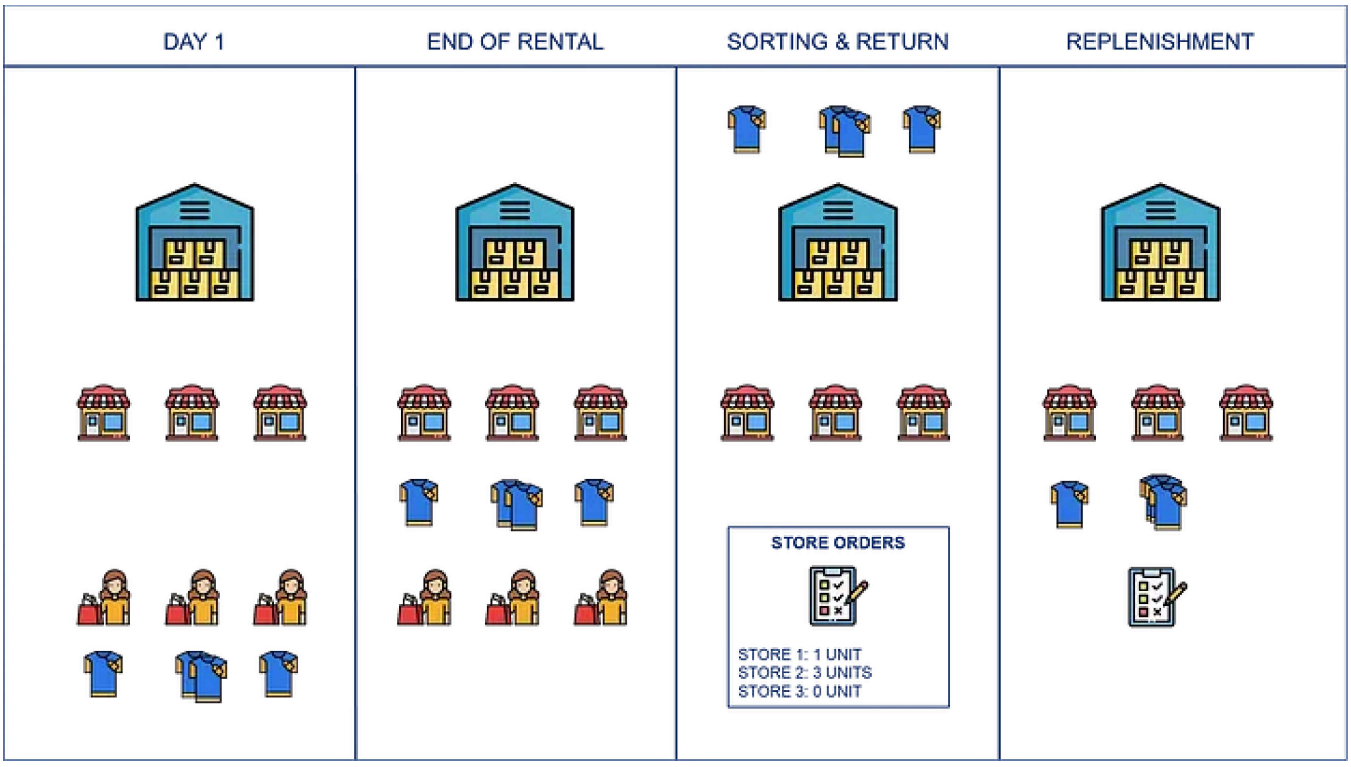
Inventory Management Model

Unlike a common linear model, our inventory will include two types of items.

If a customer is renting a dress, she may

- Rent a dress returned by a previous customer (after cleaning).
- Rent a new dress coming from the factory.

I will apply the First-In, First-out (FIFO) principle to orchestrate these flows to every store order.



FIFO Principle on the Circular Items — (Image by Author)

Taking the example above,

- After cleaning and inspection, these four returned items are available for order.
- Store 2 sent the first replenishment order with a quantity of 3 units.
- Store 1 sent later a replenishment order with a quantity of 1 unit.

Because **store 2** ordered first, the **first three units** that arrived in the warehouse stock will be shipped there.

If the returned product inventory is too low, orders are completed with new items.

These additional parameters have been included in the simulation model following the example I presented in the article below.

Green Inventory Management — Case Study

Sustainability How to Reduce the CO2 Footprint of Fashion Retail Logistics Operations by Reducing the Frequency of...

www.samirsaci.com

Estimate Savings with Life Cycle Assessments

To assess the performance of your circular economy, we focus on the

- Total CO2e emissions of your Supply Chain **(kg CO2e)**
- Quantity of water used to produce and deliver items to stores **(L)**

Linear (Top) vs. Circular Model (Bottom) — (Image by Author)

In the example above, we switch from 5 purchases to 5 rentals of this item.

The footprint of the circular model includes

- **A single full cycle** from raw material extraction to store delivery.
- **Four return cycles with** reverse logistics and cleaning process.

We can then estimate the savings using the formulas below,

CO_2 emissions of items sold via a linear model

$$CO_2(i,n) = Units_{CO_2}(i) * n$$

$Units_{CO_2}(i)$: CO2 emissions from production to delivery of SKU i

n : number of pieces of SKU i ordered by store j

CO_2 emissions of items sold via a circular model

$$CO2(i,j,k) = Units_{CO_2}(i) * j + Returns_{CO_2}(i) * k$$

$Returns_{CO_2}(i)$: CO2 emissions of the return process of SKU i

j : number of new items used for the circular model

k : number of items reused for the circular model

With,

$$n = j + k$$

CO2 emissions (Linear vs. Circular) — (Image by Author)

The major assumption behind this approach is that the percentage of items reused will drive the savings.

If you need more information about Life Cycle Assessments,

What is a Life Cycle Assessment? LCA

Learn how Life Cycle Assessment can help businesses evaluate the environmental impacts of a product over its entire...

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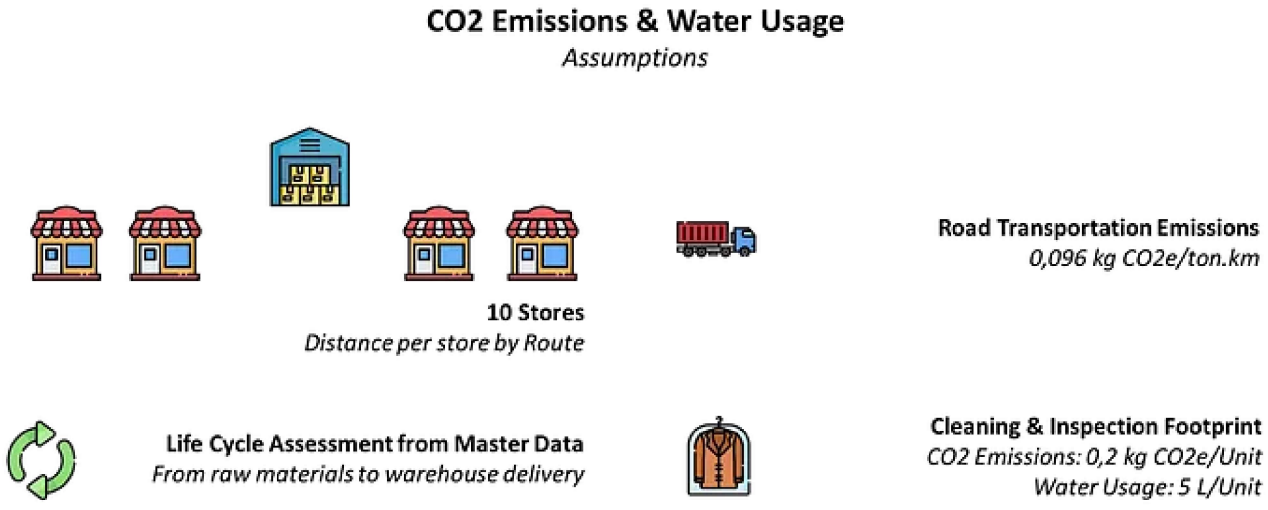
These formulas should be coupled with **life cycle assessment** metrics linked to each item in the scope of analysis.



Assumptions — (Image by Author)

- Emissions and water are taken from the master data.
- The additional impacts are estimated using the parameters listed above.

The remaining parameter that should be defined is the **rental duration**.

Simulation Scenarios

After discussing this with the merchandising and logistics teams, you have selected potential durations of **2, 7, 14, and 28 days.**

Using actual sales transactions, you will simulate the forward and reverse flows for each scenario.

Let us now see the results for these four different rental periods.

> Could you guess which period provides the highest emissions (and water usage) reduction?

