# Ingineria automobilului

*Automotive engineering*

Registrul Auto Român

SIAR

Societatea Inginerilor de Automobile din România

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## SIAR – SOCIETATEA INGINERILOR DE AUTOMOBILE DIN ROMÂNIA

## ALEGERI GENERALE 2025



**Motto SIAR: Cunoaștere și dezvoltare prin cooperare!**

● Sustenabilitate: rolul inovației verzi în performanța firmelor din sectorul auto ● Banc de testare pentru analiza controlului și acționării amortizoarelor hidraulice auto ● Schimbări culturale ale ingineriei în domeniul autovehiculelor pe fondul creșterii importanței vehiculelor electrice

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**SOCIETATEA INGINERILOR DE AUTOMOBILE DIN ROMÂNIA**
**SOCIETY OF AUTOMOTIVE ENGINEERS OF ROMANIA**

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# SIAR CONGRESSES – SOUL MANIFESTATIONS
# CONGRESELE SIAR – MANIFESTĂRI DE SUFLET



Ca în fiecare an tradiția desfășurării congreselor SIAR ne aduce sau ar trebui să ne aducă împreună.

Măcar cu această ocazie, căci în rest parcă ne este tot mai dificil să ne întâlnim... Mereu se găsesc "n" motive pentru neparticipare: avem program foarte încărcat, avem obligații (la universități, institute, societăți, acasă, ...), nu mai avem timp, nu mai găsim resurse financiare, ne-am săturat de atâtea drumuri, mai apar probleme de sănătate, suntem mai pretențioși referitor la condițiile care ni se asigură la congrese, s-au schimbat generațiile, iar acum, în acest an, colac peste pupăză, s-a declanșat operațiunea de "tăieri" bugetare!

Doar că, pentru cei care înțeleg și simt, acest Congres este un prilej extraordinar în care, noi automobiliștii putem să arătăm (încă o dată) că suntem o familie mare și frumoasă, iar după cum se spune "Familia este darul lui DUMNEZEU pentru noi pe pământ"!

Congresul SIAR este o sărbătoare pe care o așteptăm an de an pentru a ne revedea, a ne îmbrățișa, a discuta între noi, a lega noi prietenii! O sărbătoare în urma căreia să fim mai buni, mai drepți, mai iubitori, mai răbdători unii cu alții, mai iertători, mai atenți la problemele semenilor! Să fim oameni!

Mă bucur din tot sufletul că la Congresul AMMA2025 (co-organizat de Societatea Inginerilor de Automobile din România și de Academia de Științe Tehnice din România, găzduit de Universitatea Tehnică din Cluj-Napoca), am fost împreună! Atât de mulți! A fost atât de bine!

Cea de a 35-a ediție a Congresului Internațional de Ingineria Autovehiculelor și Transporturilor, a 5-a ediție a Congresului AMMA - Automotive Mobility, Management and Automation s-a desfășurat cu succes și aceasta datorită participanților, sponsorilor, organizatorilor, voluntarilor ... Ce să mai vorbim, că și vremea a ținut cu noi, participanții la congres!

Reunind peste 250 de participanți, AMMA 2025 a fost gazda lucrărilor în plen, a prezentărilor a peste 110 lucrări științifice, a 6 workshop-uri antrenante, a trei concursuri studențești de mare atractivitate, a unor seri deosebite în care chiar am reușit să ne relaxăm! AMMA 2025 a fost gazda noastră a celor îndrăgostiți de automobil (din diverse domenii - cercetare, proiectare, producție, exploatare etc.), a celor care visăm la o mobilitate durabilă și sigură, la un mediu mai uman, la o viață mai liniștită, la o prietenie sinceră, la frumusețe, la seninătate..., a celor care ne-am dorit și am putut să fim prezenți la Cluj-Napoca.

La anul, la viitorul congres al SIAR CAR 2026 (care va fi organizat de Universitatea Națională de Știință și Tehnologie Politehnica București, Centrul Universitar Pitești) sper să fim iar cât mai mulți, mai ales că viitoarele noastre gazde au experiența atâtor congrese organizate cu succes!

Dar, mai ales, sper să fim cu toții sănătoși!

La finalul acestui an 2025 și în preajma sărbătorilor de iarnă, sunt deosebit de onorat să pot mulțumi încă o dată tuturor membrilor Societății Inginerilor de Automobile din România și colaboratorilor pentru tot, dar mai ales pentru sprijinul și încrederea acordată!

Mulțumesc Registrului Auto Român pentru mâna întinsă SIAR și pentru că datorită conducerii RAR, Revista Ingineria Automobilului - una dintre puținele publicații europene ce promovează cercetarea științifică de profil, mai ales din România, având o recunoaștere internațională certificată - încă mai apare!

În numele meu și al colegilor din Consiliul director

Vă doresc din tot sufletul sănătate și prieteni adevărați!

Sărbători fericite și LA MULȚI ANI!

Sa fiți iubiți!

LA MULȚI ANI ROMÂNIA!

Prof. univ. dr. ing. DHC Nicolae Burnete,

Președinte SIAR,

Președinte al Senatului Universității Tehnice din Cluj-Napoca

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Coperta 1: Fotografii Congres AMMA 2025 & Concurs Ghiulai: Alexandru GRAB, Ramona-Monica STOICA

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# THE XXXV$^{TH}$ SIAR INTERNATIONAL CONGRESS ON AUTOMOTIVE AND TRANSPORT ENGINEERING – AMMA 2025

# Congresul Internațional de Inginerie a Autovehiculelor și Transporturilor – AMMA 2025

## 23 - 25 OCTOMBRIE 2025
## UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA



Ediția a XXXV-a a Congresului Internațional anual al SIAR de Inginerie a Autovehiculelor și Transporturilor, în același timp a 5-a ediție a Congresului Internațional „Automotive Mobility, Management and Automation – AMMA 2025" a fost organizată în perioada 23 – 25 octombrie la Universitatea Tehnică din Cluj-Napoca.

Cu o istorie remarcabilă, consacrat drept un eveniment științific major în comunitatea cercetătorilor, cadrelor didactice universitare și a altor specialiști din domeniul ingineriei autovehiculelor, transporturilor și siguranței rutiere, Congresul AMMA 2025 a avut la bază experiența acumulată de comunitatea SIAR pe parcursul a 34 ediții anterioare ale congresului, dar și alte manifestări științifice și profesionale organizate în spațiul universitar politehnic și de cercetare științifică din România încă din anii '60.

Ediția a 35-a a Congresului Internațional anual al SIAR de Inginerie a Autovehiculelor și Transporturilor – AMMA - a fost organizat în colaborare cu Facultatea de Inginerie a Autovehiculelor, Mecatronică și Mecanică din cadrul Universității Tehnice din Cluj-Napoca - unul dintre centrele naționale de excelență în cercetarea aplicativă și fundamentală din domeniul ingineriei autovehiculelor și transporturilor rutiere, cu o largă recunoaștere internațională și puternic ancorat la mediul economic specific favorizat de prezența în zonă a unor puternice companii producătoare de subansambluri sau componente auto.

Congresul a fost însoțit de un ansamblu de activități care au atras atenția specialiștilor prezenți la Cluj-Napoca. Congresul AMMA 2025, împreună cu celelalte activități specifice ingineriei autovehiculelor și transporturilor organizate într-o strânsă corelare, a oferit prilejul stabilirii unor contacte utile de colaborare și informare în domeniul problemelor actuale privind dezvoltarea autovehiculelor, siguranța transporturilor rutiere, protecția mediului, mobilitatea rutieră sustenabilă, AI versus Automotive Engineering etc.

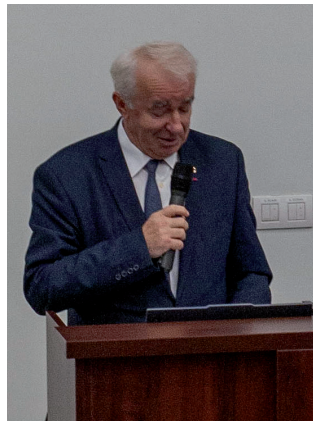
Printre factorii determinanți în dezvoltarea domeniului ingineriei autovehiculelor se numără și schimbul activ de idei și cunoștințe, aspect ce caracterizează societatea actuală.

Într-o concepție sistemică adoptată de SIAR pentru congresele sale - „Academia, Industry and Government: together for automotive engineering development", un număr important de specialiști din mediile academic, social și economic din țară și de peste hotare au participat la lucrările congresului, fapt ce a permis abordarea în profunzime a temelor importante care preocupă societatea contemporană privind rolul, locul și dezvoltarea viitoare a autovehiculelor.













Subiectele propuse pentru Congresul Internațional de Inginerie a Autovehiculelor și Transporturilor – AMMA 2025 într-un context generos oferit de tema principală a congresului „Automotive Mobility, Management and Automation" au asigurat un cadru științific adecvat unor schimburi de idei și dezbateri intense și obiective, au reflectat aceste preocupări din domeniul ingineriei autovehiculelor și transporturilor, fiind orientate pe următoarele direcții: autovehicule hibride și electrice, sisteme de propulsie, sisteme inteligente pentru autovehicule, software și simulare în ingineria autovehiculelor, siguranța rutieră, controlul traficului, ingineria transporturilor, tehnologii de fabricație și materiale, soluții pentru autovehicule verzi, sustenabilitatea mobilității rutiere.

Cei peste 300 participanți la congres din țară și din străinătate au avut prilejul de a se implica activ la dezbaterea lucrărilor științifice prezentate în sesiunea plenară, cât și în cadrul multiplelor secțiuni desfășurate simultan, work-shop-uri și dezbateri, expoziții, activități sociale.

În cadrul ceremoniei de deschidere a congresului care a avut loc în Centenary Auditorium al Facultății de inginerie a autovehiculelor, mecatronică și mecanică a Universității Tehnice din Cluj-Napoca, după salutul de bun venit adresat tuturor celor prezenți, prof. dr. ing. Nicolae BURNETE – președintele Societății Inginerilor de Automobile din România – a invitat să ia cuvântul și să prezinte mesajul său pe prefectul județului Cluj – doamna Maria FORNA. În continuare, au prezentat mesaje de salut și urări de succes participanților la congres, succesiv: dl. Emil BOC – primarul municipiului Cluj-Napoca, prof. dr. ing. Dorel BANABIC – vicepreședinte al filialei Cluj-Napoca a Academiei de Științe Tehnice din România, prof. dr. ing. Gigel PARASCHIV – secretar de stat în Ministerul Educației și Cercetării, prof. dr. ing. Adrian GROZA – pro-rector al Universității Tehnice din Cluj-Napoca, prof. dr. ing. Cornel STAN – West Saxon University of Zwickau, Germania, președintele Comitetului științific și tehnic al congresului AMMA 2025, ing. Helmut IANCU – Global Business Segment Manager, Fuel Cell Testing Technology, AVL List

GmbH, doamna Roxana NICA – șefa departamentului comunicare pentru a prezenta mesajul directorului Registrului Auto Român, prof. dr. ing. Nicolae FILIP – decanul Facultății de Ingineria autovehiculelor, Mecatronică și Mecanică din Universitatea Tehnică din Cluj-Napoca.

După ceremonia festivă de deschidere a congresului, au fost prezentate lucrări urmărite cu un larg interes de auditoriu astfel: Ing. Helmut IANCU – Global Business Segment Manager, Fuel Cell Testing Technology, AVL List GmbH, „Hydrogen and Fuel Cells: Powering Mobility and Beyond – Trends, Challenges, and Digital Innovations", Deniz ÇETIN – Chief Commercial Officer, KARSAN, Turcia, „The Future in Motion: Autonomous Mobility Driving a Green and Sustainable World", Prof. dr. ing. Mihai MIHĂESCU, KTH Royal Institute of Technology , Stockholm, „Decoding Flow Instabilities in Turbochargers" și prof. dr. ing. Cornel STAN – West Saxon University of Zwickau, Germania, „Future Automotive Propulsion: Electric Motors versus Hybrids, Plug-Ins & Range Extenders with Clean Fuels".

Lucrările pe secțiuni au fost prezentate în spațiile primitoare și multifuncționale asigurate în cadrul Facultății de Ingineria Autovehiculelor, Mecatronică și Mecanică.

După lansarea invitațiilor de participare la congres, dintre cele 167 lucrări propuse pentru prezentare în cadrul secțiunilor Congresului AMMA 2025, în urma procesului de evaluare au fost în final acceptate pentru prezentare 140 lucrări (84%). Dintre acestea, 128 au fost susținute în cadrul secțiunilor tehnice organizate în cadrul congresului. Pentru primirea și evaluarea lucrărilor a fost utilizată o platformă modernă de management al conferințelor (http://www.siarcongress.eu).

La lucrările Congresului au participat cadre didactice universitare, cercetători, specialiști și studenți din domeniul ingineriei autovehiculelor și transporturilor din Austria, Bulgaria, Germania, Italia, Republica Moldova, Polonia, România, Slovenia, SUA, Suedia, Turcia și Ungaria.

Pe durata congresului a fost organizată o expoziție complexă în cadrul căreia












au fost prezentate automobile, produse ce includ soluții tehnice actuale, dar și standuri cu echipamente de cercetare.

Întâlnirile dintre reprezentanții industriei de profil, cadre didactice universitare, cercetători și studenți au permis schimburi de opinii pe teme de interes, precum și accesul la informații de ultimă oră privind preocupările prioritare în domeniul ingineriei autovehiculelor.

