Economic, environmental and technical recycling of plastics in the automotive industry

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Abstract. This paper talks about the use of recycled polypropylene (pp) with fiberglass or calcium carbonate for the production of automotive spare parts . it illustrates the problem of global plastic waste by focusing on production of light weight and strong materials suitable for applications like side mirrors , wheels cover, door trims within the automotive industry. This process involves mixing recycled pp with additives to create high performance using techniques like : thermoforming, silicone molding, 3d printing and injection molding. With quality testing and characterization by ftir,dsc, melt flow index and density to ensure the codes and standards. This project promotes sustainability objectives to decrease the use of virgin material and reduce cost and reduce environmental impact to encourage sustainable manufacturing.

1. Introduction

The international car enterprise is challenge to sizeable modifications because of technological advances, environmental rules and elevated call for for sustainable substances. [1] One of cutting-edge maximum essential demanding situations is the elevated trouble of plastic waste and its dangerous outcomes at the environment. [2] With over 350 million tonnes of plastic produced yearly across the world, recycling and reuse of those substances has emerge as extraordinarily essential in fighting environmental degradation. A promising technique to the usage of recycled polymers which includes polypropylene (PP) in car programs to lessen waste, preserve resources, and decrease CO2 footprints with severa examined solutions. In the car enterprise, it's far appreciably disbursed because of its cheaper and easy houses, high-quality mechanical houses and easy processing. [4] Currently, over 50% of automobiles in a car are product of polypropylene, indicating that it's far critical for the manufacturing of diverse additives together with bumpers, door panels, and facet mirrors. Despite its advantages, multiplied intake of PP ends in large-scale waste batteries that require green recycling methods. This task will make stronger them with fillers together with glass fiber and calcium carbonate to increase sustainable car elements which are uncovered to recycled polypropylene and feature progressed mechanical and thermal performance. This trouble is addressed via way of means of the function of reinforcements in enhancing the residences of recycled PPs. Glass fibers beautify the strength, stiffness and effect resistance of the polymer, ensuring they're appropriate for extraordinarily interesting packages together with facet mirrors and door handles. Calcium carbonate, on the alternative hand, gives cheaper reinforcements that enhance size balance and warmth resistance. [8] By incorporating these materials into recycled polypropylene, this project aims to create components that meet or exceed the performance requirements of virgin polymers in automotive production. of manual technology and laboratory measurements for the production of automotive components. [10] Silicon gum foam is used to irrigate parts and provide an accessible, inexpensive alternative to traditional spray layers. [11] This process ensures efficient use of recycled materials without advanced industrial machinery according to the mechanical and thermal properties of the developed composite materials. Tests such as Fourier transform infrared spectroscopy (FTIR), differential scan calorimetry (DSC), melting flow index, and sealing are performed to ensure the quality and compliance of industry material standards. These checks are of critical importance for optimizing formulation and processing parameters to achieve high performance sections.

2.Automotive Plastics and Sustainability Approach

2.1 Plast Plastic is ubiquitous, however tough to define.

The time period plastic is usually known, however given that plastic become developed, it has now no longer been smooth to explain for maximum people [7]. Nevertheless, there are a few definitions, however a few very unique and consequently extra restrictive than others. It can be his talent in objects, films, or filaments as herbal substances together with bitumen. The definition of plastic also can be accommodated, and it's miles essential to differentiate among herbal and artificial plastics [2]. Furthermore, plastics from petrochemicals together with crude oil, coal, and herbal fueloline are produced. Bridson [5], one of the maximum famous authors of plastics in general, emphasised the invention of rubber withinside the nineteenth century as a trifling place to begin for plastics, as this fabric become an vital predecessor to the plastic industry. It's there. Inventors together with Charles Goodyear and Thomas Hancock have carried out considerable studies on rubber, main to the improvement of substances together with volcanoes, ebonites

2.2Factors Influencing Plastic Use: technological Advancements: Innovations in plastic processing and programs in numerous industries, specially automotive.