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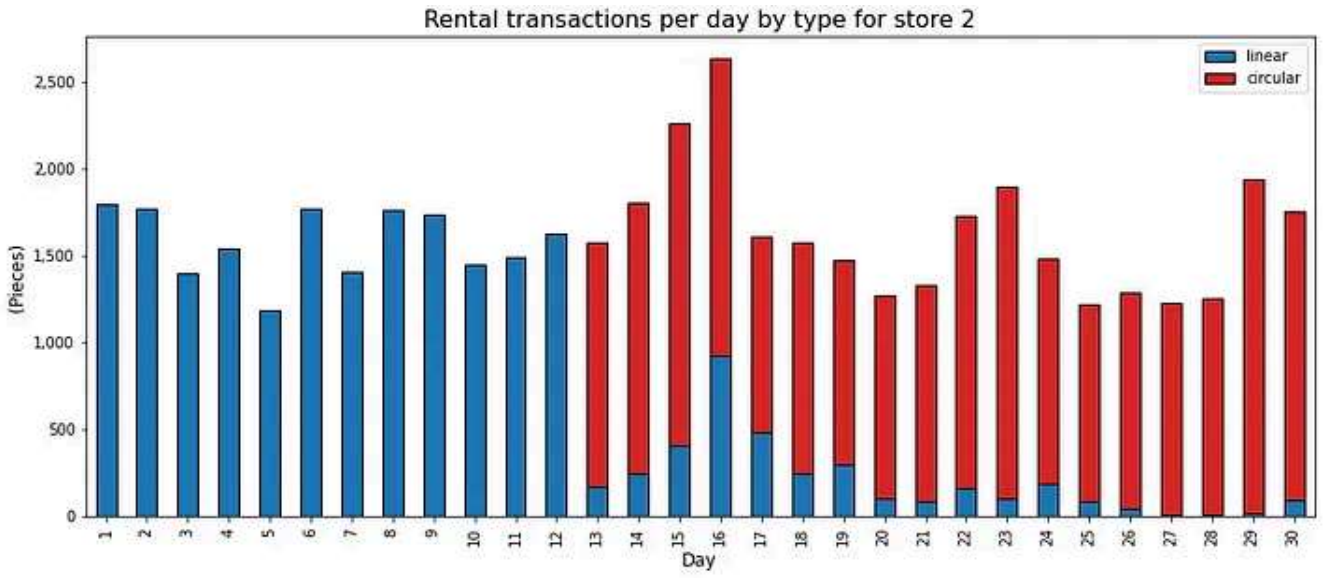
Simulation for a rental period of 7 days

Now that we have built our model with the right assumptions, we can start exploring the results with a **one-week rental period.**

The percentage of circularity

> What is the percentage of new items used?



Percentage of circular items per day for store 2 — (Image by Author)

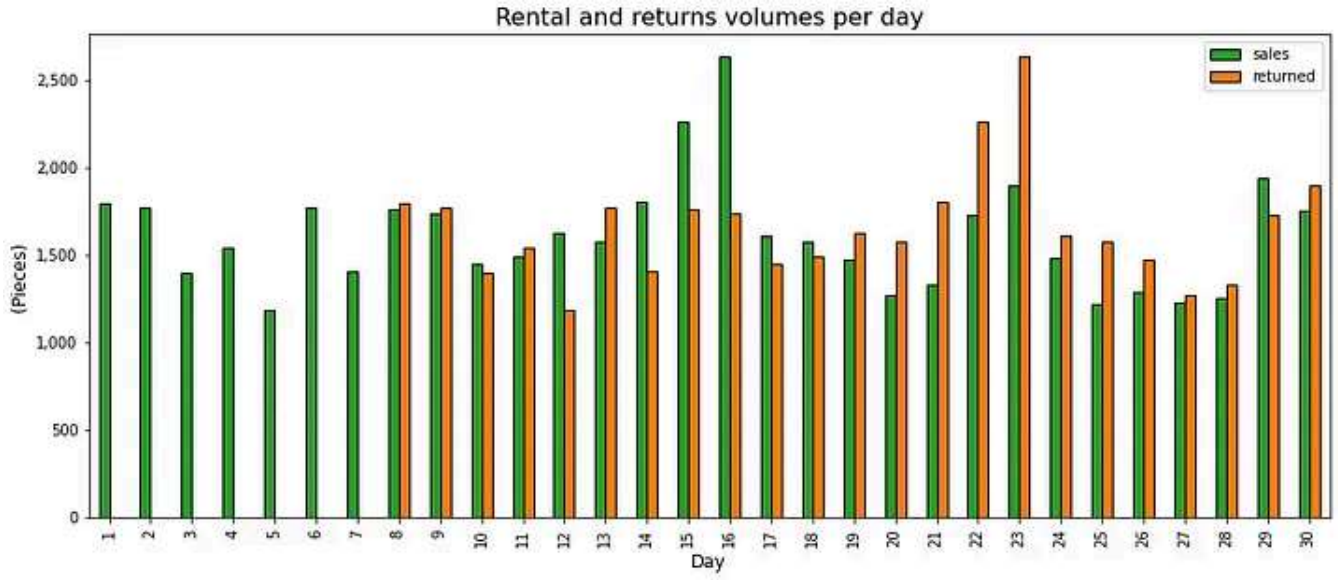
💡 Insights

- During the first 12 days, the inventory of returned items is zero, so the store is using **only new items for rental.**
- When there are volume peaks, like on day 16, the accumulated inventory of returned items cannot meet the demand.

The **percentage of circularity** (%) **is the** ratio of returned items for the rental transactions.

This is an important parameter influencing the environmental performance of your circular model.

During the first 12 days, the footprint of your rental model is the highest as we are using new items.

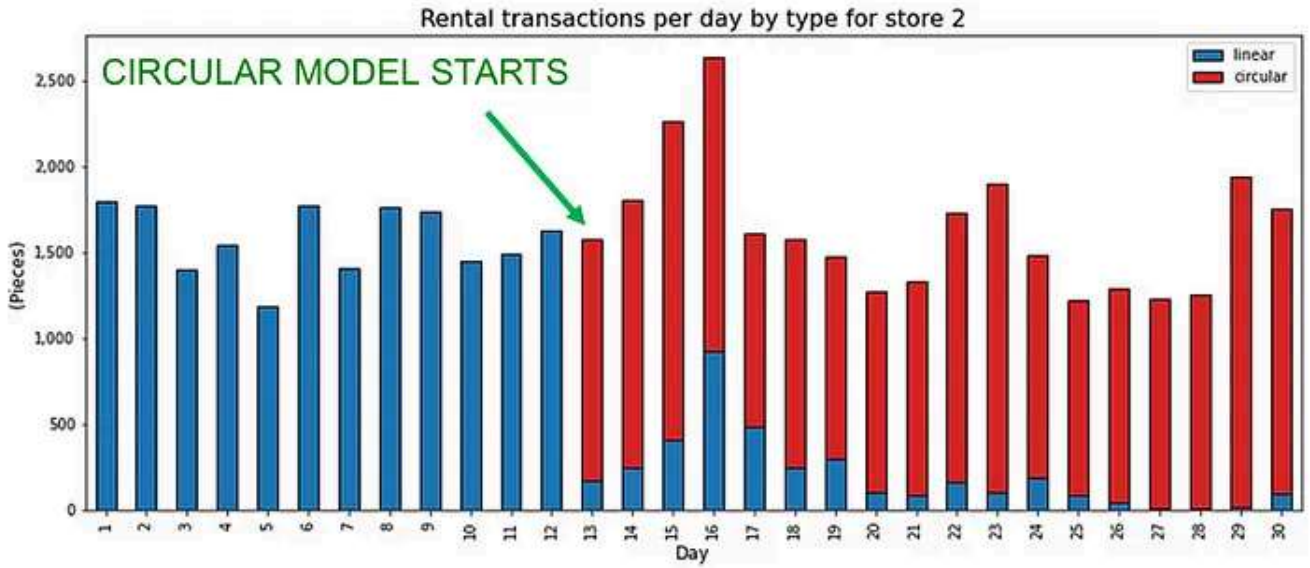


Number of returned items per day — (Image by Author)

This can be easily explained by looking at the volume of returned items.

Indeed, we can see that the first batch of rented items was returned **on the 8th day**.

After **5 days** for the return process (pick-up, cleaning and store shipping), they are available on **day 13** for new sales.

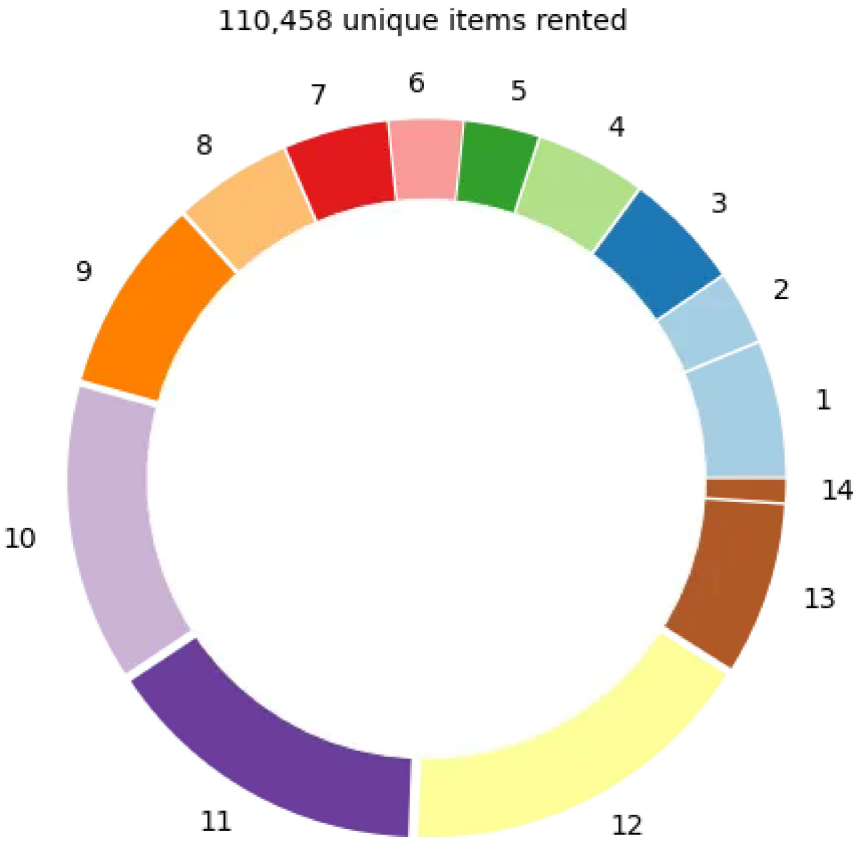


% of circular items increasing starting from Day 13 — (Image by Author)

From this day, we have a balanced distribution of rented and returned items to obtain enough inventory to reuse more than 75% of items.