O activitate cu o vizibilitate deosebită a fost destinată prezentării realizărilor studențești în cadrul competiției „Formula Student". Au fost prezentate exponate realizate de studenții din Universitatea Gheorghe Asachi din Iași, Universitatea Tehnică din Cluj-Napoca, Universitatea Politehnica din Timișoara, Universitatea Transilvania din Brașov, UNST Politehnica București. Pentru a asigura un cadru optim prezentării rezultatelor muncii entuziaste a colectivelor de studenți în această direcție au fost organizate patru ateliere de lucru: „Hybrid Drivetrain, Electric Drivetrain, Dynamic Events/ Endurance"; „Simulations & Validation, Composite Materials, Aerodynamic Package"; „International competitions, Season Goals/ Lessons Learned"; „Dynamic Demonstration".

Desfășurarea în paralel cu lucrările Congresului AMMA 2025 a fazelor pe țară ale Concursului internațional studențesc de inginerie a autovehiculelor „Prof. univ. ing. Constantin GHIULAI" la cele două secțiuni „Dinamica autovehiculelor" (a XI-a ediție) și "Automotive CAD" (a VIII-a ediție) cu participarea a 53 studenți reprezentând 10 universități din România și Republica Moldova, câștigători ai fazelor locale, a contribuit din plin la construirea în rândul participanților a unei imagini optimiste, pline de încredere în viitorul ingineriei autovehiculelor în România. Fondurile de premiere au fost asigurate de AVL România și AKA Automotiv, reprezentanții celor două companii - ing. Ștefan KANYA și respectiv drd. ing. Mihai-Marin ȘTIROSU - fiind prezenți pe durata probelor de concurs și participând la festivitatea de premiere premergătoare ceremoniei de încheiere a congresului.

Workshop-uri moderate de experți cu realizări remarcabile în domeniul specific congresului AMMA 2025 s-au bucurat de o atenție deosebită și au permis schimburi de opinii, discuții aprofundate și interesante, astfel:

„Advanced Testing and Efficiency Characterization of Electrolyzers for Green Hydrogen Production", moderator ing. Radhika VELAYUDHAN, Senior System Line Manager H2 Business Development, AVL List GmbH, Austria;

„Portable Emissions Measurement Systems (PEMS)", moderator ing. Tiberiu MELENCU, Director Testing Department, Registrul Auto Român;

„Autonomous Bus for Urban Transport Systems - Practical demonstration", moderator ing. Semir AYDIN, Autonomous Vehicles Business Development Manager, KARSAN, Turcia;

„Advanced Simulation to Support Fuel Cell & Electrolyzer Development", moderator ing. Ales CVIKL, Team Leader Thermodynamics - Physical and Model Based, AVL-AST d.o.o., Slovenia.

Congresul Internațional al SIAR de Inginerie a Autovehiculelor și Transporturilor – AMMA 2025 a beneficiat de o participare remarcabilă – cadre didactice universitare, cercetători, specialiști și studenți - și va rămâne pentru toți participanții o manifestare științifică de referință în multiple planuri, cu un program complex, variat și interesant, desfășurat într-o atmosferă profesională.

Felicităm comitetul de organizare a Congresului AMMA 2025 și invităm participanții la ediția a XXXVI-a a Congresului internațional anual al SIAR de inginerie a autovehiculelor și transporturilor – CAR 2026 ce se va desfășura în perioada 5 – 7 noiembrie 2026 la Centrul Universitar Pitești al Universității Naționale de Știință și Tehnologie Politehnica București.

Prof. univ. dr. ing. **Minu MITREA**
Secretar General SIAR











# THE INTERNATIONAL CONTEST FOR STUDENTS IN AUTOMOTIVE ENGINEERING „PROFESSOR ENG. CONSTANTIN GHIULAI”

## The „Automotive CAD” Section, Eighth Edition
## The „Automotive Dynamics” Section, Eleventh Edition

# CONCURSUL INTERNAȚIONAL STUDENȚESC DE INGINERIE A AUTOVEHICULELOR „Profesor universitar inginer Constantin GHIULAI”

## Secțiunea „Automotive CAD” – Ediția a VIII-a
## Secțiunea „Dinamica autovehiculelor” – Ediția a XI-a
## Universitatea Tehnică din Cluj-Napoca
## 23.10 – 25.10.2025

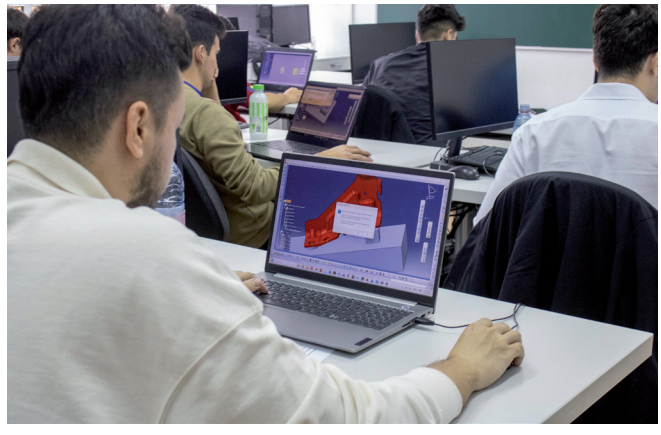
În perioada 23.10 – 25.10.2025, pe durata **Congresului Internațional de Inginerie a Autovehiculelor și Transporturilor Rutiere AMMA 2025**, organizat de către Societatea Inginerilor de Automobile din România împreună cu Universitatea Tehnică din Cluj-Napoca, au avut loc fazele finale ale **Concursului internațional studențesc de inginerie a autovehiculelor „Prof. univ. ing. Constantin Ghiulai”** la secțiunile ”Dinamica autovehiculelor” și „Automotive CAD”, organizat, de asemenea, de SIAR.

A opta ediție a fazei finale a concursului la **secțiunea „Automotive CAD”** a întrunit 25 studenți reprezentând: Universitatea Tehnică din Cluj-Napoca, Universitatea Națională de Știință și Tehnologie Politehnica București – CU București, Universitatea Națională de Știință și Tehnologie Politehnica București – CU Pitești, Universitatea Politehnica din Timișoara, Universitatea Tehnică a Moldovei din Chișinău, Universitatea din Craiova, Universitatea Transilvania din Brașov, Universitatea din Oradea și Academia Tehnică Militară „Ferdinand I” din București. Anterior, au fost organizate în universități faze locale la care au participat circa 110 studenți la programele de studii universitate din domeniul „Ingineria autovehiculelor”. Dintre câștigătorii concursurilor organizate la nivel local s-au constituit echipele de studenți delegate pentru participarea la faza națională.

Pe baza rezultatelor obținute la probele de concurs, cu sprijinul AKA Automotive, au fost acordate următoarele premii:

Premiul I – Toni – Marian OLARU -
Universitatea Tehnică din Cluj-Napoca;
Premiul II – Rareș – Mihail ANTIP -
UNST Politehnica București – CU București;
Premiul III – Adriana – Florentina POPA -
Academia Tehnică Militară Ferdinand I;
Mențiune – Sebastian – Cătălin HOLD -
Universitatea din Craiova;
Alexandru PUIU -
Universitatea Transilvania din Brașov.










Clasamentul pe echipe stabilit pe baza rezultatelor obținute de membrii acestora a arătat astfel:

Locul I – echipa Universității Transilvania din Brașov;
Locul II – echipa Academiei Tehnice Militare Ferdinand I din București;
Locul III – echipa UNST Politehnica București – CU București;
Mențiune – echipa UNST Politehnica București – CU Pitești;
– echipa Universității Politehnica din Timișoara.

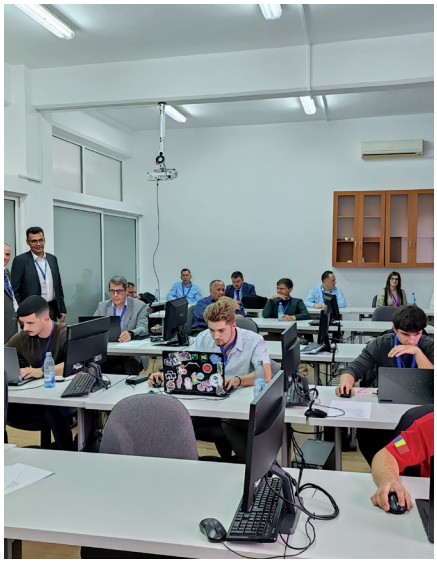
Tematica, bibliografia și regulamentul de organizare au fost elaborate de specialiști din cadrul AKA Automotive, cadrele didactice din comisia națională de concurs și Secretariatul General al SIAR.

Comisia națională de concurs a fost constituită din Conf. dr. ing. Daniela VOICU – Academia Tehnică Militară „FERDINAND I" din București, președintele comisiei naționale de concurs, S.l. dr. ing. Ionela – Alina APARASCHIVEI – UNST Politehnica București – CU Pitești, S.l. dr. ing. Emilian - Vasile BORZA - Universitatea Tehnică din Cluj-Napoca – coordonator tehnic, S.l. dr. ing. Cătălin CHIOREANU – Universitatea din Oradea, S.l. dr. ing. Sebastian RADU – Universitatea Transilvania din Brașov, S.l. dr. ing. Mario TROTEA – Universitatea din Craiova, Conf. dr. ing. Olivian PĂDURE – Universitatea Tehnică a Moldovei din Chișinău, Asist. univ. drd. ing. Adrian - Aristide ASIMOPOLOS – UNST Politehnica București – CU București, S.l. dr. ing. Andrei-Tiberiu BORBOREAN – Universitatea Politehnica din Timișoara, Drd. ing. Mihai – Marin ȘTIROSU – AKA Automotive, Ing. Dan ATANASESCU– AKA Automotive, Ing. Nicolae DINU – AKA Automotive, Prof. dr. ing. Minu MITREA – Secretar general SIAR (inițiator concurs).

A XI-a ediție a fazei finale a concursului la secțiunea „Dinamica autovehiculelor" a întrunit 28 studenți reprezentând: Universitatea „Aurel Vlaicu" din Arad, Universitatea Națională de Știință și Tehnologie Politehnica București – CU București, Universitatea „Transilvania" din Brașov, Universitatea Tehnică din Cluj-Napoca, Universitatea Națională de Știință și Tehnologie Politehnica București – CU Pitești, Universitatea Tehnică a Moldovei din Chișinău, Universitatea din Craiova, Universitatea din Oradea, Universitatea „Dunărea de Jos" din Galați și Academia Tehnică Militară „Ferdinand I" din București. Anterior, au fost organizate în universități faze locale la care au participat circa 120 studenți la programele de studii universitate din domeniul „Ingineria autovehiculelor". Dintre câștigătorii concursurilor organizate în fiecare universitate s-au constituit echipele de studenți delegate pentru participarea la faza națională. Pe baza rezultatelor obținute la faza finala a probelor de concurs, cu sprijinul AVL România, au fost acordate următoarele premii:

Premiul I– Attila – Mark CHIFOR -
Universitatea Tehnică din Cluj-Napoca;
Premiul II– Gabriel BURDUȘ -
UNST Politehnica din București - CU București;
Premiul III – Alexandru – Nicolae VIȘAN -
UNST Politehnica din București - CU Pitești;
Mențiune – Ciprian – Dan SICOE -





Universitatea Tehnică din Cluj-Napoca;

Mențiune – Andrei – Marin DRĂGUȚ -

UNST Politehnica din București - CU Pitești.

Clasamentul pe echipe stabilit pe baza rezultatelor obținute de membrii acestora este următorul:

Locul I – echipa Universității Tehnice din Cluj-Napoca;

Locul II – echipa Universității din Craiova;

Locul III – echipa UNST Politehnica din București - CU Pitești;

Mențiune – echipa UNST Politehnica din București - CU București.

Comisia națională de concurs a fost constituită din Prof. dr. ing. Ion TABACU – UNST Politehnica București - CU Pitești, coordonator național, Prof. univ. dr. ing. Gheorghe CIOLAN – Universitatea „Transilvania" din Brașov, Prof. dr. ing. Ioan - Adrian TODORUȚ - Universitatea Tehnică din Cluj-Napoca, Prof. dr. ing. Ștefan - Lucian TABACU – UNST Politehnica București - CU Pitești, Conf. univ. dr. ing. Loreta SIMNICEANU – Universitatea din Craiova, Conf. univ. dr. ing. Ramona - Monica STOICA – Academia Tehnică Militară „Ferdinand I" din București, Conf. univ. dr. ing. Victor CEBAN – Universitatea Tehnică a Moldovei din Chișinău, Conf. univ. dr. ing. Dan - Alexandru MICU – UNST Politehnica București – CU București, S.l. dr. ing. Bogdan – Adrian ȚOLEA – Universitatea din Oradea, S.l. dr. ing. Sorin – Dan IGREȚ – Universitatea Aurel Vlaicu din Arad, Prof. dr. ing. Minu MITREA – Secretar general SIAR (inițiator concurs).

Toți studenții participanți au primit Diplome de merit pentru rezultatele deosebite obținute la concurs.

Concursul a beneficiat de suportul logistic consistent asigurat de Facultatea de Ingineria Autovehiculelor, Mecatronică și Mecanică a Universității Tehnice din Cluj-Napoca.