Market Demand: Increasing call for for lightweight, long lasting substances in automobile manufacturing.
Environmental Considerations: The want for sustainable practices in plastic manufacturing and recycling. (Plastic is al fabric which incorporates as an important factor a excessive polymer and which, for the duration of its processing into completed products, may be formed via way of means of flow. Elastomeric substances, which can be additionally formed via way of means of flow, aren't taken into consideration to be plastics. (ISO 2013) A polymer is a "excessive molecular weight molecule, herbal or synthetic, whose chemical shape may be represented via way of means of repeated small gadgets which together shape molecular chains.... This cloth elegance has 3 primary sub-groups: elastomers, thermoplastics and thermosets." (a hundred and fifty 2011).An elastomer is a "macromolecular cloth which returns unexpectedly to its preliminary dimensions and form after enormous deformation via way of means of a susceptible pressure and launch of the pressure. [16] The definition. applies beneathneath room temperature check conditions, the distinction among the call for (57Mt) and the converter call for (45.9Mt) of plastics in Europe because of import and export trading. This plastics call for is essentially that specialize in sure styles of plastics. In fact, the maximum outstanding plastic sorts in regards to marketplace proportion withinside the EU-28+N/CH in 2015 are in line with Plastics Europe (4):
low density PE (PE-LD) and linear low density PE (PE-LLD) [17.3%] excessive (PE-HD) and medium density PE (PE-MD) (12.1%) polypropylene (PP) [19.1%], polyvinyl chloride (PVC) (10.1%) polystyrene solid (PS), expandable (PS-E) [6.9%] polyurethane (PUR) [7.5%] polyethylene terephthalate (PET) [7.1%] others [19.9%], These styles of plastics constitute the European plastics call for with the 3 maximum produced styles of resin being polyethylene (29.4%), polypropylene (19.1%), and polyvinyl chloride (10.1%) [20].

2.3 The Life-Cycle of Plastics

To understand the life cycle of plastics, it is essential to examine the manufacturing stage, usage phase, and end-of-life phase. According to Jean-Charles et al. [15], as illustrated in their study, plastic production relies on crude oil as a source of hydrocarbon monomers, various forms of energy, and additives required for the polymerization process. This production process is governed by multiple legal regulations within the European Union, including the "Registration, Evaluation, Authorization, and Restriction of Chemicals" (REACH) (European Commission DG Enterprise and Industry 2014b) and the "Restriction of Hazardous Substances Directive" (RoHS) [4], which aim to limit hazardous substances. Once produced, plastic materials are molded into the desired shape to create the final product.
Following the usage phase, plastic products turn into post-consumer waste, which can be collected for further waste management. One option is "incineration," which allows for energy recovery from the plastic material. Another option is "landfilling," where plastic waste is stored, though this method has the drawback of generating emissions [10].

3.Experimental Part

3.1Materials:

Black plastic sheets (Polypropylene or ABS), Thermoforming machine, Mold for the desired part (side mirror casing), Polypropylene resin, Two-roll mill machine, Compression molding machine.

3.2 Procedure: Thermoforming Process

1. The plastic sheet is clamped and heated to the required temperature (usually 150-180°C for polypropylene).
2. The softened plastic sheet is placed over the mold inside the thermoforming machine.
3. Vacuum is applied to force the sheet to conform to the mold shape.

4. The formed part is cooled and removed for finishing.
5. Making Polypropylene Sheets
6. Polypropylene resin is fed into the two-roll mill at a temperature of 180-200°C.
7. The molten polypropylene is sheeted out by continuous rolling.
8. The sheet is cooled slightly and cut into appropriate sizes.
9. Further compression molding is performed to achieve uniform thickness.
10. The final polypropylene sheet is allowed to cool and tested for quality.

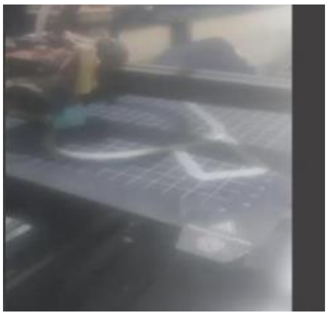

Figure 1. 3d printing process

Figure 2. 3d back view of the mirror

Software and Tools Used: 3d printing process
Software: SolidWorks (or similar CAD software), Scaling Parameters: Uniform scaling applied at 2950% for X, Y, and Z dimensions. Initial Dimensions: X: 188.8971 mm Y: 185.4434 mm Z: 53.5415 mm.

3D Model Creation:
The side mirror was designed using a combination of surface modeling and solid features. Key components, including the mirror, housing, and mounting base, were created.

Figure 3. applying molten polypropylene to square mold

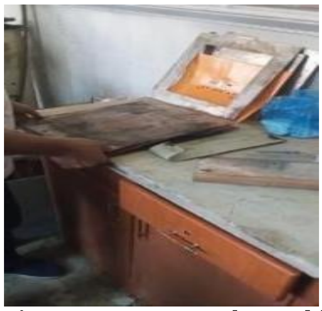

Figure 4. pressing the mold

3.3 Selection of Raw Materials
The choice of materials is crucial for ensuring the durability, flexibility, and aesthetic quality of the final product.