How many times an item is rented on average?

This chart shows the distribution of items by the number of rental cycles along the simulation period.



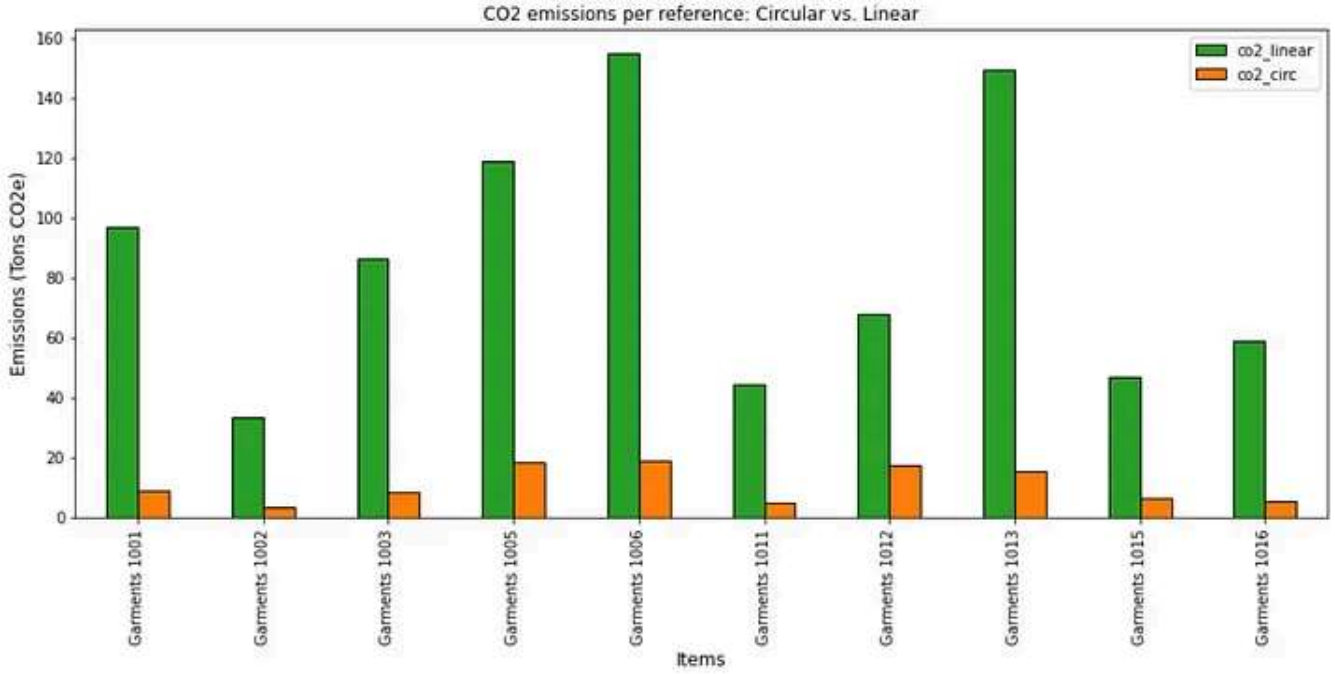
Number of cycles along the six months — (Image by Author)

For instance, 9.8% of items have been used 10 times.

💡 **Insights**

- **110,458 unique items** are used to fulfil **951,856 rental transactions**
  An average of 8.61 rental ***cycles per item.***
- Some items can reach **14 cycles.**
- A non-negligible part of the inventory is only used a single time.

What is the environemental impact for each item?



CO2 emissions for 10 SKU — (Image by Author)

Let us take the example of a coat rented to **35 customers** using only **10 unique pieces.**

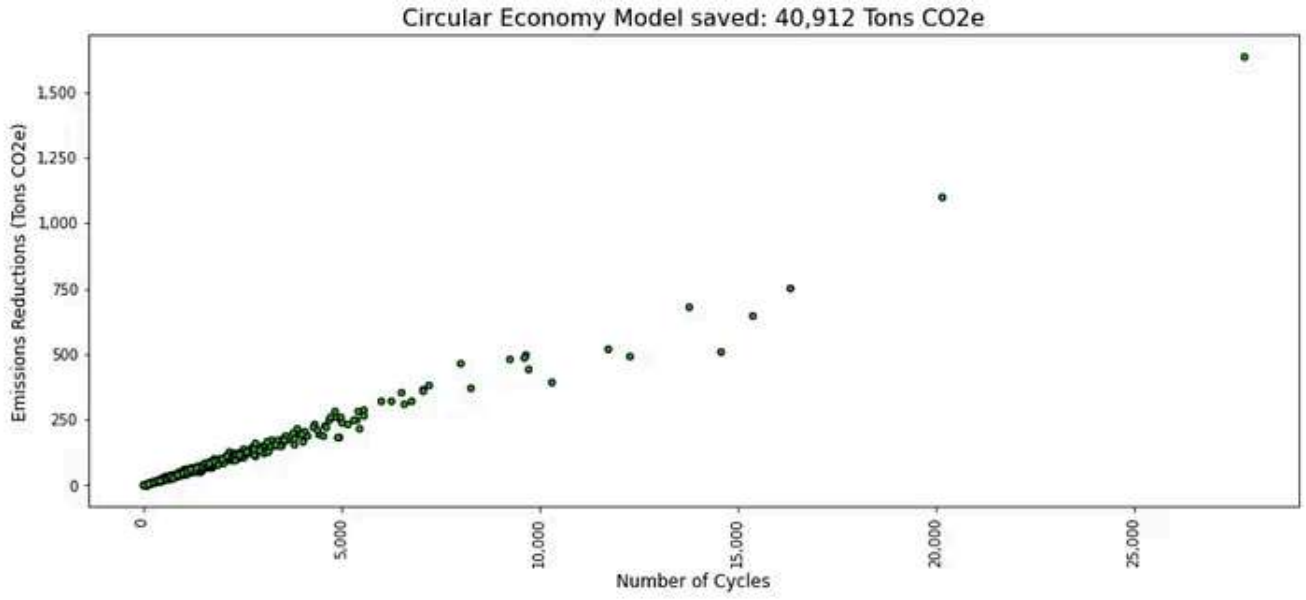
We define the linear model's emissions (**co2_linear** in green) as the total footprint if these customers **purchased** 35 coats items.

The circular model's emissions (**co2_circ** in orange) only include the production of **10 unique coats** and the **logistics for return management.**

Is there any correlation between emissions reductions and the number of rental cycles?

What is the impact of demand variability?

As expected, the amount of CO2e reduction is linearly linked with the number of cycles.



CO2 Emissions Reductions = f(Cycles) — (Image by Author)

What does impact the percentage of reused items?

Therefore, we would like to reach **100% of rental transactions** with reused items and limit the number of **new items purchased**.

What influences the percentage of transactions with reused items?

When demand is highly volatile, the inventory of returned items is quickly finished. Therefore, you need to purchase newly produced items.

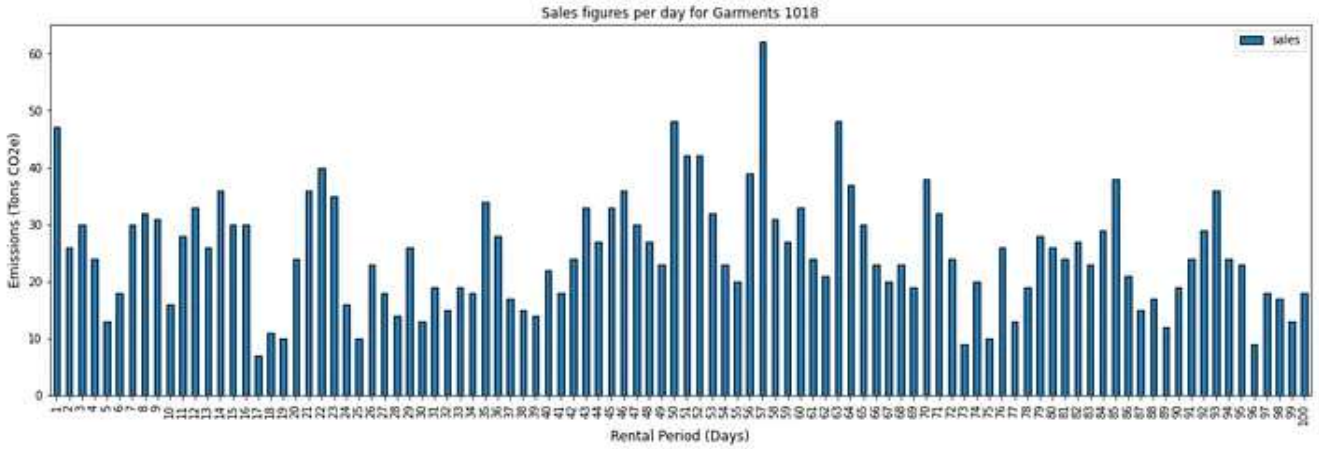
Example of High Variability Demand SKU — (Image by Author)

In the example above, the demand distribution is highly skewed.