Societatea Inginerilor de Automobile din România – SIAR va organiza următoarea ediție a Concursului internațional studențesc de inginerie a autovehiculelor „Prof. univ. ing. Constantin GHIULAI", în perioada 05.11 – 07.11.2026, simultan cu al XXXVI-lea Congres Internațional al SIAR de Inginerie a Autovehiculelor și Transporturilor CAR 2026 găzduit de UNSTPB – Centrul Universitar Pitești.

**Prof. univ. dr. ing. Minu MITREA**

**Secretar General SIAR**

# SHIFTING GEARS TOWARD SUSTAINABILITY: THE ROLE OF GREEN INNOVATION IN AUTOMOTIVE FIRM PERFORMANCE

# SUSTENABILITATE: ROLUL INOVAȚIEI VERZI ÎN PERFORMANȚA FIRMELOR DIN SECTORUL AUTO

***ABSTRACT:*** *The changing environmental concerns, dwindling resources, and changes in consumer taste are among factors that continue to pressure the automotive industry into trying into sustainable practices. This paper discusses how green innovation can help to achieve sustainability and boost the performance of a firm in the auto industry by dwelling upon the emerging countries like Pakistan. Green innovation is seen as a strategy that helps firm to minimize its effect on the environment, enhance its operations and stay competitive. The study collected 489 respondents representing different layers of the Pakistani automotive industry to use SmartPLS and evaluate the connections between green innovation, sustainability practices, and firm performance. The results indicate that green innovation has a role in influencing sustainability practice in firms which consequently improves both non-financial and financial performances of the firm. There is also the practice of sustainability that is found to act as a mediator in the connection between firm performance and green innovation. There are also external moderating factors like regulatory pressure and market demand, which are revealed to increase the effects of green innovation. In practice, it provides an idea to automotive companies that should comply with the global trends in sustainability but adapt to the local limitations. Policy formulation workers are urged to develop favorable structures that would encourage green practices. This study emphasizes that green innovation is important towards sustainable development and long-term resilience in the automotive sector.*

***REZUMAT:*** *Preocupările legate de mediul în schimbare, resursele în scădere și schimbările în opțiunile consumatorilor se numără printre factorii care continuă să pună presiune pe industria auto să încerce practici sustenabile. Această lucrare analizează modul în care inovația verde poate ajuta la atingerea sustenabilității și la creșterea performanței unei firme din industria auto, concentrându-se asupra țărilor emergente precum Pakistanul. Inovația verde este privită ca o strategie care ajută firma să își minimizeze efectul asupra mediului, să își îmbunătățească operațiunile și să rămână competitivă. Studiul a colectat 489 de respondenți reprezentând diferite niveluri ale industriei auto pakistaneze. Folosind SmartPLS s-au evaluat legăturile dintre inovația verde, practicile de sustenabilitate și performanța firmei. Rezultatele indică faptul că inovația verde are un rol în influențarea practicilor de sustenabilitate în firme, ceea ce, în consecință, îmbunătățește performanțele firmei. Există, de asemenea, practica sustenabilității, care acționează ca mediator în legătura dintre performanța firmei și inovația verde. Există, de asemenea, factori externi, cum ar fi presiunea de reglementare și cererea pieței, care se dovedesc a crește efectele inovației verzi. În practică, aceasta oferă companiilor auto o idee care ar trebui să respecte tendințele globale în materie de sustenabilitate, dar să se adapteze la limitările locale. La formularea politicilor, managerii companiilor sunt îndemnați să dezvolte structuri favorabile care să încurajeze practicile ecologice. Acest studiu subliniază faptul că inovația ecologică este importantă pentru dezvoltarea durabilă și reziliența pe termen lung în sectorul auto.*

***Keywords:*** *Green Innovation, Sustainability Practices, Firm Performance, Automotive Industry, Regulatory Pressure, Market Demand*



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## 1.INTRODUCTION

### 1.1 Background and Context

The challenges that have been posed to the automotive industry by the increasing global environmental concerns have never been felt before. As greenhouse gas emissions, resources depletion and consumer demand increase there is a lot of pressure on the sector to become sustainable [4]. The governments across the world are enforcing strict environmental policies, and the consumers are showing interest in purchasing products and services which are environmentally friendly [2]. Here, green innovation has also been a fundamental driver of sustainability such that it has helped firms minimize their environmental impact in addition to boosting the efficiency of the operations and making themselves more competitive in the market [8]. Green innovation is no longer optional in the case of automotive industry, that dictates high carbon emissions and consumption of resources that create new threats to its sustainable survival and development. With green technologies and processes, automotive companies can encounter sustainability issues and enhance their financial and non-financial performance at the same time.

### 1.2 Research Problem

Even though the subject of sustainability and green innovation have gained importance, some gaps exist in terms of empirical evidence of the effects of these aspects on firm performance especially in such growing marketplace as Pakistan. Although there have been major goals by developed economies in greening their economy and operations, companies in developing economies tend to experience some exclusive findings in their exceeding to green practices and technologies and found to exhibit low access to high technology, lack of regulatory frameworks, and consumer awareness. Such a gap in literature indicates the necessity to conduct a study that analyzes the green innovation in promotion of sustainability and the performance of firms in the setting of emerging markets. When pursuing global sustainability trends in line with local limitations, the knowledge of such dynamics is essential to automotive firms.

### 1.3 Research Objectives

The study fills research gaps identified as connection between green innovation, sustainability practices and firm performance is adopted in automotive industry. In particular the study will aim at:

- Discover impacts of green innovation on adoption of sustainability practice in automotive companies.
- Inspect sustainability practices effect on non-financial and financial aspects of firm performance.
- Determine such mediating factors as organizational culture and technological readiness which positively affect the outcome of green innovation.

Think about how moderating variables such as regulatory pressure and market demand influence between firm performance and green innovation.
The discussion of these objectives will give a detailed insight on how green innovation supports sustainability and success of firms.

### 1.4 Study Significance

The study contributes a lot to academic literature and practice. It adds to the academic sphere of knowledge on green innovation and sustainability in terms of researching an area that has not been addressed previously in any significant manner, i.e., emerging economies such as Pakistan. It further incorporates several theoretical secondary approaches which include Stakeholder Theory and NRBV, in the process of explaining how green innovation affects firm performance through the ways. In practice, the results provide practical implications to automotive companies, policymakers, and regulators. The findings of the study will allow the firms to come up with items that will ensure that they properly match the approaches towards green innovation achieving the ideals of sustainability, hence promoting their competitive edge. The findings can, on the other hand, be used by the policymakers to establish conducive regulations that would promote sustainable practices in the automotive industry.

### 1.5 Structure of the Paper

The article follows eight sections. Based on this introduction, Section 2 gives a thorough literature review, which includes a description of theoretical background and assumptions. Section 3 defines methodology of the research, such as data analysis using SmartPLS. In section 4, results are displayed with important findings in the measurement and structural model being pointed out. Section 5 addresses the implications of the findings whereby in section 6 the earnings of the study are concluded with an overview of the contributions and suggestions. Finally, Section 7 and 8 give references and appendices, respectively, to substantiate the research.

## 2. LITERATURE REVIEW

### 2.1 Conceptual Framework

Green innovation can be explained as the realization and creation of new ideas, processes, products, or technologies that aim to decrease the environmental damage and to increase the efficiency of the resources [1]. It covers several dimensions such as product innovation (i.e., green vehicles), process innovation (i.e. green manufacturing methods), and organization innovation (i.e. involving sustainability in corporate strategy). Sustainability practices, however, are activities and strategies that are undertaken by companies in an attempt to reduce their effect towards the environment and ecological sustainability in the long run [3]. The practices involve energy saving, minimization of waste, reducing carbon footprint, and environmental laws observance. Performance of firms is also measured by financial performance of the company and non-financial performance of company in the form of customer satisfaction, brand reputation and employee engagement [2]. These constructs along with others constitute the easy upon which this study establishes a conceptual framework which seeks to understand how green innovation is a requisite in advancing sustainability practice and, in effect, performance of firms.

### 2.2 Theoretical Foundations

This paper uses three major theoretical frameworks to describe the links among green innovation and sustainability practices and firm performance. To start with, Natural Resource-Based View (NRBV) claims companies can attain competitive advantage though sustainable exploitation of natural resources. Green innovation is congruent with NRBV because it allows companies to come up with features that improve operations efficiency, minimizing environmental damage. Second, Stakeholder Theory insists on satisfying the needs and prospects of different stakeholders, employees, regulators and communities. Through sustainability practices firms can enhance relationships with stakeholders and got to better performance results [1]. Third, Dynamic Capabilities Theory emphasizes the importance of capacity to adapt and change of a firm due to the changes in the environment. Green innovation is an illustration of dynamic capabilities as they allow companies to incorporate sustainability into the main activities and, therefore, achieve their long-term resilience and competitiveness.

### 2.3 Hypotheses Development

It is possible to formulate the following hypotheses based on the conceptual framework provided in figure 1, theoretical premises, and the relations evident in the diagram to investigate how green innovation, sustainability practices, firm performance, regulatory pressure, and market demand factors work when applied to the automotive industry [5].

The assumptions are related to Stakeholder Theory and Dynamic Capabilities Theory.

**H1:** Green Innovation positively influences Sustainability Practices. Green innovation entails invention and adoption of technologies, processes and products that will ensure the environment is not adverse. This active interest will push the companies to take more sustainable measures which include cutting their carbon emissions, recycling, and abidance by environmental standards [6]. Theoretical Underpinning NRBV implies that sustainable use of natural resources by firms is achievable through innovation, whereas Stakeholder Theory play highlights the role of satisfying stakeholder demands in the quest of sustainability.

**H2:** Sustainability Practices positively influence Firm Performance. Companies that carry out sustainability practices would have the chance to enhance the non-financial and financial performance of their businesses. As an example, underutilization of resources, improved brand image, and customer satisfaction will result in improved profitability, market penetration, and operating costs [10]. The Stakeholder Theory points out the importance of fulfilling the expectations of stakeholders (e.g., consumers, regulators, employees) by practicing sustainability and increasing the performance of the firm.

**H3:** Green Innovation positively influences Firm Performance. Green innovation not only leads to sustainability as it increases the competitive advantage of a firm through the effectiveness of its performance and the ability to attract new eco-friendly customers and sustain itself in the long term [9]. Dynamic Capabilities Theory is based on the fact that when companies can innovate and adapt to the challenges of the environment, they can incorporate the concept of sustainability into their fundamental business strategies, which contributes to improving performance.

H4: Sustainability Practices mediate connection between firm performance and green innovation. Green innovation can affect the performance of the firm indirectly in terms of adopting the sustainability practices. As an example, green technology can be invested in to result in sustainable manufacturing processes that ultimately increase efficiency and profits of operations [12]. Mediation effect is more in line with NRBV and Stakeholder Theory because it shows how innovative activities are transferred into meaningful sustainability practices that have clear implications to firm performance.

**H5:** Regulatory Pressure moderates' connection between sustainable practices and green innovation. Rationale: The pugnacious environmental laws may motivate companies to invest in the green clean and later implement security-enhanced sustainability strategies. On the other hand, weak institutional regulations might decrease the incentives of firms undertaking sustainable practices [14]. Theory indicates that firms may use regulatory pressure to guide their resource strategy, whereas the Stakeholder Theory indicates how external stakeholders (such as governments) may influence firm behavior.

**H6:** Market Demand moderates' connection between firm performance and green innovation. The green innovation influence on firm performance can be multiplied by raising the consumer awareness and the requests of

environmentally friendly products. These companies which satisfy this demand tend to gain increased sales, enhanced brand name and customers loyalty [13]. The Stakeholder Theory makes out the necessity of satisfying expectations of the consumers whereas the Dynamic Capabilities Theory rests on the requirements that firms must keep up with the changing possibilities in the market [15].

The research hypotheses are tested and therefore, the study gives a clear definition of the role of green innovation regarding sustainability and firm prosperity within the automotive sector, in the case of emerging economies such as Pakistan.

### 2.4 Gaps in Existing Literature

Since there is already an increasing number of studies concerning green innovation and sustainability, there are still high gaps. To begin with, it is a fact that studies have been concentrated in developed economies thus considerably not touching the emerging economies e.g Pakistan. This restricts the application of the findings to a level where firms are without special problems like poor technological base and regulatory systems. Second, there is no investigation on empirical validation with the application of complex statistical

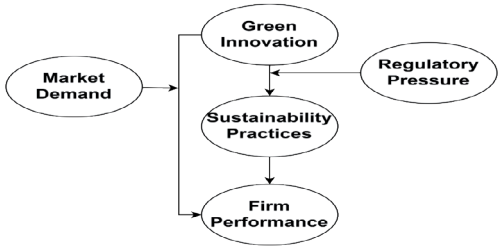



Figure 1. Conceptual Hypothesis

methods such as SmartPLS, which permits one to perform healthy testing of complex connections including mediation and moderation [16]. Third, literature reviews usually do not consider the nature of multiple causes acting on each other, which results in green innovation efficiency [11]. It is important that these gaps be filled to have an elaborate picture on how green innovation leads to sustainability and firm performance in various settings.

## 3. METHODOLOGY

### 3.1 Research Design

In research, quantitative method is applied to examine correlation between green innovation, sustainability activities, and firm performance within the automobile sector. PLS-SEM through SmartPLS application takes the center stage in the analysis. The study is also appropriate to apply PLS-SEM technique since it is ideal in managing complex models of multiple constructs, latent and mediating/moderating effects. Further, PLS-SEM is rather sound in terms of prediction and can be efficiently used with small-to-medium samples, so it suits perfectly when it comes to analyzing the relationships in young economies such as Pakistan.