- **Base Polymer: Polypropylene (PP) – High-Impact Grade:** Selected for its lightweight, flexibility, and resistance to weather conditions.
  - **Fillers :**
    - **Glass Fibers (20%)**: Increases rigidity and impact strength.
    - **Talc (5%)**: Improves dimensional stability and heat resistance.
  - **Additives:**
    - **UV Stabilizers:** Prevents degradation due to prolonged sun exposure.
    - **Color Masterbatch:** Ensures uniform color distribution.
    - **Antioxidants:** Prevents oxidation at high temperatures.

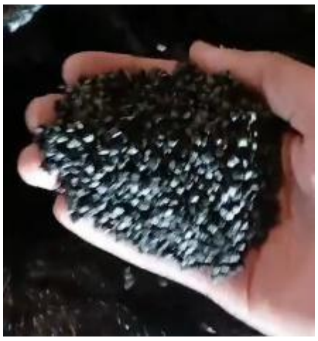

Figure 5 . polypropylene pellets (PP) with 20% fiber glass

3.4 Drying Process

- If using **glass fiber-reinforced polypropylene**, drying is essential to remove moisture.
- Material is dried in a **hot air dryer at 80-100°C for 2-4 hours**.
- Failure to dry properly may result in **bubbles, weak mechanical properties, and poor surface finish**.

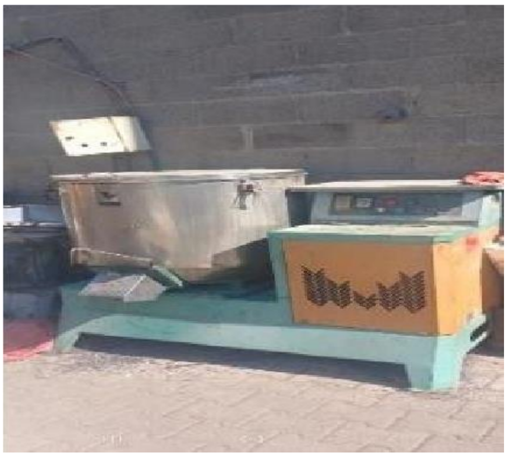

Figure 6. drying machine for pellets.

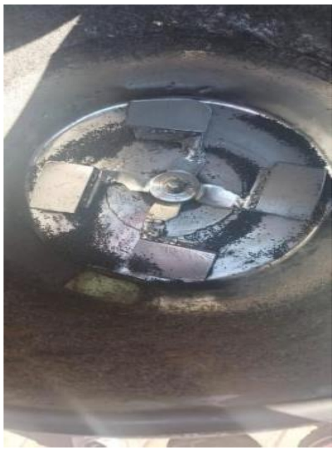

Figure 7. drying process at 90C for 2 hour

3.5 Injection Molding Machine Setup

- **Machine Type:** Standard **200-400 Ton** injection molding machine.
- **Mold Type:** Two-plate mold (Core and Cavity), designed with :

  o Cooling channels to ensure uniform cooling.

  o Ejector pins to remove the finished product. o Venting system to prevent trapped air and defect