- 60% of the total demand for this reference occurs at the peak of day 105
- Therefore, the percentage of circularity (number of sales transactions fulfilled with reused items) is **only 40%.**

What if we have a stable demand?

The bar chart below shows the sales distribution of the **SKU Garments 1018**; this high runner has a stable distribution.



Example of Low Variability Demand SKU — (Image by author)

- Except for the first days, the demand distribution provides enough flexibility to build an inventory of returned products.
- Therefore, we can reach **89%** of sales transactions with reused products.

With these two examples, you start to understand the correlation between demand variability and the coefficient of circularity.

Introduction of the coefficient of variation

Let me introduce the Coefficient of Variation CV:

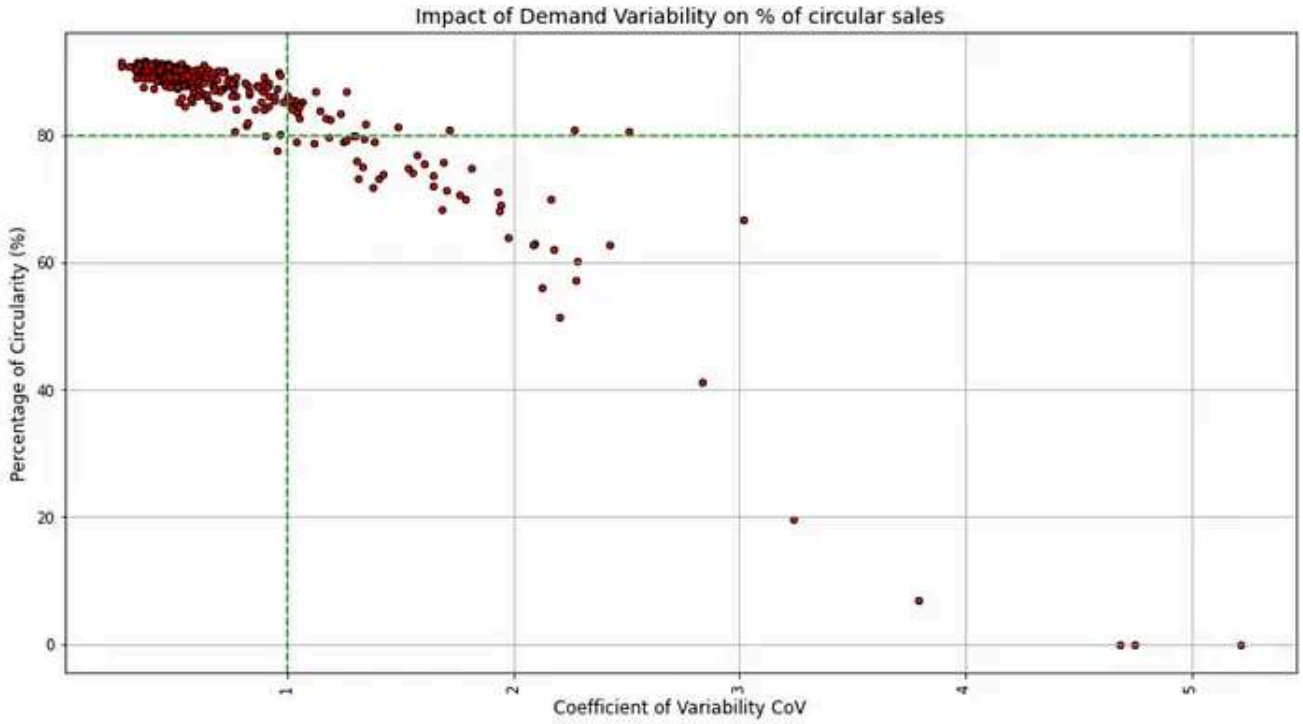
$$Coefficient\ of\ variation\ :\ CV$$
$$CoV = \frac{\sigma}{\mu}$$

$$\sigma\ :\ standard\ deviation\ of\ the\ demand$$
$$\mu\ :\ mean\ of\ the\ demand$$

Coefficient of Variation — (Image by Author)

A demand distribution can be considered volatile when CV > 1.

> What is the variability of the 400 items included in the scope?

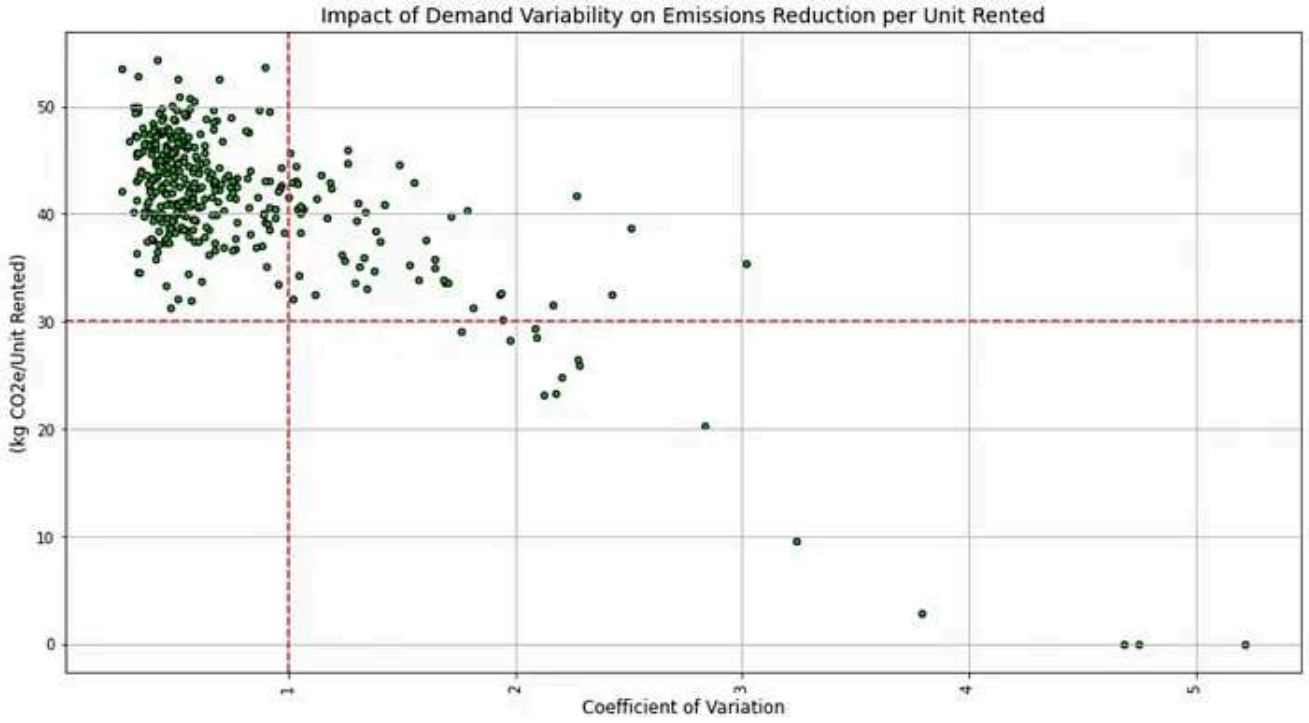


(Image by Author)

💡 **Insights**

- **99.9%** of items with **CV<1** have a percentage of circularity sales higher than **80%**
- However, some items with **CV > 1.5** have a percentage of circularity higher than 70%.

Logically, we can see the impact on the emissions reduction per item rented,



Emissions per Unit = f(CV) — (Image by Author)

💡 Insights

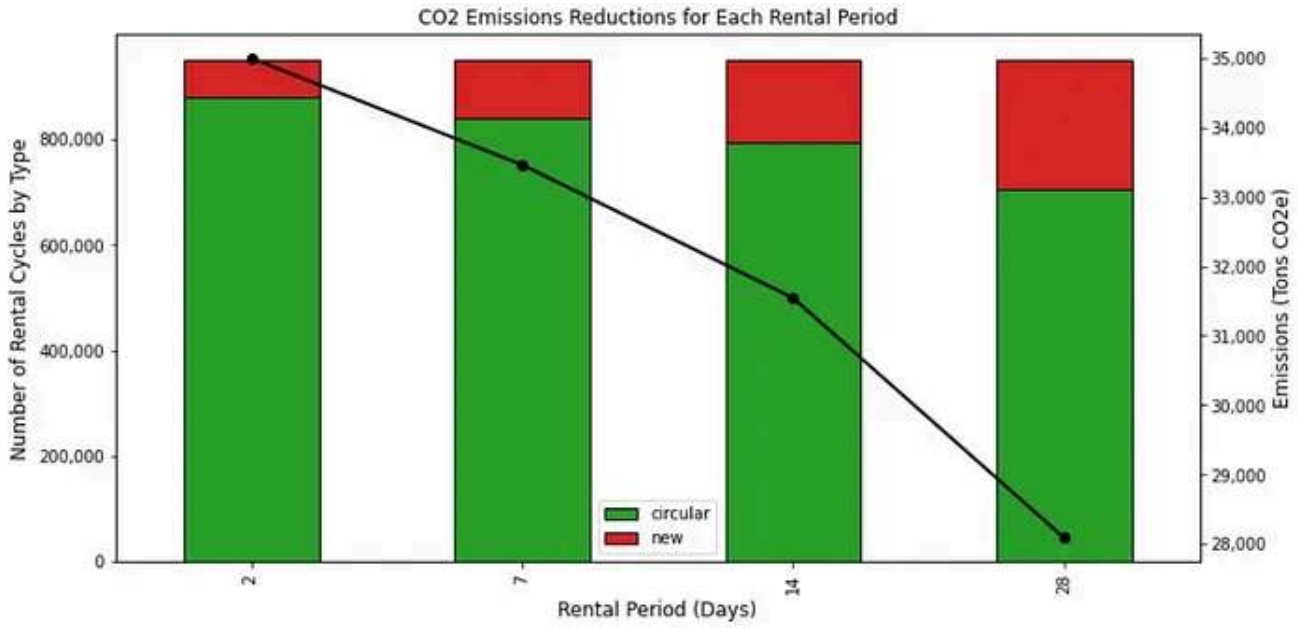
- 100% of items with **CV<1** have a reduction higher than **30 kg CO2e per Unit Rented.**