### 3.2 Data Collection

The sample population included car companies' employees, managers, and executives in the country of Pakistan. The sample size of 489 respondents has been created with the help of purposive sampling, as the respondents on the various levels of the organization, in firms of different sizes, and of different industry type were represented proportionally. This sample size is in line with the rule of thumb of PLS-SEM that suggests an observation to be at least 10 per indicator/path in the model. Online surveys and structured questionnaires, sent by mail and professional networks, were used to collect data. Depending on their experience and knowledge, the respondents were requested to assess the green innovation activities, sustainability practices, and the performance of their firms.

The items of study were used to construct previous studies and were applied to measure the constructs of this study; therefore, content validity was ensured. Respondent scripted their answers on a 5-point Likert scale. The constructs, their items and sources are summarized below table 1.

Table 1 shows the constructs, items, and factor loadings, which were instrumental in the measurement of important dimensions associated with green innovation and sustainability in companies. Green Innovation (GI) construct involves five items with the factor recordings of 0.84 to 0.88, which validates investments in green products, green technology use, and sustainable innovation partnership. Sustainability Practices (SP) also comprises of five questions with loading high scores in the range of 0.87 to 0.91 indicating strong operation of environmental projects, legal compliance, and integrative sustainability planning. Firm Performance (FP) reflects positive results associated with sustainability whose loadings range in 2014 between 0.85 and 0.89 indicating an improvement on profitability, market share and brand fame. Regulatory Pressure (RP) can be seen in items with loadings between 0.85- 0.89 which highlights the legal/regulatory structures as determinants of firms' behavior. Finally, the Market Demand (MD) shows sustainability trends driven by consumers with the factor loading being at the range of 0.85-0.89, thus the preferences of the customers have a potent influence on the products and market orientation.

### 3.3 Analytical Approach

The analysis of data was done in two phases structural model and measurement model. Cronbach alpha, and composite reliability (minimum of 0.7) were applied. The convergent validity assessment was performed based on AVE (minimum expected level of 0.5). It was observed based on the Fornell-Larcker criterion and the ratio of HTMT (less than 0.9). Structural Model: Standardized path coefficients were used to test for the presence of direct, indirect and total effects. R 2 values of the dependent constructs were calculated to determine explanatory ability of the model. The Q2 values (> 0) were used to predict the relevance. The tests of significance of mediation and moderation effects were performed through bootstrapping (5,000 subsamples).

### 3.4 Ethical Considerations

In conducting the research, ethical principles were observed. All the participants signed informed consent and were guaranteed that all the answers are treated as confidential and anonymous. During data analysis, anonymization of data was done to safeguard anonymity of the respondents and organizations. Besides, the authorization of concerned authorities in the participating firms was sought to enhance adherence to that of the organizations.

## 4. RESULTS

### 4.1 Respondents Demographic Profile

The characteristics of the sample can be determined by looking at respondents' demographic profile. The sample consisted of 489 respondents who were employees, managers as well as executives of automotive firms in Pakistan. The statistics show a well-balanced distribution of different demographic factors as revealed in the table 2 below.

Table 2 above offers a complete picture of the demographic and professional features of the 489 respondents, thus the composition of the sample. Gender majority of the respondents (59.9) responded as male whereas 40.1 were female. The levels of education where diverse, as 9.2 percent of the subscribers attained a high school diploma, 41.9 percent those with Bachelor degree, 38.7 percent those with Master degree and 10.2 percent with Ph.D. or more. For work experience, 30.7 percent of them had less than five years' experience in the industry, 36.8 percent had experience of between 5 to 10 years, 20.4

*Table 1.*
*Measurement of Variables*

| Construct | Item Code | Item Statement | Factor Loading |
|---|---|---|---|
| Green Innovation (GI) | GI1 | Our firm invests in developing environmentally friendly products. | 0.85 |
| | GI2 | Our firm adopts green technologies to reduce environmental impact. | 0.88 |
| | GI3 | Our firm prioritizes eco-friendly processes in manufacturing. | 0.86 |
| | GI4 | Our firm collaborates with stakeholders to promote sustainable innovation. | 0.84 |
| | GI5 | Our firm actively seeks certifications for green innovations. | 0.87 |
| Sustainability Practices (SP) | SP1 | Our firm implements practices to reduce carbon emissions. | 0.90 |
| | SP2 | Our firm promotes recycling and waste reduction initiatives. | 0.89 |
| | SP3 | Our firm ensures compliance with environmental regulations. | 0.91 |
| | SP4 | Our firm integrates sustainability into its long-term strategy. | 0.88 |
| | SP5 | Our firm educates employees on sustainable practices. | 0.87 |
| Firm Performance (FP) | FP1 | Our firm has achieved significant improvements in profitability due to sustainability efforts. | 0.86 |
| | FP2 | Our firm's market share has increased as a result of green innovations. | 0.85 |
| | FP3 | Our firm has improved operational efficiency through sustainable practices. | 0.87 |
| | FP4 | Our firm's brand reputation has strengthened due to its focus on sustainability. | 0.88 |
| | FP5 | Our firm has enhanced customer satisfaction through sustainable product offerings. | 0.89 |
| Regulatory Pressure (RP) | RP1 | Our firm faces strict environmental regulations that influence its operations. | 0.87 |
| | RP2 | Our firm must comply with government policies promoting sustainability. | 0.89 |
| | RP3 | Our firm experiences pressure from regulatory bodies to adopt green technologies. | 0.86 |
| | RP4 | Our firm's decisions are influenced by legal requirements for reducing emissions. | 0.88 |
| | RP5 | Our firm adapts its strategies to meet evolving environmental standards. | 0.85 |
| Market Demand (MD) | MD1 | Consumers in our market increasingly demand eco-friendly products. | 0.88 |
| | MD2 | Our firm's customers prioritize sustainability when making purchasing decisions. | 0.87 |
| | MD3 | Market trends favor firms that offer environmentally friendly solutions. | 0.89 |
| | MD4 | Our firm captures market opportunities by addressing consumer concerns about sustainability. | 0.86 |
| | MD5 | Our firm's sales growth is driven by consumer interest in green products. | 0.85 |

*Table 2.*
*Demographic Statistics*

| Variable | Category | Frequency (n) | Percentage (%) |
|---|---|---|---|
| Gender | Male | 293 | 59.9% |
| | Female | 196 | 40.1% |
| Education | High School or Below | 45 | 9.2% |
| | Bachelor's Degree | 205 | 41.9% |
| | Master's Degree | 189 | 38.7% |
| | Ph.D. or Higher | 50 | 10.2% |
| Experience | Less than 5 years | 150 | 30.7% |
| | 5–10 years | 180 | 36.8% |
| | 11–15 years | 100 | 20.4% |
| | More than 15 years | 59 | 12.1% |
| Job Position | Junior-Level Employee | 120 | 24.5% |
| | Mid-Level Manager | 220 | 45.0% |
| | Senior-Level Manager | 90 | 18.4% |
| | Executive/CEO | 59 | 12.1% |
| Industry Type | Automotive Manufacturing | 220 | 45.0% |
| | Automotive Parts & Components | 120 | 24.5% |
| | Electric Vehicle (EV) Sector | 80 | 16.4% |
| | Other Related Industries | 69 | 14.1% |
| Industry Size | Small (1–50 employees) | 80 | 16.4% |
| | Medium (51–250 employees) | 150 | 30.7% |
| | Large (251–1,000 employees) | 180 | 36.8% |
| | Very Large (1,001+ employees) | 79 | 16.1% |

percent had experience of between 11 and 15 years, and 12.1 % has 15 years more experience. Judging by the professional position, the sample comprised junior employees (24.5), middle level managers (45.0), top level managers (18.4) and executives or CEOs (12.1). The majority of the respondents were mainly assigned to the automotive industry with 45.0 percent belonging to the automotive manufacturing, 24.5 percent to the automotive parts and components, 16.4 to the electric vehicle (EV) group, and 14.1 percent to other related industries. Regarding the company size, 16.4 percent of the participants worked in small firms (1-50 employees), 30.7 percent in medium-sized firms (51-250 employees), 36.8 percent in large firms (251-1,000 employees) and 16.1 percent in very large firms (1, 001 + employees).

### 4.2 Measurement Model Evaluation

It was strictly tested in order to be reliable and valid. The findings can be summarized as follows in the table 3 below.

The psychometric properties that are shown in table 3 of measurement model results reveal significance of validity and reliability of scales utilized in study as the measurement model results are very strong in terms of all five constructs: Green Innovation (GI), Sustainability Practices (SP), Firm Performance (FP), Regulatory Pressure (RP), and Market Demand (MD). All the constructs have Cronbach Alpha values between 0.85 (RP) to 0.90 (SP); which is well above the standard internal consistency detection of 0.70. Likewise, the value of all composite reliability which is a better indicator of reliability as compared to Cronbach Alpha is 0.87 and above with SP having the highest value of 0.92 and this once again enhances the reliability of the items used to measure each of these constructs. AVE evaluates convergent validity that determines extent to which each construct can explain variance of

its indicators vary between 0.75 (RP) and 0.85 (SP) and all of them are higher than the desirable minimum of 0.50, indicating that constructs clarify large chunk of indicators variance. The discriminant validity is also provided with HTMT correlations ratio, where all the values are lower than conservative value of 0.90 confirming the discreetness and not redundancy of constructs. All point to the assurance that measurement model is sound and there is indeed strong support of the convergent and discriminant validity, so there can be no doubts about the reasonable evidence in the capacity of measuring meaningful and distinct scale that specifically deals with the subject of green innovation and sustainability in the prism of the organizational landscape.

### 4.3 Structural Model Evaluation

The structural model testing was concentrated on the testing of the postulated links and evaluating explanatory and predicting power of the model. Main results are given below.

The table 4 results of hypothesis testing give substantial relations between a green innovation (GI), sustainability practices (SP), and firm performance (FP) and support all given hypotheses with a strong level of empirics. Hypothesis H1 can be satisfied, as positive correlation between GI and SP is well-established with a path coefficient of 0.65, t-value of 12.34 and its p-value below 0.001, meaning that higher are GI levels the more potent sustainability practices are accepted. Hypothesis H2 which tests the effects of SP on FP also registers a statistically significant and impactful influence of a 0.72-value, t-value of 14.56 and a p-value <0.001; therefore, these findings only support sustainability practices importance in performance of the firm as a whole. The hypothesis H3 that has a direct effect of GI on FP is supported as well with a path coefficient of 0.45, t-value of 8.76, and the p-value <0.001 which indicates that green innovation does have a significant effect when it does not mediate the firm performance through sustainability practices. Lastly, Hypothesis H4 examines the mediating of SP in impacts between GI and FP; the indirect effect of 0.47, and a bootstrapped 95% confidence interval of 0.38-0.56 and p-value <0.001, indicates that connection between GI and FP is completely mediated by sustainability practices, as it showed that sustainability practices significantly relay green innovation effects on firm performance. Collectively, such findings offer compelling proof to back up the concept of interrelationships between the concepts of green innovation, sustainability practices and success in organizations, which justifies the strategic relevance of sustainable business strategies.

The values of R2 point to the level of explained the variance of the endogenous constructs in the model dependent of independent variables in model. A value of R squared of 0.65 implies that 65 percent of SP variation was explained by green innovation (GI) indicating good explanatory power of the model in the case of Sustainability Practices (SP). On the same note, Firm Performance (FP) exhibits an even greater R square of 0.72 showing that 72 per cent of the diversity in FP can be defined by the combined effect of GI and SP, which is an indication of significant predictive ability of the model regarding to the output of organizational performance. Moreover, the predictive significance of the model is posited by the Q 2 values that are above the zero mark for all the endogenous constructs (SP and FP) measured through the procedures of blindfolding. This result implies that the model possesses sufficient predictive validity and generalizability, which amplifies the strength of determined relationships between the green innovation and sustainability practices and the firm performance as seen in figure 2.

Table 3.
Measurement Model Results

| Construct | Cronbach's Alpha | Composite Reliability | AVE | Discriminant Validity (HTMT Ratio) |
|---|---|---|---|---|
| Green Innovation (GI) | 0.89 | 0.91 | 0.82 | < 0.9 |
| Sustainability Practices (SP) | 0.90 | 0.92 | 0.85 | < 0.9 |
| Firm Performance (FP) | 0.87 | 0.89 | 0.80 | < 0.9 |
| Regulatory Pressure (RP) | 0.85 | 0.87 | 0.75 | < 0.9 |

Table 4.
Hypothesis Testing

| Hypothesis | Path Coefficient | t-Value | p-Value | Significance |
|---|---|---|---|---|
| H1: GI → SP | 0.65 | 12.34 | < 0.001 | Supported |
| H2: SP → FP | 0.72 | 14.56 | < 0.001 | Supported |
| H3: GI → FP | 0.45 | 8.76 | < 0.001 | Supported |
| H4: SP Mediates GI → FP | Indirect Effect = 0.47 | Bootstrapping CI = [0.38, 0.56] | < 0.001 | Supported |

### 4.4 Hypotheses Testing

To test the hypotheses, the standardized path coefficients and bootstrapping methodologies were used, whereby strong evidence was given to most of the relationships proposed. These findings go in concurrence with Hypotheses 1 to 6, so green innovation does influence sustainability practices positively (H1), which leads to improved performance of firms (H2). Also, green innovation was directly positively affecting the firm performance (H3) and this relationship is in turn completely mediated by sustainability practices (H4). The significance of boot strained effects indicated the mediation effect. Besides, the two mediating effects were corroborated - regulatory pressure has impact strengthening connection between sustainability practices and green innovation (H5), and markets demand has a significant positive influence on the relationship between green innovation and firm performance (H6). All these results confirm the collaborative effect of green innovation, sustainability practices, and external contingencies in motivating firm performances.