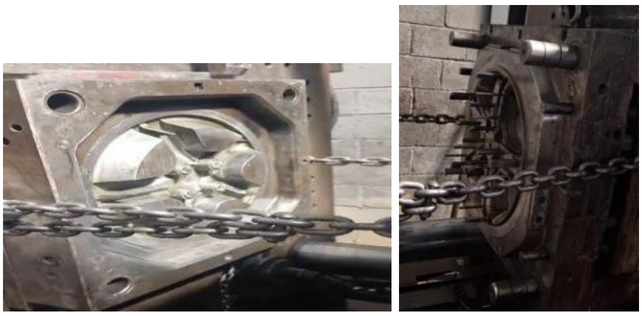

Figure 8. injection molding machine

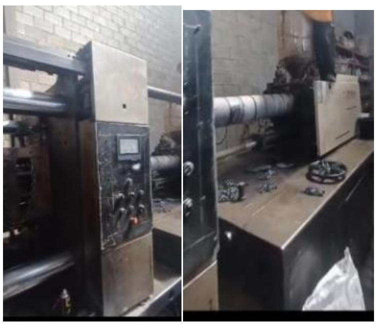

Figure 9. mold cavity

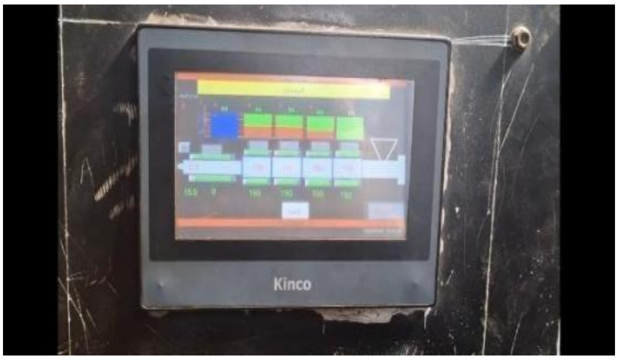

Figure 10. mold core.

Figure 11. adjusting temperature of the barrel

3.6 Injection Molding Parameters

These settings ensure proper melting, flow, and cooling of the polypropylene:

Table1. process conditions

Parameter	Value (for PP)
Melt Temperature	200 - 250°C
Mold Temperature	40 - 60°C
Injection Pressure	800 - 1500 bar
Holding Pressure	500 - 800 bar
Cooling Time	15 - 30 sec
Injection Speed	Medium to high
Clamp Force	200 - 400 Tons

3.7 Step-by-Step Injection Molding Process

1. **Clamping Stage**

The mold closes tightly under hydraulic pressure.
Ensures no plastic leaks during injection.

2. **Injection Stage**

Polypropylene (PP) is heated and injected at high pressure.
Fills the mold cavity completely.

3. **Holding & Packing Stage**

Additional plastic is pushed in to compensate for shrinkage.
Reduces defects such as **sink marks** and **voids**.

4. **Cooling Stage**

The mold is cooled using **water or oil circulation systems**.
Ensures uniform solidification.

5. **Ejection Stage**

The mold opens and ejector pins push the solidified mirror cover out.
The part is collected for further processing.

6. **Post-Processing**

Removal of excess plastic(flash trimming)
Surface finishing (painting or coating).

Figure 12. Visual & Dimensional Inspection of the product

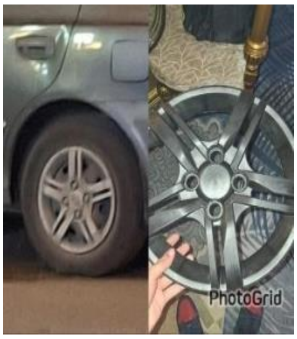

Figure 13. final product in application

4. Results and Discussion

- The produced spare part (side mirror casing) successfully conformed to the mold shape with minimal defects. (3d printing)

Surface finish quality was affected by heating temperature and vacuum pressure. The use of ABS resulted in better rigidity and impact resistance compared to polypropylene.

- Polypropylene Sheet Formation(thermoforming)

The sheets produced had good flexibility and uniform thickness (~1-2 mm).

The rolling process ensured proper dispersion of the material, reducing defects.

Increasing rolling time improved sheet homogeneity but could lead to material degradation if overheated.

Material Preparation (injection molding process)

Before the injection process, the raw material (typically polypropylene for automotive mirrors) undergoes:

- **Drying:** Ensuring minimal moisture content to avoid defects like bubbles or weak spots.
- **Pellet Feeding:** The polymer pellets are fed into the hopper, where they are transported to the heating barrel.
- **Melting & Homogenization:** The material is heated and mixed using a reciprocating screw, ensuring uniform viscosity and flowability.

Injection Molding Process Steps a) Clamping Phase

- The mold is closed using hydraulic or mechanical force to ensure no gaps exist between the two halves.
- Proper alignment of the core and cavity is crucial to prevent defects. **b) Injection Phase**
- The screw moves forward, forcing the molten plastic into the mold cavity under high pressure.
- Key parameters:
  - o **Injection pressure:** Ensures full cavity filling.
  - o **Speed & temperature:** Optimized to prevent defects like short shots or

burns. **c) Cooling Phase**

- Once the cavity is filled, the material begins to solidify.
- The cooling system (channels circulating water or oil) helps regulate temperature and reduce cycle time.

• Uneven cooling may cause warping or internal stresses.

d) Holding & Packing Phase

 Extra material is injected to compensate for shrinkage during cooling. Proper holding pressure ensures dimensional stability.

e) Mold Opening & Ejection Phase

• The clamping unit releases, and the moving half retracts.

• Ejector pins push the solidified part out of the mold.

• If the part sticks to the core, additional mechanisms (air blast or ejector plates) assist removal.