As we do not control the demand variability, let's explore the idea of increasing the emissions reductions by **changing the rental period.**

Simulation with several rental periods

In the previous section, we simulated a rental period of **7 days.**

We can now run the model with rental periods between **two** and **twenty-eight days.**

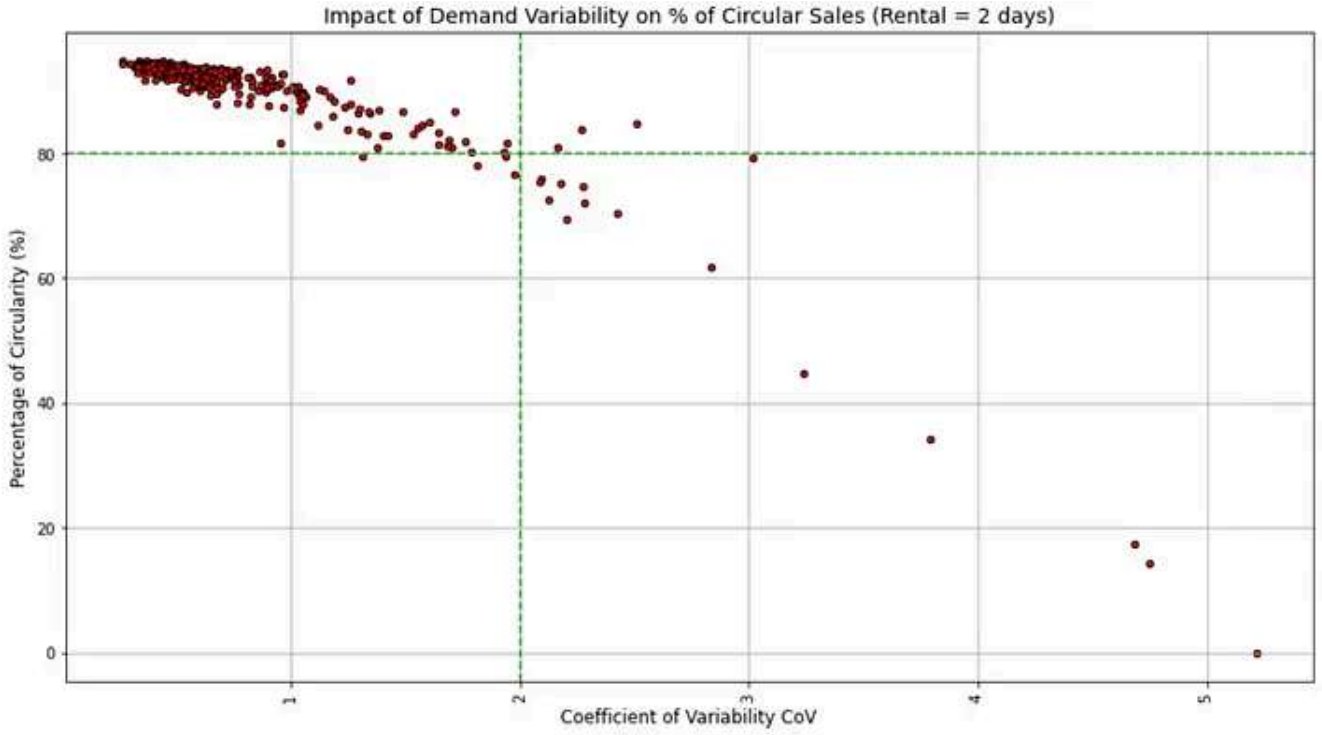


CO2 emissions reductions for each scenario — (Image by Author)

💡 Insights

- The reduction level drops when you increase the rental period.
- The optimal rental period is 2 days, with emissions cut reaching 35k Tons CO2e.
- Increasing the rental period reduces the percentage of circular items used.

This can be verified by looking at the percentage of circularity of items with a rental period of 2 days,



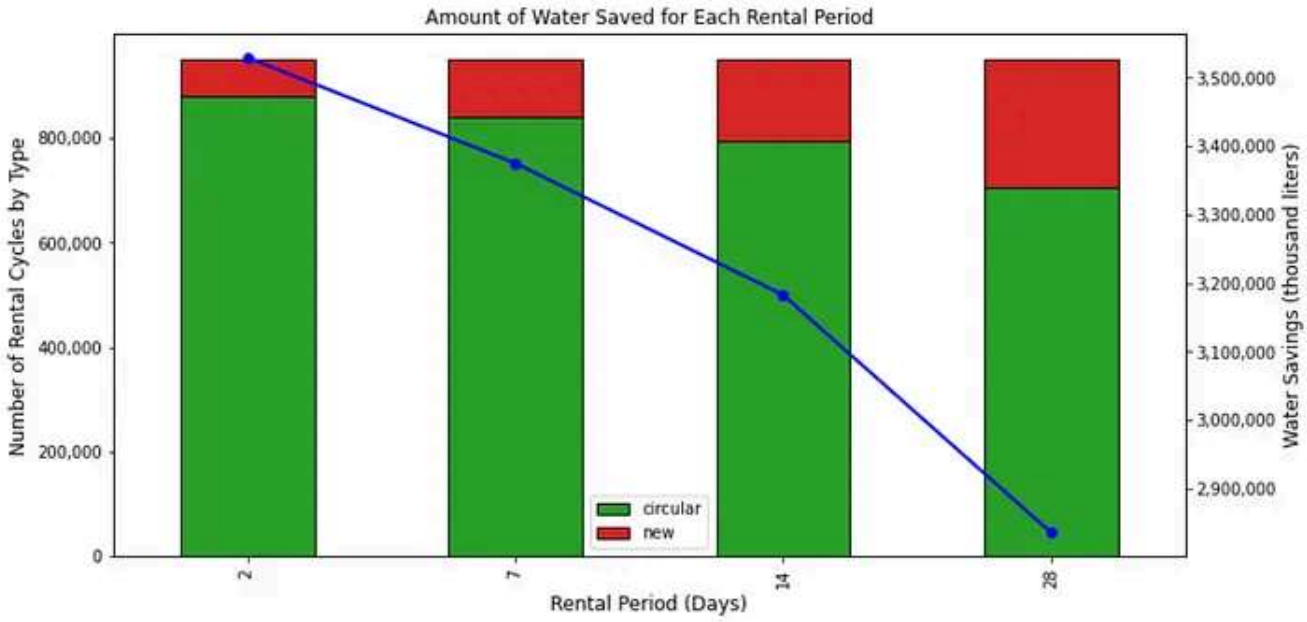
Impact of Demand Variability with now (Rental = 2 days) — (Image by Author)

💡 Insights

- **99%** of items with **CV < 2** have more than 80% of their rental transactions fulfilled with reused items (versus CV<1 for rental period = 7 days)

That means a **short rental period** provides **more flexibility** in dealing with demand variability.

Without any surprise, we can see the same trend with the amount of water saved,



Water Savings — (Image by Author)

With longer rental periods, item availability for a rental is dropping.

Thus, you are losing inventory flexibility to absorb demand variability.

Rental Period	Rentals	New	Circular		CO2 Reduction		Water Savings	
Unit	*(Pieces)*	*(Pieces)*	*(Pieces)*	*(%)*	*(Tons CO2e)*	*(%)*	*x 1000 Liters*	*(%)*
2 days	951 856	71 940	879 916	92%	34 997	75%	3 529 275	92%
7 days	951 856	110 458	841 398	88%	33 460	72%	3 375 037	88%
14 days	951 856	158 538	793 318	83%	31 543	68%	3 182 656	83%
28 days	951 856	245 076	706 780	74%	28 092	60%	2 835 880	74%

Summarized Results — (Image by Author)

However, your circular model's performance remains impressive for a rental period of 28 days (60% CO2 reduction vs. a linear model).

This table can help to drive discussions and find the balance between commercial requirements and sustainability targets.

Conclusion

Even in the worst-case scenario, a rental period of **28 days**, we can achieve a **60% reduction** in CO2 and **-74% reduction in water usage.**

That means the additional emissions due to the logistics of returned products are not offsetting the savings generated by reusing your products.