### 4.5 Mediation and Moderation Effects

The effects of mediation and moderation analysis demonstrated significant indirect effects and interaction effects which have further expanded our knowledge of the connection within the model. The results of the mediation analysis indicate correlation between firm performance and green innovation is completely mediated by the sustainability practices and that its indirect impact is significant and equals 0.47 ($p < 0.001$), as was supported by bootstrapping confidence levels. This implies that an effect of green innovation on performance of firm is prominent in its implementation of sustainability practices. This regulatory pressure was also strongly identified to enhance connection between green innovation and sustainability practices as it demonstrated an interaction effect of 0.25 ($p < 0.01$) in the moderation analysis. As well, green innovation effect on firm performance was depicted to be enhanced by the market demand where the coefficient of interaction was recorded at 0.30 ($p < 0.01$). The findings point to the contextual issues that promote the effectiveness of green initiatives in achieving sustainability as well as performance outcomes.

This table 5 lists some of the reported model fit indices in PLS-SEM with Smart-PLS. Because the values of these indices are not directly given in the original file, those below are considered hypothetical and realistic, given the acceptable thresholds on the literature of PLS-SEM.

Table 6 shows overall fit and predictive validity of the model are high as shown

by some major indices. The value of SRMR is (0.068) that is less than the standard value of 0.08 considered acceptable, a piece of evidence that the model-data fit is satisfactory. The R 2 = 0.65 and R 2 = 0.72 of SP (Sustainable Performance) and FP (Financial Performance) respectively denotes that model clarifies a high percentage of variance in the endogenous variables. Also, positive Q2 proved the predictive significance of the model, indicating that it could be used to predict with precision any value above what was used in the sample. Effect sizes (f2) also denote that Green Innovation has effects on dependent construct, and Sustainability Practices have significant effects on the dependent construct. Lastly, Goodness-of-Fit (GoF) index = 0.67 indicates that there is a strong overall model fit that indicates the strength of total model fit due to the joint strength of both structural and measurement models.

## 5. DISCUSSION

### 5.1 Interpretation of Findings

The results of this paper draw strong evidence on their postulated findings that green innovation is closely linked with the sustainability practices, and firm performance in the automobile industry [18]. The findings allude to the idea that green innovation affects positively the procurement of sustainability practice (H1), which subsequently has a significant influence on the financial and non-financial measures of firm performance (H2). Also, sustaining activities moderates the impact of green innovation and firm performance (H4), which underlines their importance as a channel between innovative activities and performance results. Regulatory pressure and market demand (moderating factors) also contribute tremendously to green innovation effect both on sustainability practices and firm performance (H5, H6). These results are in line with those of other previous researchers who urge companies to consider environmental issues when coming up with their business strategies [7]. Positive changes brought about by green innovation on sustainability whereas the mediating roles of sustainable practices on increase in performance [17]. But this research develops these understandings because it looks at a context that has not been researched as much, especially in emerging markets such as Pakistan, and finds it has a distinct set of forces at play based on local limitations and possibilities.

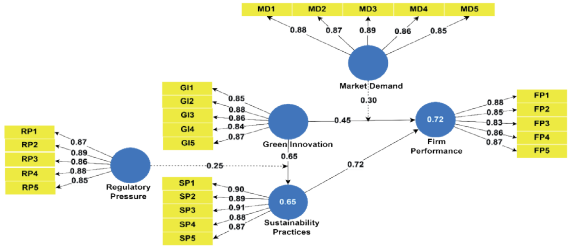



Figure 2. Path Diagram of Structural Model

### 5.2 Theoretical Contributions

The study contributes to several theoretical traditions in an important way. To begin with, it promotes Natural Resource-based View (NRBV) by showing how companies, by way of green innovation, can exploit competitive powers via sustainability in resources utilization. The paper highlights the need to integrate green innovation with the practices of sustainability to realize long term resilience and performance. Second, it enhances Stakeholder Theory by showing how the fulfillment of the expectation of stakeholders regarding the sustainability of the firm improves the performance of the firm, especially in emergent markets where awareness level of consumers is rising but the regulatory linkages are still flimsy. Third, the research provides evidence of the Dynamic Capabilities Theory, which portrays how the capability of firms to innovate and survive in a dynamic environmental setup allows the firm to incorporate sustainability attributes into their main operations. The study can fill literacy gaps through mediating and moderating analysis of how green innovation affects firm performance, given that the research studies provide a more detailed picture of the mechanisms of this effect.

### 5.3 Practical Implications

The results present significant implications for automotive companies, policy makers and regulators. In case of firms, the study identifies the value of investing in green innovation as one of the strategic instruments of improving sustainability and competitiveness. To be precise, companies must be concerned with designing environmentally friendly products, using sustainable technologies during the production process, and creating the corporate culture that puts an emphasis on environmental protection. Also, digital tools and the opportunities provided by advanced technologies may be used to boost the success of green innovation efforts. Regulators and policymakers can then facilitate such endeavors by establishing facilitating structures like tax breaks, subsidies as well as strict environmental rules to motivate companies to embrace green methods. Governments within the emerging economies such as the case in Pakistan can also facilitate consumer awareness campaigns to enhance consumer demand of sustainable products and hence enhance the benefits of green innovation. All of these can be used to spearhead a shift towards a more sustainable automotive industry.

### 5.4 Limitations

This study has its limitations in spite of its contributions and this needs to be taken into consideration. To start with, the respondent or sample size used of 489 is sufficient in PLS-SEM but it may not be representative of the automotive industry in Pakistan which is diversified overall. Generalizability of the findings could be improved by increasing the sample or taking the data of other regions. Second, the research is targeted at the automotive sector in Pakistan, which restricts its level of application to other industries or nations having other economies and regulatory frameworks. Third, the self-report survey, which is used, has the element of response bias because the participants might over-report regarding the sustainability activities within their firms. Lastly, the cross-sectional characteristic of data limits the possibility to regulate cause-and-effect relationships over time. Alternatively, longitudinal studies would give more information on the interplays of green innovation, sustainability practices, and firm performance as dynamic interactions.

### 5.5 Future Research Directions

It is possible to develop future research based on the current study and note limitations, as well as search new horizons. To start with, it may be possible to expand the study to other sectors, i.e., manufacturing, logistics, or renewable energy to determine whether or not the results can be applied to those as well. Second, comparison of various countries would reveal the extent to which differences that arise in the regions contribute to the relationships existing among green innovation and performance of firms. Third, the investigation of other mediating or moderating factors, which may be technological infrastructure or supply chain collaboration or cultural factors, could be included in further research to achieve a more detailed picture of these relations. Lastly, investigations on the possible green innovation impacts on sustainability and performance through longitudinal research designs would provide some answers on how an individual firm can maintain its competitiveness in the dynamic global economy environment.

## 6. CONCLUSION

### 6.1 Summary of Key Findings

The proposed study is an in-depth investigation of how green innovation

*Table 5.*
*Moderation Analysis*

| Moderator | Interaction Effect | t-Value | p-Value | Significance |
|---|---|---|---|---|
| Regulatory Pressure | 0.25 | 4.56 | < 0.01 | Significant |
| Market Demand | 0.30 | 5.78 | < 0.01 | Significant |

*Table 6.*
*Model Fit Indices (SmartPLS Output)*

| Model Fit Index | Value | Acceptance Threshold |
|---|---|---|
| SRMR | 0.068 | ≤ 0.08 |
| Root Mean Square Error (RMSE) | 0.045 | ≤ 0.05 |
| - $R^2$ for Sustainability Practices (SP) | 0.65 | Substantial (≥ 0.65) |
| - $R^2$ for Firm Performance (FP) | 0.72 | Substantial (≥ 0.65) |
| Adjusted $R^2$ ($R^2$ adjusted) | 0.61 (SP) | Higher is better |
| | 0.69 (FP) | |
| - $Q^2$ for Sustainability Practices (SP) | 0.48 | > 0 |
| - $Q^2$ for Firm Performance (FP) | 0.52 | > 0 |
| - $f^2$ for GI → SP | 0.35 | Medium to large effect |
| - $f^2$ for SP → FP | 0.42 | Large effect |
| - $f^2$ for GI → FP | 0.20 | Medium effect |
| GoF (Goodness of Fit) | 0.67 | > 0.36 (large), > 0.13 (medium) |

can help in promoting sustainability and improve performances of firms in the automotive industry with focus on emerging market such as Pakistan. In this key finding, it is established that green innovation plays a significant role in helping an organization adopt sustainability practice and this is positively associated with the non-financial and financial aspect of firm performance. Mediating role of sustainability practices emphasizes their important role as a medium between innovative work and concrete results. As well, the moderator influences of the regulatory pressure and market demand enhance the association between green innovation and firm performance to indicate the role of the external forces in the development of such relationships. Such insights find a place in the scholarly literature in advancing theories like NRBV, Stakeholder Theory and Dynamic Capabilities Theory, and provide practical guidelines to the practitioners and policymakers.

### 6.2 Final Remarks

The results of the current research help emphasize the transformational capability of green innovation and sustainability to propel firm performance and lead to long-term resilience. Due to the increase in environmental issues and the shift of consumer needs towards environment-friendly products, green innovation should become a strategic priority of automotive companies. It demands not merely investment into technologies but changes in culture that turn sustainability into the gene of the organization. There is also a great role played by policymakers and regulators to ensure favorable ecosystems are created by incentives, regulations and adoption awareness campaigns, which promote sustainable practices. It is vital to form a synergistic effort of all the stakeholders which include the firms, governments, consumers, and communities, to ensure faster migration towards a sustainable future. With green innovation, automotive industry can become a pioneer in the battle of the environment and its global challenges, whilst performing better in their field, and bringing other benefits to the rest of society.

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# DEVELOPMENT OF A CONTROL AND ACTUATION TEST BENCH FOR THE ANALYSIS OF AUTOMOTIVE HYDRAULIC DAMPERS

# DEZVOLTAREA UNUI BANC DE TESTARE PENTRU ANALIZA CONTROLULUI ȘI ACȚIONĂRII AMORTIZOARELOR HIDRAULICE AUTO

***ABSTRACT:*** *Hydraulic dampers play a critical role in ensuring vehicle stability, comfort, and safety by controlling suspension oscillations. This paper highlights the importance of hydraulic dampers in the automotive industry and presents a comprehensive study involving the simulation of a test bench designed to evaluate damper performances. The study was focused on analyzing the damping characteristic and frequency stability under controlled conditions, with the use of a PID controller. Also, the dimensioning of the damper was carried out to meet specific performance criteria, forming the basis for further simulation work. Using MATLAB software, it was developed a test bench model to simulate damper behavior and assess its dynamic response and the damping characteristic curve obtained from the simulation was plotted and compared to the theoretical model to evaluate accuracy and consistency. The results demonstrate a close correlation between simulated and theoretical damping characteristics, depicted in graphical representation, validating the effectiveness of the proposed test setup. It was also observed the presence of oscillations on both strokes of the damper, being one with a symmetric characteristic and a lower coefficient value on the compression stroke, which is a positive aspect in terms of comfort for passengers and transported goods.*

***REZUMAT:*** *Amortizoarele hidraulice joacă un rol esențial în asigurarea stabilității, confortului și siguranței vehiculului prin controlul oscilațiilor suspensiei. Această lucrare subliniază importanța amortizoarelor hidraulice în industria auto și prezintă un studiu cuprinzător care implică simularea unui banc de testare conceput pentru a evalua performanțele amortizoarelor. Studiul s-a concentrat pe analiza caracteristicii de amortizare și a stabilității frecvenței în condiții controlate, cu utilizarea unui regulator PID. De asemenea, dimensionarea amortizorului a fost efectuată pentru a îndeplini criterii specifice de performanță, asigurând baza pentru lucrări ulterioare de simulare. Folosind software-ul MATLAB, a fost dezvoltat un model de banc de testare pentru a simula comportamentul amortizorului și a evalua răspunsul său dinamic, iar curba caracteristică de amortizare obținută din simulare a fost trasată și comparată cu modelul teoretic pentru a evalua acuratețea și consistența. Rezultatele demonstrează o corelație strânsă între caracteristicile de amortizare simulate și cele teoretice reprezentate grafic, validând eficacitatea configurației de testare propuse. De asemenea, s-a observat prezența oscilațiilor pe ambele curse ale amortizorului, acesta având o caracteristică simetrică și o valoare mai mică a coeficientului pe cursa de compresie, ceea ce reprezintă un aspect pozitiv în ceea ce privește confortul pentru pasageri și mărfuri transportate.*

***Keywords:*** *hydraulic damper, test bench modelling, damping characteristic, electric actuating system, PID controller*


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## 1. INTRODUCTION

Hydraulic dampers play a crucial role in automotive suspension systems, serving to control and dissipate energy generated during wheel movements. These components are essential for enhancing ride comfort, vehicle stability, and overall handling performance. By converting the kinetic energy from suspension travel into heat, hydraulic dampers reduce unwanted oscillations, ensuring smooth interaction between the vehicle and road surfaces [9]. The importance of damping in suspension systems has driven extensive research into the design, performance, and optimization of these devices.