Process Optimization & Challenges

• **Shrinkage Control:** Proper packing pressure prevents voids.

• **Cycle Time Optimization:** Faster cooling enhances productivity but requires careful balancing to avoid defects. **Defects Analysis:** o **Flash formation:** Occurs if the mold doesn't close properly. o **Weld lines:** Form due to improper flow of molten plastic. o **Burn marks:** Result from excessive heating or trapped air

The injection molding process is a highly controlled method that ensures repeatable and high-quality production. Optimizing temperature, pressure, and cooling time is crucial for defect-free parts. Proper mold design, including balanced gating and efficient ejection mechanisms, plays a key role in overall process efficiency.

Process Overview

Table 2 .comparison between 3 methodes

Aspect	Injection Molding	Thermoforming	3D Printing
Process	Molten plastic is injected into a mold cavity and solidifies into shape.	A plastic sheet is heated and then formed over a mold using vacuum or pressure.	Material is deposited layer by layer to build a part from a digital model.
Materials Used	Thermoplastics like PP, ABS, PE, and PC.	Thermoplastics like ABS, PET, PVC, and polystyrene sheets.	Filaments (PLA, ABS, PETG), resins, and powders (SLS, metal, etc.).
Mold Requirement	Requires expensive metal molds.	Requires a mold but is simpler and cheaper than injection molding.	No mold required; prints directly from a CAD model.

Table 3. product shape

Aspect	Injection Molding	Thermoforming	3D Printing
Part Complexity	High—can produce detailed, intricate parts.	Limited—sharp details are harder to achieve.	Extremely high—can create complex geometries.
Dimensional Accuracy	Very high precision.	Moderate—thickness variations may occur.	Good but depends on the printer quality.

Surface Finish	Smooth and professional.	Requires additional trimming and finishing.	Layer lines are visible; post-processing needed for smooth finish.

Table 4. mechanical properties comarison

Aspect	Injection Molding	Thermoforming	3D Printing
Mechanical Strength	Very high—produces strong, durable parts.	Good for nonstructural applications.	Varies; FDM prints are weaker due to layer adhesion issues.
Heat Resistance	High (depending on material).	Moderate—depends on plastic type.	Low to moderate (except for highperformance materials).

Best for Mass Production → Injection Molding □ Lowest per-unit cost for large-scale production.

- High precision & surface finish—ideal for automotive, medical, and consumer products.
- Strong, durable parts due to high-pressure injection.
- Consistent quality with minimal defects. **Limitations:**
- High initial mold cost for complex molds).
- Not cost-effective for small production runs

Best for Large, Simple Parts & Mid-Scale Production → Thermoforming **Lower tooling cost** than injection molding.

- **Faster production cycle** for large plastic sheets (e.g., packaging, automotive interior panels).
- **Good material flexibility** (e.g., food trays, machine covers). **Limitations:**
- **Less precision & detail** compared to injection molding.
- **More material waste** due to trimming excess plastic.

□ **Limited part complexity** (best for simple geometries).

Best for Prototyping & Custom Parts → 3D Printing

- **No mold required → Low startup cost** (good for prototypes or small batches).
- **Highly complex geometries possible** (e.g., medical implants, aerospace components).

□ **Quick iterations & customization** (ideal for product development). **Limitations:**

- **Slow production speed** → Not practical for large-scale manufacturing.
- **Weaker parts** (especially FDM prints with layer adhesion issues).
- **Higher per-unit cost** (especially for large quantities).5. Cost Analysis and Environmental Impact

5.1. Cost Analysis Model

This section evaluates the cost benefits of using recycled polypropylene (PP) with reinforcements (fiberglass, calcium carbonate) compared to virgin PP in automotive applications.

Table 5. cost comparison

5.2 Material Cost Comparison

Material Type	Cost per kg (EGP)	Source/Notes
Virgin PP	**75.8 – 101**	**Standard market price**
Recycled PP	**40.4 – 60.6**	**Dependent on purity & supplier**
Fiberglass (20%)	**126 – 176**	**Higher strength, cost varies**
Calcium Carbonate ($CaCO_3$)	**15 – 25**	**Low-cost filler, improves heat resistance**

Recycled PP is 30-50% cheaper than virgin PP.

Adding fiberglass increases cost but improves mechanical properties.

• Calcium carbonate ($CaCO_3$) is the most cost-effective filler to enhance material performance while keeping costs low.