However, this assumes that stores and logistics operations can manage this rental process for 400 items.

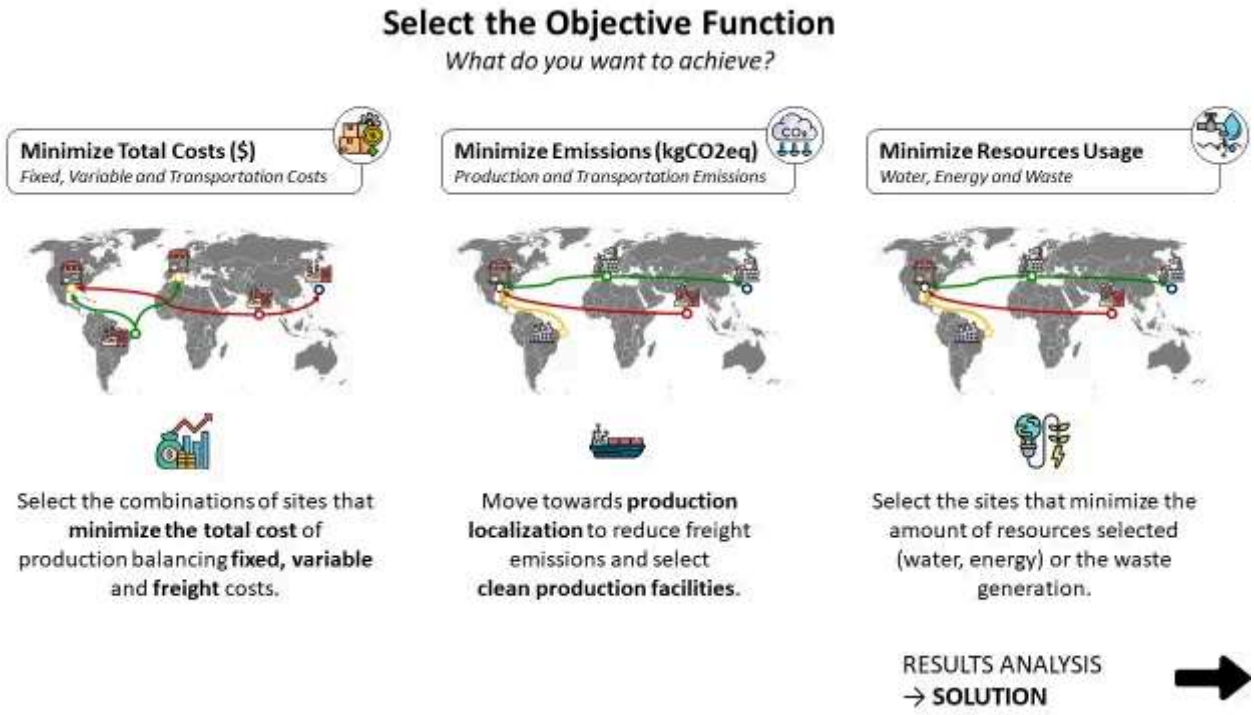
Additional parameters would be needed to have a complete assessment,

- Additional staff and systems to manage the return flows
- Additional packaging or handling material needed?

Supply Chain Network Optimization

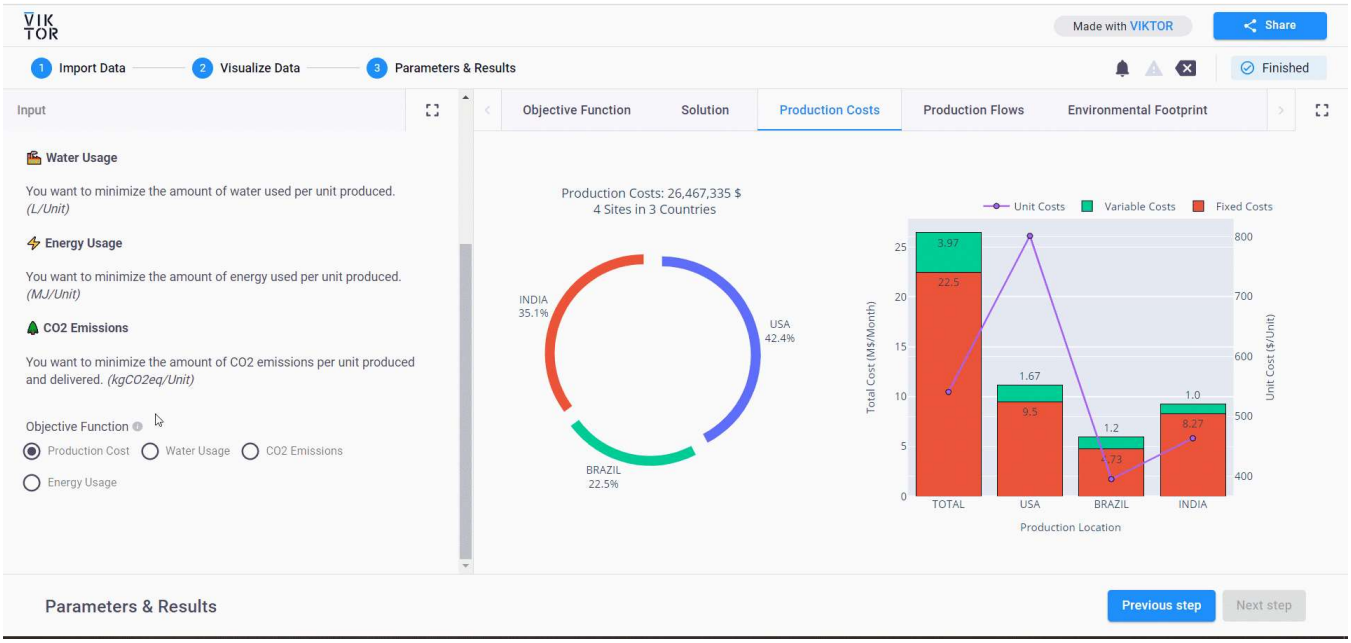
To go beyond, you can explore solutions to reduce the environmental impact of the upstream flow *(Sourcing, Production and Delivery to the Warehouse)*.

> What is the optimal network of factories to minimize CO2 emissions, Water Usage or Production Costs?



Supply Chain Network Design Problem — (Image by Author)

Sustainable Supply Chain Optimization is an approach to network design that integrates economic constraints and environmental indicators.

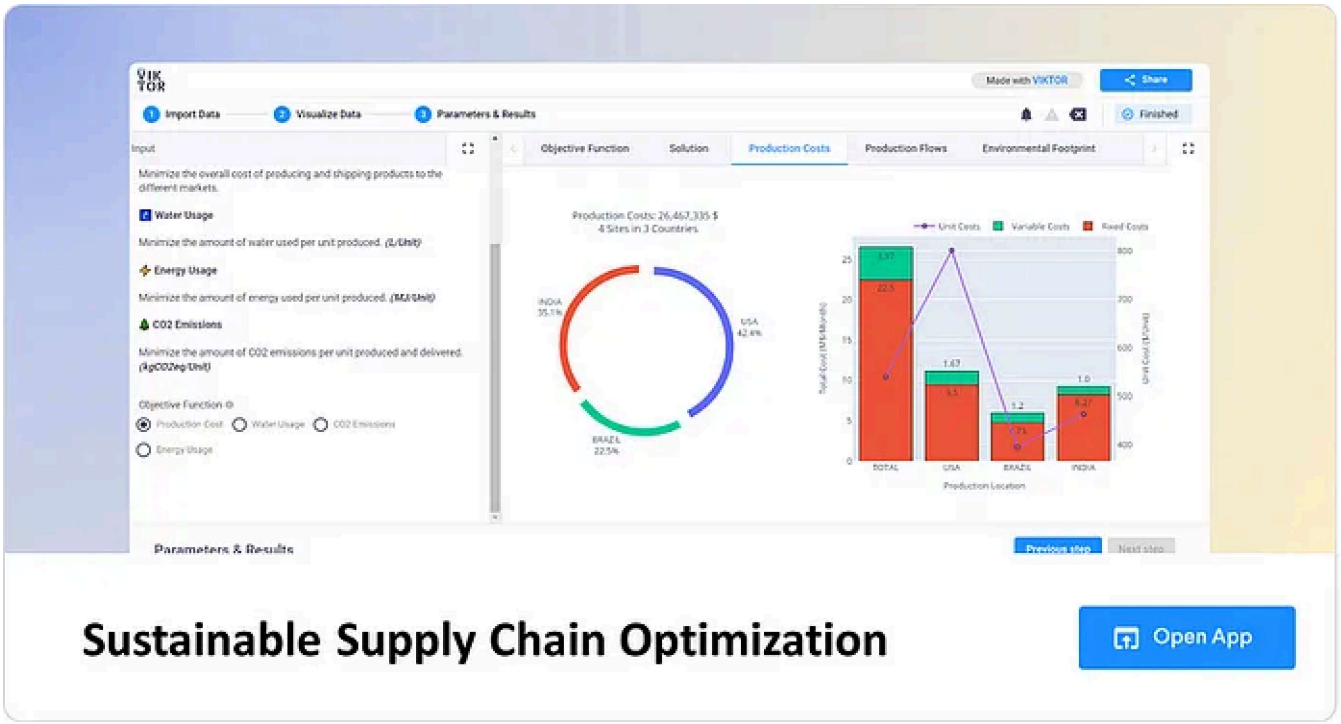


Sustainable Supply Chain Optimization [Try it: App] — (Image by Author)

In a previous article, I introduced a web application that supports supplier selection to **minimize the environmental impact** of the supply chain.