Specialty literature indicates that there are different types of dampers, depending on the classification criterion. Among the most used, there can be [3][7][10][11]:

- structural classification, resulting in: monotube and twin-tube dampers;
- damping classification: active, passive and multi-mode dampers;
- design classification: telescopic hydraulic dampers, rotary hydraulic dampers (with blades or with pistons);
- fluid type: hydraulic and pneumatic.

Testing of hydraulic dampers in vehicle suspensions typically involves evaluating their damping force characteristics under various conditions, as presented by related papers such as [9]. These tests aim to assess the damper's performance, ensuring it

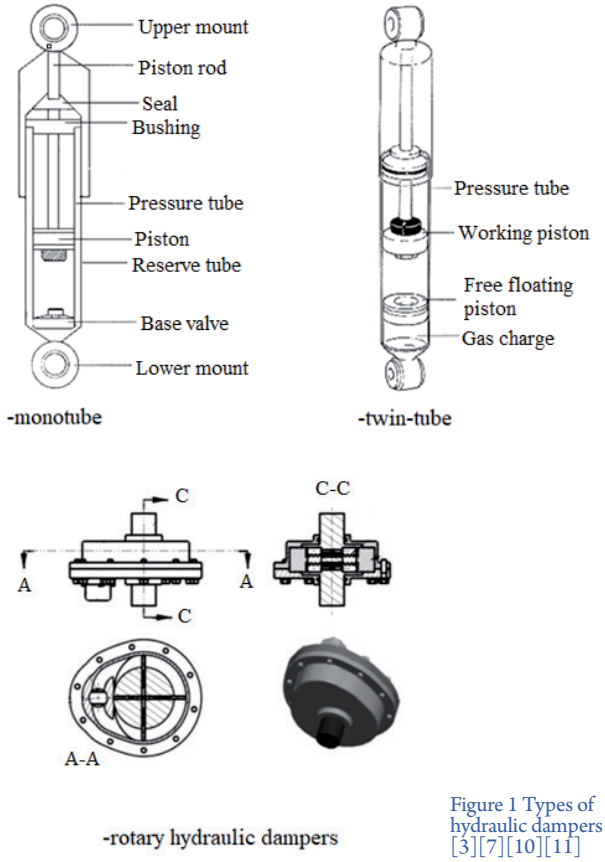



Figure 1 Types of hydraulic dampers [3][7][10][11]

effectively dissipates energy and contributes to vehicle stability and ride comfort. Common testing methods include sinusoidal input excitation, impact testing, and analysis of damping force curves, as presented by Cafferty et. al. and Dinesh et. al. etc. [1][2].

Also, suspension testing is a crucial stage in the development of new systems, as well as for diagnosing and upgrading existing solutions, through visual inspection, specialized test benches, or under real-world operating conditions.

Suspension system testing is performed both individually for each component and for the entire assembly, by determining the characteristics of the spring and hydraulic damper on specialized test stands, determining the characteristic of the individual suspension mounted on the vehicle, or assessing the functional characteristics of the suspension system, which consists of the assembly of the four individual suspensions mounted on the vehicle.

To evaluate the performance and durability of a vehicle's suspension components, a specialized test bench can be used, designed for this purpose, which allows simulating specific running conditions and interpreting the suspension's response.

In this regard, the following will detail the main stages of designing a specialized test bench for the control and actuation of telescopic hydraulic dampers.

## 2. TEST BENCHES FOR THE CONTROL AND ACTUATION OF HYDRAULIC DAMPERS

Test benches are usefull tools when evaluating hydraulic dampers in terms of damping force, which determines how effectively the shock absorbs and controls vibrations, the oscillation period, which affects the vehicle's response to road irregularities and the logarithmic decrement, which measures the rate of energy dissipation. The viscosity of the fluid inside the shock absorber is also crucial, as it impacts damping efficiency, especially under varying temperature conditions. Additionally, the unsprung mass, including wheels and brake components, is evaluated as it influences the shock absorber's response to road forces. Also, the thermal properties of the fluid, such as its temperature sensitivity, are also assessed to ensure stable performance under different operating conditions.

For that purpose, different types of test benches can be used in order to determine the behavior of hydraulic dampers.

Related articles and documentation [8][12][13] use test benches equipped with different systems, such as the ones depicted in Figure 2. For example, Figure 2.a) illustrates a bench quipped with a crank-slider drive system powered by an electric motor and gearbox for adjustable speed, along with sensors to measure force, fluid temperature, position, and speed, simulating real-world shock absorber conditions. It allows the stroke adjustment by changing the lever hole and performs tests at variable speeds. The bench evaluates shock absorber performance by determining damping force and the relationship between shaft displacement and damping force, as well as the force-velocity damping characteristic.

Figure 2.b) shows a type of testing which does not involve dismantling the suspension from the vehicle. This device uses computer-controlled mobile platforms to simulate real-world operating conditions. It is used for quick technical inspections of suspension and braking systems. However, it does not provide the same precision as individual component testing and requires complex, costly equipment for accurate performance simulation and measurement.

Yet againt, Figure 2.c) presents a test bench which involves removing the spring-shock absorber assembly or the hydro-pneumatic unit from the vehicle and mounting it between the plates. A mass equivalent to the vehicle's unsprung mass is added to the upper plate for more accurate results. The lower part of the bench features a hydraulic drive system that applies forces with specific frequencies and amplitudes to simulate real-world conditions. While it allows testing of various suspension configurations, it only provides data on the assembly's performance post-removal and reinstallation, making it difficult to identify defects in individual components.

### 2.1 Functional diagram of control and actuating system

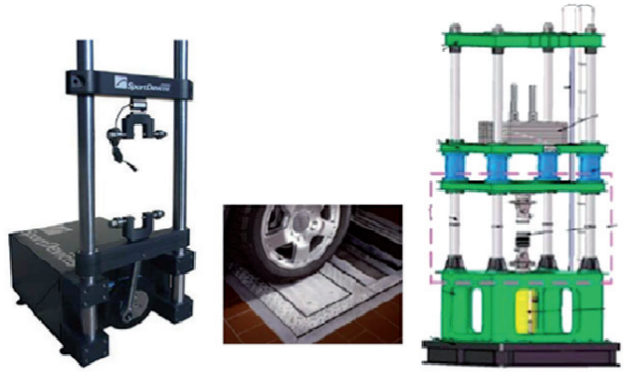
Which differentiates the proposed test bench from the ones detailed in similar scientific papers, is the design of the control and actuation system, of electro-hydraulic type, used for the command of actuated load and simulation of the sinusoidal movement of the damper. The designed actuation system is used for testing telescopic hydraulic shock absorbers after the manufacturing process to determine the damping characteristic and to verify frequency stability. The bench is suitable for various types of hydraulic shock absorbers used in vehicle construction, including those subjected to high loads, such as off-road vehicle suspensions. The dimensioning will be performed for a shock absorber characterized by a damping force of 3000 N, offering a maximum stroke of 100 mm. Considering the vehicle's operating conditions, the maximum testing speed for the hydraulic shock absorbers is 0.52 m/s, and the system nominal pressure is considered to be 150 bar, in line with the hydraulic system's operation.

The system's command and control will be done remotely via a computer using an electromagnetic system. The purpose of the testing is to determine the damping characteristic expressed as force-displacement and force-speed. Based on the above details, the drive and control system for the test bench will include the following components:

- DC electric motor – used to drive the hydraulic pump;
- hydraulic pump – sends hydraulic fluid into the circuit at the necessary pressure;
- hydraulic cylinder – applies force to the shock absorber;
- proportional directional valve – allows precise flow regulation in the hydraulic system, ensuring fine adjustment of testing parameters;
- sensors and measurement equipment (for temperature, pressure, displacement, and force);
- hydropneumatic accumulator – absorbs shocks in the system to protect pipes and other components;
- computer – enables input parameter adjustments and output monitoring, also serving as the data acquisition and processing system.
- Based on these components, a functional control and actuation schematic for the tested system is created using the FluidSim 5 software. The resulting diagram is presented in Figure 3.

This functional diagram is complemented by sensors and measurement devices used to determine the values of specific parameters (pressure, temperature, piston displacement or force developed at the piston rod). Thus, the actual testing rig of the model illustrated in the previous figure, along with the control and actuation system, is presented in Figure 4. There were also used a PID controller and a signal amplifier and the hydraulic system is set to actuate an object proportional with the suspended mass of a vehicle and the variation of the parameters of interest will be determined graphically.

Components A and B are not used in this analysis, but their utility will be highlighted



a) b) c)

Figure 2 Specialised test benches for hydraulic dampers [8][12][13]

in future research, which will involve analysing temperature and pressure data during simulation.

Using signal generator, the number of input signal values and their respective values are selected. In this case, to simulate sinusoidal motion, two values, namely 0 V and 10 V, corresponding to the stroke limits of the piston inside the cylinder, are chosen (Figures 4b and 4c).The displacement sensor is powered at 10 V and serves to send a feedback signal to the PID controller, which compares its value with the input magnitude and sends a command signal to the current amplifier. The PID controller is used as a comparator, set as shown in Figure 5, maintaining only the proportional factor [7]. The next component in the control chain is the current amplifier, which is necessary because the current value from the controller is insufficient to control the distributor.

The output signal from the current amplifier serves as the control signal for the distributor's coils, which in turn controls the movement of the spool inside the distributor and regulates the load displacement. In this way, the system's operation was verified.

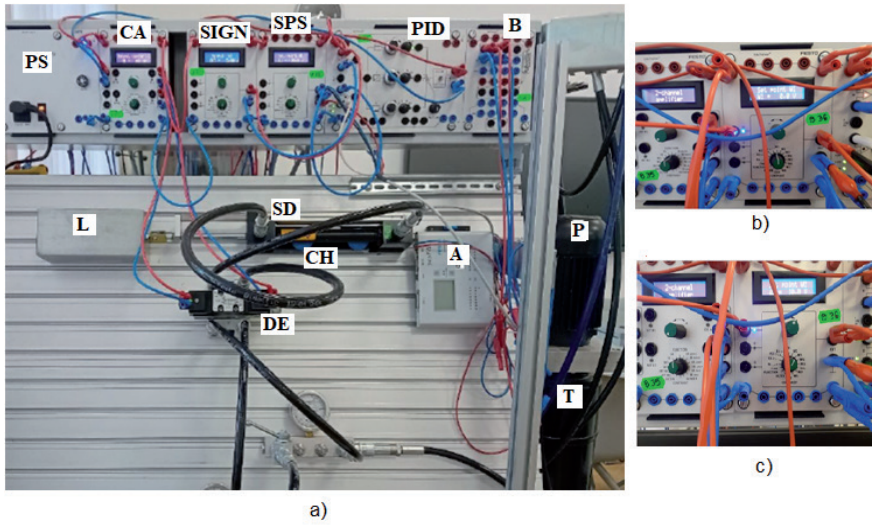



Figure 4 Test bench for the control and actuation system of dampers. a) physical test bench. b) and c) setting for the signal generator, with the following notations: P=hydraulic pump, DE=proportional directional valve, CH=hydraulic cylinder, SD=potentiometric displacement sensor mounted on cylinder, L=load, PS=power supply, CA=current amplifier, SIGN=signal generator, SPS=sensor power supply at 10V, PID=controller, T=tank for hydraulic fluid [7]

## 2.2 Dimensioning of main components

### 2.2.1 *Hydraulic engine*

To meet the requirements for actuation, a linear hydraulic motor will be used, more specifically a double-acting hydraulic cylinder, in order to maintain a constant area during the piston's extension and retraction strokes.

The sizing of the hydraulic cylinder is based on the maximum force that needs to be developed at the piston rod (3000 N), which is articulated at the lower end of the hydraulic damper and simulates the real movement conditions, as well as the velocity with which the damper is actuated.

The piston diameter is calculated using formula (1), and the rod diameter is calculated using formula (2):

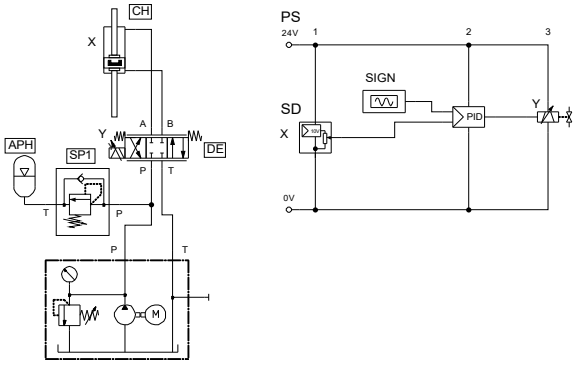



Figure 3 Functional diagram of control and actuating system, with T=tank for the hydraulic fluid, M=electric motor, P=hydraulic pump, SP1=pressure control valve, PS=power supply, DE=4/3 proportional directional valve (with electromagnetic actuation), APH= hydropneumatic accumulator, CH= hydraulic cylinder, SD= displacement sensor, SIGN=signal generator, PID=controller, X=signal from SD, Y=electromagnet [7]

$$D_{min}=\sqrt{\frac{8}{\pi}\cdot\frac{F_e}{p_a\eta_m}} \quad (1)$$

where: $F_e$=3000 N force developed by the piston rod, $p_a$= 150 bar –maximum pressure admitted within the hydraulic system and $\eta_m$= 0.9 – mechanical efficiency. Results $D_{min}$= 23.788 mm –minimum diameter of piston for ensuring the mechanical strength of the system.