Table 6 . Manufacturing Cost Comparison: cost comparison

Material Type	CO_2 Emissions (kg CO_2e/kg)	Energy Use (MJ/kg)
Virgin PP	**2.0 - 2.5**	**75 - 90**
Recycled PP	0.5 - 1.0	30 - 50
PP + 20% Fiberglass	1.5 - 2.0	60 - 80
PP + 10% $CaCO_3$	0.8 - 1.3	40 - 60

Process Type	Mold Cost (EGP)	Per Unit Cost (EGP)	Best For
Injection Molding	505700 - 2528500	76 - 151	Large-scale production
Thermoforming	252850 - 758550	101 - 202	Mid-scale production
3D Printing	No mold needed	253 - 506	Prototyping & small batches

Observations:

- Injection molding is best for mass production despite high mold cost.
- Thermoforming works well for simpler parts but has more material waste.
- 3D printing is only viable for custom or prototype parts due to high per-unit cost

5.4. Environmental Impact Assessment (LCA) Model

This section evaluates the carbon footprint and environmental benefits of using recycled PP versus virgin PP.

5.5 Carbon Footprint Comparison Key Findings:

- • Using recycled PP reduces CO_2 emissions by 50-75% compared to virgin PP. • Fiberglass reinforcement increases strength but has a higher carbon footprint.
- • Calcium carbonate ($CaCO_3$) reduces emissions and improves heat resistanc

References

[1] Choi, B. C., & Pak, A. W. (2006). Maltidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. Clinical and Investigative Medicine, 29(6), 151.

[2] Coates, J. F. (1976). The role of formal models in technology assessment. Technological Forecasting and Social Change, 9(1), 139-190.

[3] Cook, J., et al. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. Environmental Research Letters, 8(2), IOP Publishing. https://doi.org/10.1088/17484326/8/2/024024

[4] Crutzen, P. J. (2002). Geology of mankind. Nature, 415(6867), 23.

[5] Deutscher Bundestag. (1998). Abschlussbericht der Enquete Kommission "Schutz des Menschen und der Umwelt-Ziele und Rahmenbedingungen einer nachhaltigen zukunftsverträglichen Entwicklung". Boom: Konzept Nachhaltigkeit-Vom Leitbild zur Umsetzung.

[6] Deutscher Bundestag. (2013). Schlussbericht der Enquete-Kommission "Wachstum, Wohlstand, Lebensqualität: Wege zu nachhaltigem Sozialen Marktwirtschaft". Drucksache, 17(1330).

[7] Dillard, J., Dujon, V., & K. (2008). Understanding the social dimension of sustainability. Routledge

[8] DISI [Dow Jones Sustainability Index]. (2013). Dow Jones Sustainability World Index Guide V/2.1. http://www.sustainability-indices.com/images/djst-world-guidebook_tem1071-337244.pdf. Accessed November 6, 2013

[9] European Commission. (2011). A renewed EU strategy 2011-14 for Corporate Social Responsibility (Vol. 25)

[10] Finnveden, G., et al. (2009). Recent developments in life cycle assessment. Journal of Environmental Management, 91(1), 1-21.

[11] Fischer-Kowalski, M., & Swilling, M. (2011). Decoupling: Natural resource use and environmental impacts from economic growth. United Nations Environment Programme.

[12] Fischer-Kowalski, M., & Weisz, H. (1999). Society as hybrid between material and symbolic realms: Toward a theoretical framework of society-nature interaction. Advances in Human Ecology, 215-252.

[13] ISO[InternationaOrganizationforStandardization].(2001). ISO

[14] 040:2006(en). https://www.iso.org/obp/ui/f#search. Accessed December 7, 2013.

[15] Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. Ecological Economics, 79, 1-

[16] Janschitz, S., & Zimmermann, F. M. (2010). Regional modeling and the logics of sustainability: A social theory approach for regional development and change. Environmental Economics, 1116.Kant, L. (1993). Grounding for the metaphysics of morals: With, on a supposed right to lie because of philanthropic concerns. Indianapolis: Hackett Publishing.

[17] Klüver, L., Nielsen, R. O., & Jørgensen, M. L. (2015). Policy-oriented technology assessment across Europe: Expanding capacities. Basingstoke: Palgrave Macmillan.

[18] Kulke,E.(2013). Wirtschaftsgeographie. UTB: 2434: Geographie, Wirtschaftswissenscaften, vol. 5.

[19] Küng, H. (2010). Anständig wirtschaften: Warum Ökonomie Moral braucht.

[20] Definitions, objectives, and evidence of effectiveness. Clinical and Investigative Medicine, 29(6), 151.