This solution can be combined with the circular model to maximize footprint reductions and optimize resource usage.

🚀 Try the app now!



Access the Application to try it! — [App]

Impact of Demand Variability

The percentage of rental done with reused items is linked with the variability of your demand.

Assuming that we want to maximize this overall score, we should explore a solution that adapts the rental period to the **demand variability**.

We can have longer rental periods for the items with stable demands without impacting the overall performance.

About Me

Let's connect on LinkedIn and Twitter. I am a Supply Chain Engineer who uses data analytics to improve logistics operations and reduce costs.

If you are interested in data analytics and supply chain, please visit my website.

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References

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- “Carbon footprint of garment cleaning and laundry services: A review” by T. Randell, M. Sohail, and M. Reynolds (Journal of Cleaner Production, 2016)

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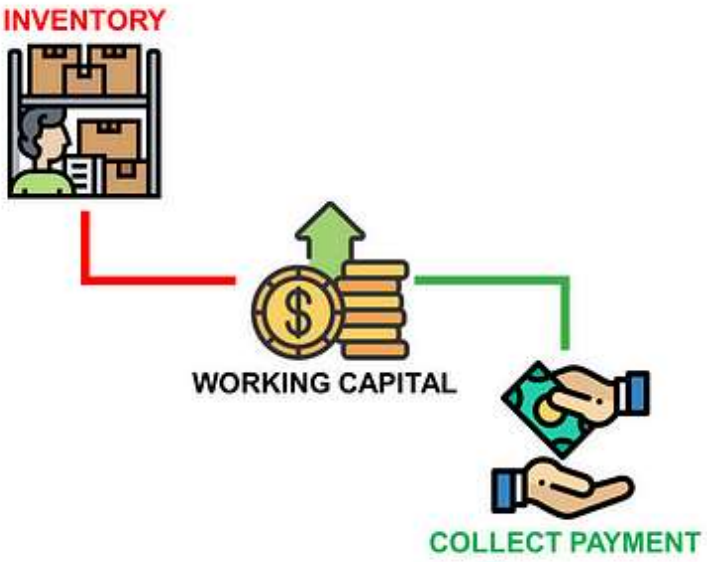

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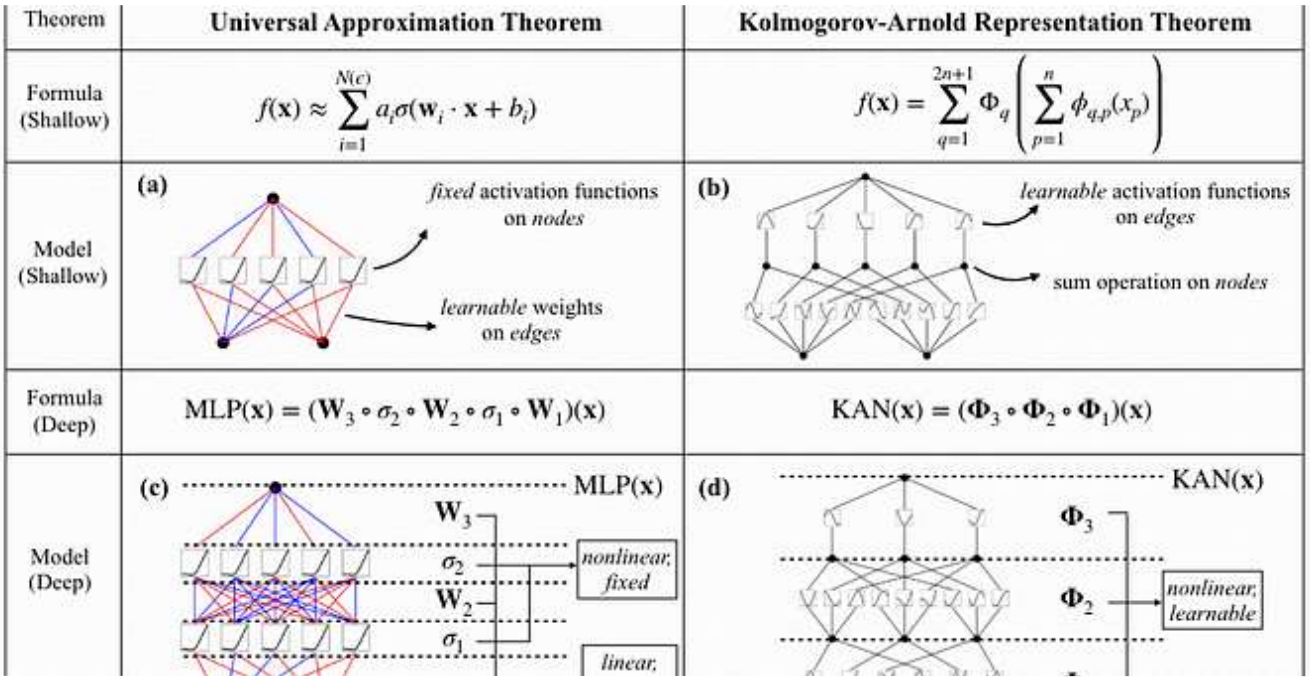

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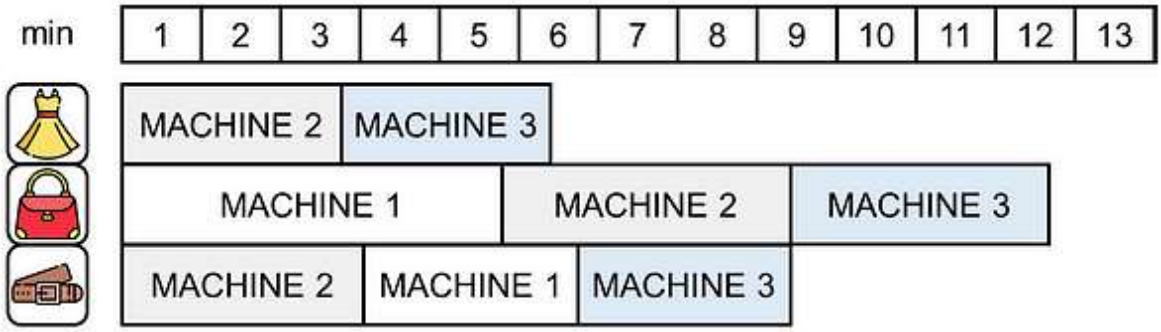

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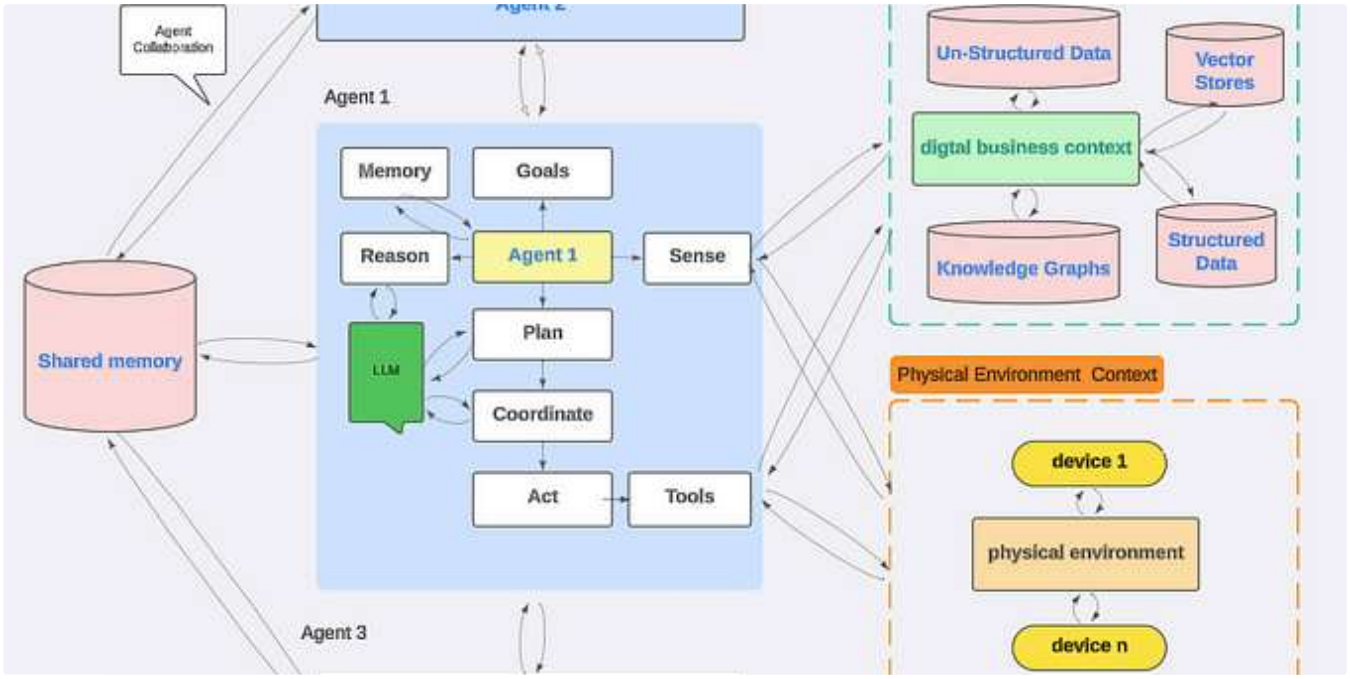