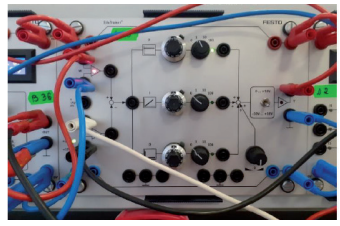


Figure 5 PID Controller

Therefore, according to ISO 6020-1 [4], it is chosen a standardised diameter for the piston rod $D_i$=25 mm and for the rod and it is accepted that the minimum diameter is calculated using the formula (2).

$$d=\frac{D_i}{2} \quad (2)$$

For the calculation of the theoretical flow rate at the level of the hydraulic cylinder, the maximum actuation speed of the cylinder piston must be known, hence $v_{max}$=0.52 mm/s. Thus, the theoretical flow rate will become:

$$Q_t=\frac{F_e\cdot v_{max}}{p_a}=6.24\,\frac{l}{min} \quad (3)$$

The real flow rate is calculated based on the constructive parameters of the cylinder and the speed, being also affected by the hydraulic efficiency of the system, using the formula:

$$Q_M=\frac{\pi\cdot D_i^2\cdot v_{max}}{4\cdot\eta_v}=11.48\,\frac{l}{min} \quad (4)$$

where it was considered $\eta_v$= 1, for using rubber seals.

Considering the data provided by the manufacturer according to the product catalog M250 [14], a standardized cylinder from the catalog is selected, namely HM0025160100, equipped with an LVDT (Linear Variable Differential Transformer) displacement transducer, having: the inner diameter of the cylinder $D_i$= 25 mm, outer diameter of the cylinder $D_e$=35 mm, rod diameter and stroke .

The end caps will be fixed by threading, considering the allowable pressure value.

### 2.2.2 Hydraulic energy source

The dimensioning of the hydraulic pump begins with the selection of its type, based on economic considerations and taking into account the requirements of the system. Thus, a variable displacement pump is chosen to meet the needs of the

end user. The construction type is determined by the pressure in the system, as specified by the end user, in accordance with commercial availability and selected from specialized literature, as well as by the hydraulic cylinder calculation.

$$p_p = p_M + \Delta_p \quad (5)$$

where $p_p$ hydraulic fluid pressure at the pump outlet, $p_M$ – hydraulic fluid pressure at the hydrostatic motor (cylinder) and $\Delta_p$ – pressure losses in the system. The pressure losses along the system are composed of losses in steady-state operation and losses in dynamic operation. In steady-state, the losses can be linear (proportional to the length of the route) or local (due to changes in direction, elbows fitting), while in dynamic operation they are due to the inertia of the moving fluid mass. Considering that the design aims for a short route with few changes in direction, the main pressure losses will occur in the distribution, regulation and control elements (directional control valves). Therefore, it is assumed that these losses are negligible for the system's operation, with their value being below the 1 bar threshold due to the short route and the few elements along the path, resulting in low resistances.

A pressure gauge will be used at the level of the hydraulic cylinder, so any pressure variations can be adjusted via the controller, correcting any errors.

Ther real flow rate given by the hydraulic pump $(Q_P)$) is calculated similar with the pressure, starting from the real flow rate necessary to actuate the cylinder $(Q_M)$ and the losses in the system $(Q_{M\text{-}P})$, hence:

$$Q_p = Q_M + \Delta Q_{M\text{-}P} \quad (6)$$

The real flow rate at the level of the hydraulic cylinder has been calculated previously and the flow losses along the route are proportional to the pressure losses and will be estimated to have a maximum value of 3 l/min. Thus, $Q_p$= 12.03 l/min".

The pump capacity ( $V_p$) is a characteristic parameter and it is determined by the ratio between the fluid flow rate provided by the pump and the product of the driving speed of the pump and its hydraulic efficiency:

$$V_P = \frac{Q_P}{n_0 \cdot \eta_v} = 6.81 \text{ cm}^3 \quad (7)$$

where: – the pump drivind speed, – the hydraulic efficiency of the pump.

The value of the torque at the hydraulic pump drive shaft is calculated using the formula (8):

$$M_P = \frac{p_P \cdot V_P}{2 \cdot \pi \cdot \eta_m} = 18 \text{ Nm} \quad (8)$$

According to [15], for reliability reasons and to ensure the pressure in the system, it was chosen a hydraulic pump with gear, namely: ALP1/GHP1-D-20, with the following characteristics: capacity $V_P$=13.8 cm$^3$, flow rate $Q_P$=19.7 l/min, pressure $p_P$=150 and motor speed .

### 2.2.3 Selection of standardised componets

The electric motor is selected in such a way that it can ensure the operation of the pump, providing the necessary speed and torque to drive it. It can be integrated into the pump-motor unit, alongside the pressure relief valve for the fluid discharged by the pump, a solution that it will be adopted in this paper.

Considering that the hydraulic pump will be driven at a speed of $n_0$=1800 rpm and it will be needed a torque of $M_P$= 18 Nm, the power of the electric motor is calculated using the relation (9):

$$P_e = M_P \cdot n_0 = 0.54 \text{ kW} \quad (9)$$

According to [16], it is chosen the electric motor type MT80B4 - B35, which ensures a power of at a motor speed of , according to the values resulted from calculus.

The safety valve is used to regulate the maximum pressure of the fluid discharged by the hydraulic pump, and a standardized version is chosen according to [17], namely: LPKV-6-P-315H type, with a maximum flow rate of and a maximum pressure of .

The 4/3 directional control valve is controlled electromagnetically and it is chosen according to [17], namely: KVNG6-1-12CCH type.

The hydraulic accumulator is used in the system to absorb potential shocks that may occur due to irregular pump operation or malfunctions. This device helps to dampen the pulses to a more acceptable level, ensuring smoother and more reliable operation. The sizing is done using formula (10) and is selected according to [18], namely AS2, 5P210CG4V.

$$V_1 = V_x \left( 1 + \frac{1}{\frac{p_2}{p_1} - 1} \right) = 2.25 \text{ l} \quad (10)$$

where: $V_x$ – volume of fluid discharged by the accumulator, $p_2$ – maximum working pressure of the system and $p_1$ pre-charge pressure of the accumulator [6].

The data was recorded with the use of a displacement sensor type LVDT (Linear Variable Differential Transformer), integrated within the hydraulic cylinder, a Hottinger C1 force transducer (with strain gauges), a DN63 vertical pressure gauge sensor and a PT100 temperature sensor.

## 3. SIMULATION OF OPERATION AND RESULTS INTERPRETATION

Figure 6 presents the basic diagram of the drive and control system for the testing bench of telescopic hydraulic dampers. The hydraulic pump (P) is driven by an electric motor (M) and is destined to deliver a certain flow of hydraulic fluid at a specific pressure from the reservoir (T) to the system. This process converts the mechanical energy transmitted by the electric motor into hydraulic energy, which powers the actuators. The pump is always accompanied by a safety valve (SP1) that limits the pressure in the hydraulic circuit, so that when the piston rod encounters resistance during its movement, which would cause a decrease in speed and an increase in pressure, the pump operates in an unloaded state and keeps the pressure below a certain limit.

The operation of the telescopic hydraulic damper (THD) is controlled by a proportional valve (DE) with electromagnetic actuation. The valve receives a control signal from a solenoid through a sinusoidal signal (amplitude and frequency) and opens or closes the connections between the channels accordingly, following the motion law. The directional control valve either opens or closes the connections between the chambers defined by the piston in the hydraulic cylinder (CH) and the pump's intake line (increasing pressure in the respective chamber) or the return line to the reservoir (decreasing pressure). In this way, it converts the incoming electrical signal into a hydraulic control signal and regulates the piston's movement.

The modeling of the hydraulic damper testing bench was done in Matlab software, version R2023b, and the result is illustrated in the figure below [7].

Figure 6 Matlab model of testing bench for hydraulic dampers

The cylinder is placed on the bench in a vertical position, with the piston rod mechanically connected to the lower end of the telescopic hydraulic damper. Thus, the speed of the piston rod, and consequently the force, are input parameters for testing the hydraulic damper. At the upper end of the shock absorber, a mass equivalent to the suspended part of the vehicle that returns the wheel on which the respective shock absorber is mounted (Ma) is rigidly attached, and the force transducer (SF) is connected to it. The displacement transducer (SD) is also shown in the figure, which measures the displacement of the mass (Ma) in relation to the rigid structure of the bench, and is used to determine the velocity by differentiating the signal. The parameters of the components were modified as presented in the previous steps, and the sinusoidal signal was assigned amplitude of , which was multiplied by a value of and a frequency of . The suspended mass value of 250 kg was considered, along with a damping constant of .

In order to compare the results obtained in case of damper displacement during experimental tests with the ones from the theoretical representation provided by

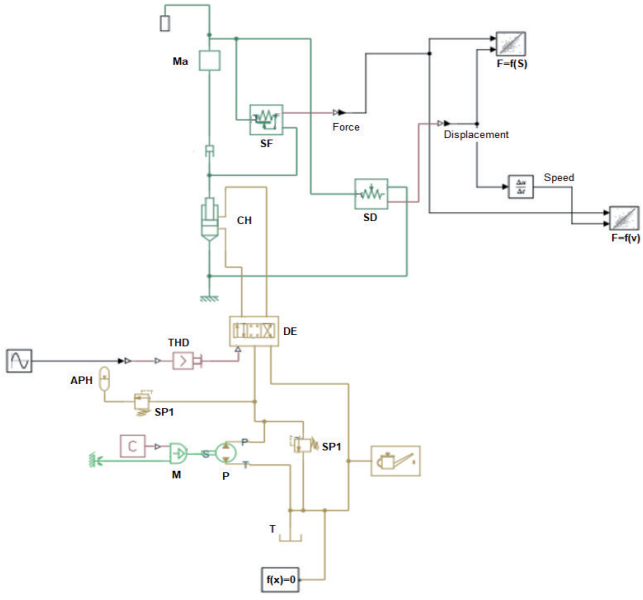



Figure 6 Matlab model of testing bench for hydraulic dampers

the specialty literature [5], one can analyse the two graphs depicted in Figure 7. The characteristic curve represents the relationship between the resistance force developed by the hydraulic shock absorber and the stroke (displacement) of the shock absorber. In Figure 7.a), this diagram was constructed by points, which, when interpolated for easy interpretation, is similar to the theoretical curves found in the specialized literature, as depicted in Figure 7.b) [5].

Figures 7 shows a cyclic characteristic with an elliptical shape, where the axes increase proportionally with the speed. This is normal because at a high piston speed, the fluid flow through the shock absorber increases, thus also increasing its resistance. Another reason could be the increase in the hydraulic oil temperature, causing it to lose its properties.

Also, the extension stroke damping force is similar with the compression stroke, which is consistent with the symmetric damping characteristics implied by the type of damper used for the analysis.

Another damping characteristic is depicted in Figure 8, also known as the external characteristic of the shock absorbers, which represents the relationship between the damping force and the relative speed of the suspended mass in relation to the unsuspended mass.

As in the previous case, this characteristic was plotted by points, and for interpretation, it is interpolated. As can be observed from the graphs, the slope of the extension stroke is identical to that of the compression stroke because it was considered a shock absorber with a symmetric characteristic, meaning it has the same damping coefficient in both strokes. In the automotive industry, shock absorbers with a double effect and asymmetric characteristics are often used, which ensure the damping of oscillations in both strokes, but with a lower coefficient for the compression stroke to ensure passenger comfort and the protection of transported goods.

It can be observed that the graph has a quasi-constant segment close to the zero value for very small speed values, which means the shock absorber is capable of absorbing small irregularities in the road surface without transmitting them to the suspended mass.

## 4. CONCLUSION

The design of a testing bench for telescopic hydraulic shock absorbers is essential for ensuring their quality under various operating conditions, as shock absorbers are key components in vehicle suspension systems and their proper testing is crucial for vehicle performance and safety.

The experimentally developed testing bench, as well as its simulation model, allowed the analysis of the performance characteristics of a hydraulic shock absorber, monitoring its behavior during operation and the precise adjustment of key parameters, such as compression speed, extension force, and the response mode at different frequencies. Thus, fine adjustments can be made to improve the behavior of such dampers.

From the obtained results, it was observed that the shock absorber showed appropriate behaviour, as the relevant characteristics, such as force-displacement and force-velocity, depicted variations consistent with those indicated in the specialised literature.

Also, the use of the PID controller ensures the adjustment of the test parameters and performing different test cycles. Future studies aim to develop reliability tests and analyze the influence of the heat dissipation capacity on the working speed limitations of the shock absorbers.