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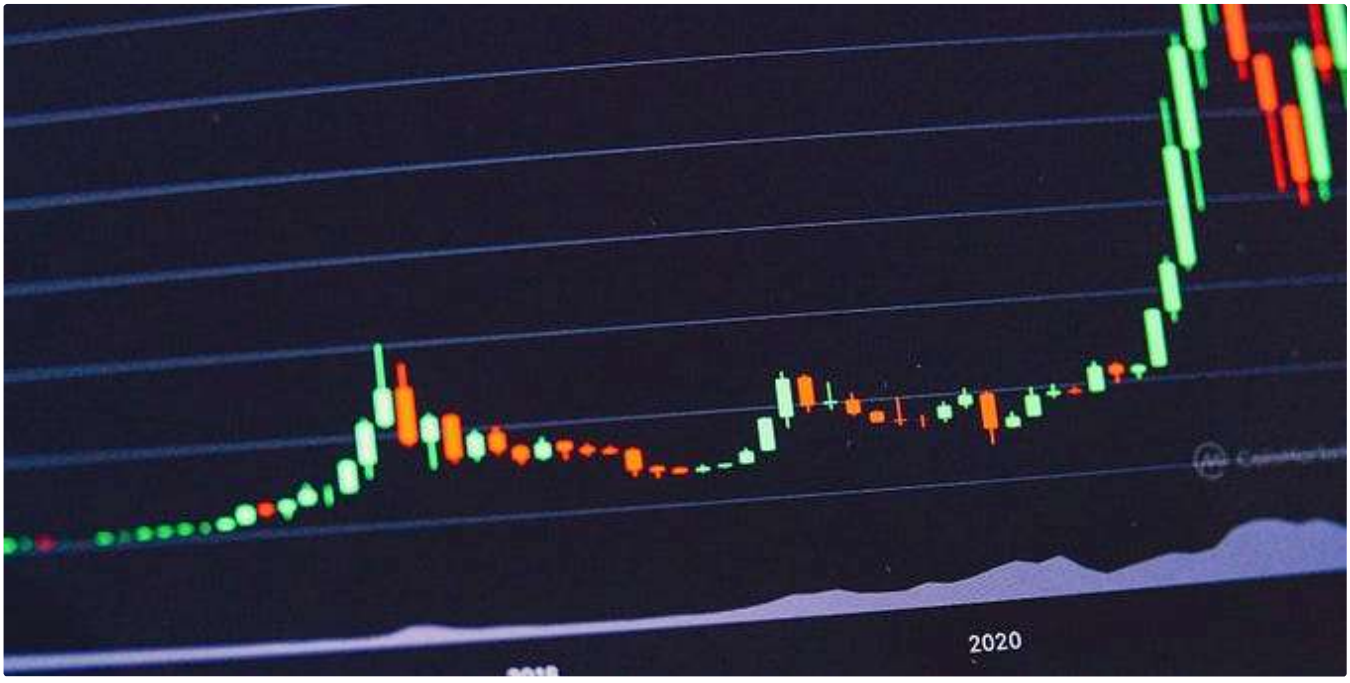

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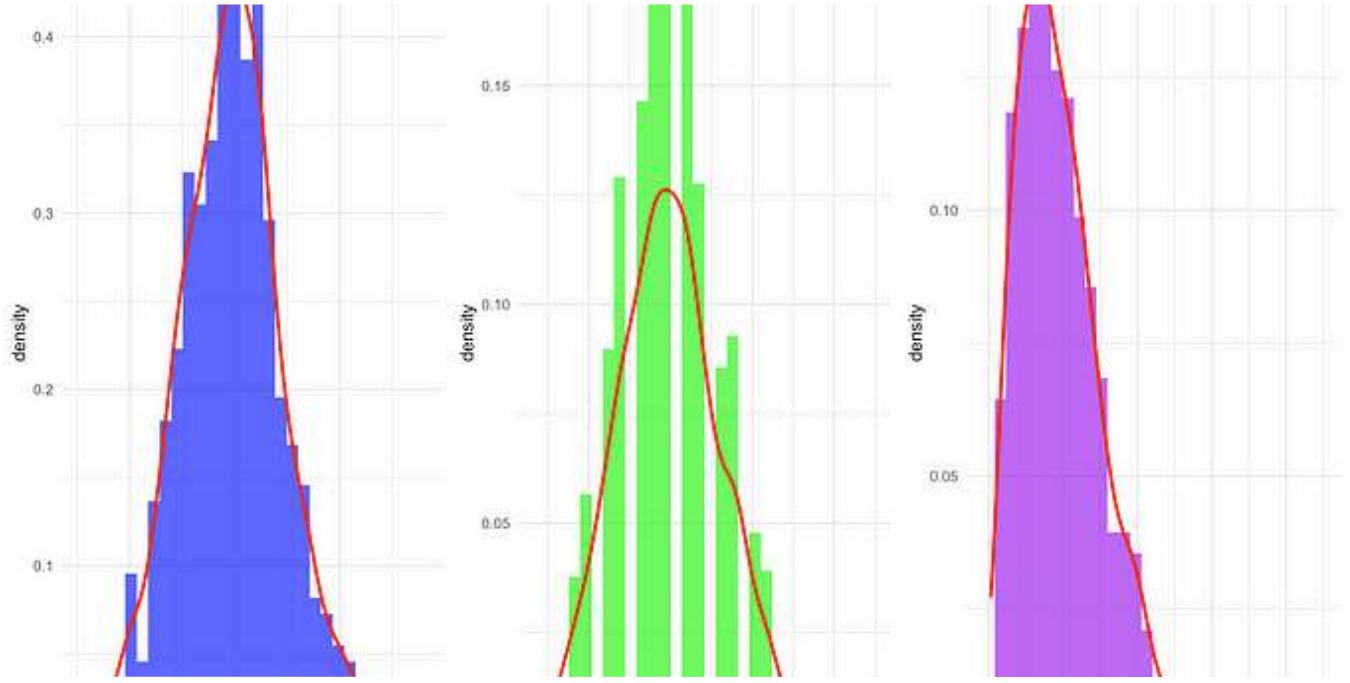

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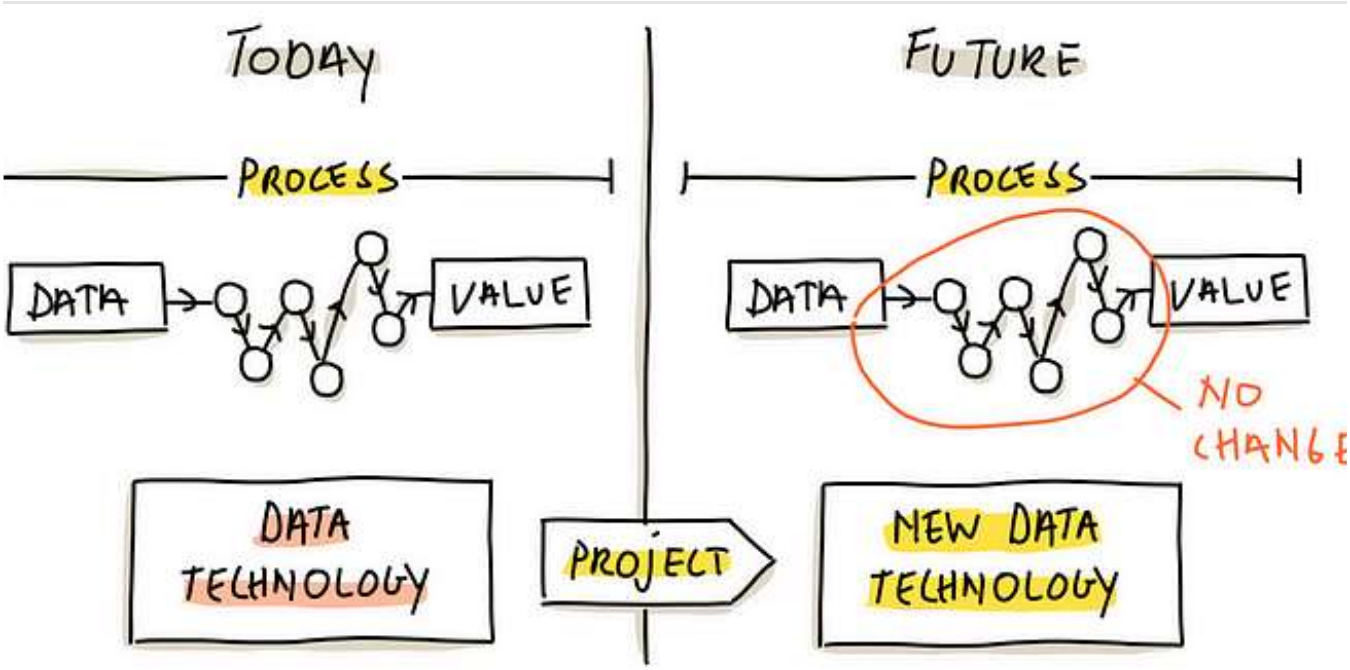

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