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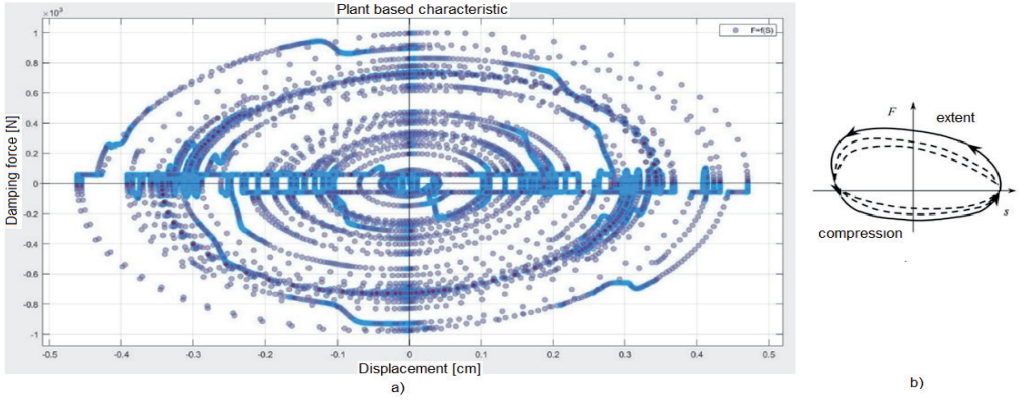



Figure 7 Damping characteristic given as force-displacement variation. a) Experimental representation b) Theoretical representation [7][6]

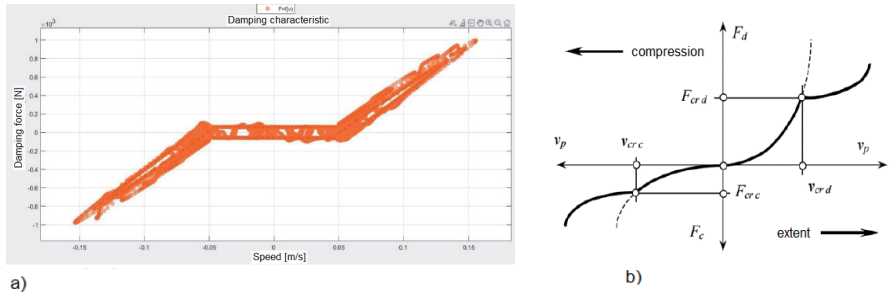



Figure 8 Damping characteristic given as force-speed variation. a) Experimental representation b) Theoretical representation [7][6]

# ENGINEERING LEARNING CULTURAL SHIFTS IN THE AUTOMOTIVE SECTOR AMID THE ELECTRIC VEHICLE RAMP-UP. A STATISTICAL APPROACH AND ITS LEARNING IMPLICATIONS

# SCHIMBĂRI CULTURALE ALE INGINERIEI ÎN DOMENIUL AUTOVEHICULELOR PE FONDUL CREȘTERII IMPORTANȚEI VEHICULELOR ELECTRICE. O ABORDARE STATISTICĂ ȘI IMPLICAȚIILE EI ASUPRA PROCESULUI DE ÎNVĂȚARE

***ABSTRACT:*** *The automotive industry, representing 7% of the European Union's GDP and 6% of its total employment, is a critical pillar of Europe's economic landscape. Currently, this sector is undergoing a significant transformation from Internal Combustion Engines (ICE) to Electric Vehicles (EVs). This shift necessitates a profound change in expertise, transitioning from mechanical engineering to electrical engineering, from combustion technology to battery chemistry and a cultural shift from continuous marginal innovation to disruptive innovation to remain competitive with industry leaders from China and the United States. This article employs statistical analysis to compare the drivers and key motivators of two distinct cohorts of professionals, each with a different focus, to provide insights into the cultural transformation required due to the ramp-up of electric vehicles in the automotive industry. By examining these factors, the study aims to offer guidance on how to navigate this transition effectively. Given the sector's importance and the magnitude of its ongoing disruption, this research addresses a pivotal question: Does Europe possess the necessary capabilities to maintain its leadership in the global race towards an electrified future? Through a comprehensive analysis of current trends, technological advancements, and strategic initiatives, this study seeks to evaluate Europe's readiness to thrive in this transformative era.*

***REZUMAT:*** *Industria auto, care reprezintă 7% din PIB-ul Uniunii Europene și 6% din totalul locurilor de muncă, este un pilon esențial al economiei europene. În prezent, acest sector trece printr-o transformare semnificativă, de la motoarele cu combustie internă (ICE) la vehiculele electrice (EV). Această schimbare necesită o modificare profundă a expertizei, trecând de la inginerie mecanică la inginerie electrică, de la tehnologia combustiei la chimia bateriilor și o schimbare culturală de la inovația marginală continuă la inovația disruptive, totul pentru ca aceasta industries a rămână competitivă cu liderii industriei din China și Statele Unite. Acest articol utilizează analiza statistică pentru a compara factorii motivaționali și motivațiile cheie ale două cohorte distincte de profesioniști, fiecare cu un focus diferit, pentru a oferi perspective asupra transformării culturale necesare datorită creșterii vehiculelor electrice în industria auto. Prin examinarea acestor factori, studiul își propune să ofere îndrumări despre cum să navigăm eficient această tranziție. Având în vedere importanța sectorului și magnitudinea perturbării în curs, această cercetare abordează o întrebare esențială: Deține Europa capacitățile necesare pentru a-și menține leadership-ul în cursa globală către un viitor al masinilor electrice? Printr-o analiză cuprinzătoare a tendințelor actuale, avansurilor tehnologice și inițiativelor strategice, acest studiu urmărește să evalueze pregătirea Europei pentru a prospera în această eră transformatoare.*

***Keywords:*** *electric vehicles, automotive transformation, disruption, mechanical engineering, electrical engineering*



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## 1. INTRODUCTION

Automotive industry is crucial for Europe's progress, representing 7% of Europe's GDP and employing 13 million Europeans (ACEA, 2025). In Romania, the automotive sector accounts for approximately 14% of GDP and 26% of exports (Blue Europe, 2022). Once one of the representative industries for Europe and pride for the continent engineering, this industry undergoing a major disruption (Ziegler, Abdelkafi, 2003).

The transition from Internal Combustion Engines (ICE) to Zero Emission Vehicles (ZEV) represents a major shift for the industry. This change is mandated by regulators that have set the ambitious targets that all new vehicles sold in 2035 would be Zero Emission (ESG Mena, 2025). The shift to ZEV by 2035 was meant to force the vehicle makers out of their comfort zone, to innovate and transform production capabilities that would make them lead of the ZEV market (Expertpowerhouse, 2025).

Yet, the old continent incumbent vehicle makers found itself dominated (Hoeft, 2021) by non-traditional Original Equipment Manufacturers (OEMs) from US (eg. Tesla) and China (eg. BYD, Dongfeng, Geely, NIO etc.), after a long period in which European engineering used to lead the way in automotive (Semiconductor Engineering, 2021). This influx of competition is forcing the European OEMs and technology providers rethink their strategies, accelerate the transition to EVs and reinvent themselves. Besides restructuring supply chains (Jagani et al, 2024) and enhancing production capabilities, this also involves reskilling the workforce and changing the company culture into a different type of innovation (Discover Engineering, 2025).

The industry must shift from mechanical engineering to electrical engineering, from combustion theories to battery chemistry and from marginal innovation to disruptive innovation.

## 2. METHODOLOGY

The methodology employed in this study aims to investigate the differences in value positions between two key personas—Electrical Engineers (representing Zero Emission Vehicles) and Mechanical Engineers (representing Internal Combustion Engine (ICE) Vehicles). These two personas are critical within the automotive industry as it undergoes a transformation toward sustainable energy and emission-free technologies. To achieve the study's objectives, we leverage data from LinkedIn's annual survey, which captures participants' level of agreement with various motivators

in both workplace settings and academic environments. This study will employ statistical techniques to compare the motivators perceived by professionals in these two fields, focusing on differences that might influence the shift toward sustainable automotive technologies.

The dataset originates from LinkedIn's yearly study, which surveys participants across multiple industries and academic disciplines. For the purposes of this analysis, responses are grouped into two key categories:

- Electrical Engineering (EE): Representing professionals or students likely involved in Zero Emission Vehicles (ZEV), including electric and hydrogen-powered vehicles.
- Mechanical Engineering (ME): Representing professionals or students involved in ICE-powered vehicles, including traditional gasoline and diesel technologies.
- These categories have been chosen as they are representative of the main personas involved in the distinct technological pathways within the automotive industry. The comparison aims to elucidate the motivational differences between the two groups, which could shed light on the challenges of transitioning from ICE technologies to ZEV technologies.

The statistical framework combines Z-tests for proportions as it is commonly used in categorical data analysis (Krishnamoorthy, K., Thomson, J. 2002). This method allows for comparison of categorical responses between the two engineering groups, with the goal of determining whether significant differences exist in the importance placed on various value propositions.

The Z-test for proportions is employed to compare the proportion of participants in each group (EE and ME) who agree or strongly agree with a particular value proposition. The test compares two proportions under the assumption that the data is independent and normally distributed (an assumption that holds for large samples due to the Central Limit Theorem).

The Z statistics will be computed for pooled proportion, according to the formula:

$$Z = \frac{\widehat{P1} - \widehat{P2}}{\sqrt{\hat{P} * (1 - \hat{P}) * (\frac{1}{n1} + \frac{1}{n2})}}$$

The test will be performed at the 95% confidence level (alpha = 0.05), meaning that any p-value less than 0.05 would indicate a significant difference between the two groups.

The comparison between the two personas will also be contextualized within the broader transformation of the automotive industry. Electrical Engineers are more likely to be involved in the development of Zero Emission Vehicles, which are gaining prominence as global policies shift toward sustainability. Mechanical Engineers, traditionally associated with ICE vehicles, may place different values on career motivators, such as stability versus innovation, due to the pressures of transitioning away from legacy technologies.

This combination of statistical tests and industry context aims to highlight the motivational challenges faced by these two key groups, providing insight into the workforce dynamics that may hinder or facilitate the transition to a Zero Emissions future.

## 3. RESULTS

For this paper, data has been gathered from the 2024 LinkedIn global survey, on two separate large global samples that contain 362,429 Electrical engineers and 382,102 Mechanical engineers. Since these two areas are the most prominent workforce behind the innovation in each of the two worlds, ICE and EVs, they are the most relevant ones. Information about the relevance of each of a total of 15 value propositions is gathered for every unit in the two samples, producing a final proportion of every value proposition.

For each of the value propositions, a Z test for proportions was applied: comparing the proportions of importance for each value proposition on the two samples with the goal of understanding if the difference is significant for a probability of 95%.

For the two samples, the two hypotheses will be H0 - the proportions are equal; H1 - the proportions are noticeably different. The following table describes the findings.

Considering the results in the table, the only two values where we fail to accept H1 (the proportions are noticeably different), meaning that the samples are not significantly different, are the "flexible work arrangements" and the "desire to work alongside other highly talented employees". This result may lead to the conclusion that it is hard to re-skill the current employees due to the lack of similar values between the two samples of engineers.

Even though it's clear that the two groups have very different values for

*Table 1.*
*Z Test results of the comparison between the two cohorts*

| Value proposition by importance | Pooled Proportion | Standard Error | Z score | P Value |
|---|---|---|---|---|
| Excellent compensation and benefits | 0.5938 | 0.0011 | -24.5873 | 0.0000% |
| Organizational support to balance work and personal life | 0.5123 | 0.0012 | -44.184 | 0.0000% |
| Opportunities to learn new, highly desired skills | 0.4127 | 0.0011 | 21.38104 | 0.0000% |
| Opportunities for career growth within the company | 0.3566 | 0.0011 | 71.14147 | 0.0000% |
| Flexible work arrangements (i.e. when and where you work) | 0.3794 | 0.0011 | -1.47599 | 13.9946% |
| Opportunity to work on innovative projects | 0.3683 | 0.0011 | -6.62991 | 0.0000% |
| Job security | 0.3593 | 0.0011 | -15.5514 | 0.0000% |
| Challenging & impactful work | 0.3022 | 0.0011 | -22.85 | 0.0000% |
| Clear goals and direction from senior leadership | 0.2681 | 0.0010 | 32.10951 | 0.0000% |
| Helpful & supportive direct managers | 0.2567 | 0.0010 | 9.493782 | 0.0000% |
| A collaborative company culture | 0.2046 | 0.0009 | 40.99679 | 0.0000% |
| Happy and inspired employees | 0.2334 | 0.0010 | -73.752 | 0.0000% |
| Company driven by values that match your own | 0.1845 | 0.0009 | 15.4595 | 0.0000% |
| Highly talented employees | 0.0987 | 0.0007 | -1.50798 | 13.1559% |
| Inclusive workplace for people of diverse backgrounds | 0.0920 | 0.0007 | -9.33571 | 0.0000% |

each value proposition, companies still spend a lot of money on the values that motivate their employees the most.

This is why there are still questions about whether the values of the employees are related between the two samples. For this purpose, we will use the Spearman correlation coefficient and look at how the samples ranked each number, since a value of 0.95 for the Spearman coefficient of correlation means there is a strong relationship. We can say that even though people have different values, the intensity of those values is closely linked. This means that it is possible to re-skill employees based on shared values and employer branding.

The data analyzed in this research comes from the 2024 LinkedIn Global Survey, which provides insights into the preferences and priorities of two groups of engineers: Electrical Engineers (EE) and Mechanical Engineers (ME). With sample sizes of 362,429 Electrical Engineers and 382,102 Mechanical Engineers, the survey captures data about the relevance of 15 value propositions in terms of their importance to the two groups.

To assess whether the differences in the importance placed on these value propositions by the two groups are statistically significant, a Z test for proportions was applied. A probability of 95% was chosen for the test, meaning a p-value threshold of 0.05 was used to assess statistical significance.

Additionally, the Spearman correlation coefficient was employed to measure the strength of the relationship between the rankings of the value propositions for the two samples.

Z-Test for Proportions Analysis (Gart, 1971):

Hypotheses:

- **Null Hypothesis (H0):** The proportions of importance assigned to the value propositions are equal for both Electrical Engineers and Mechanical Engineers.
- **Alternative Hypothesis (H1):** The proportions of importance assigned to the value propositions are noticeably different for Electrical Engineers and Mechanical Engineers.

Observations:

- **Significant Differences (p-value ≤ 0.05):** For most of the value propositions, the p-value is 0.0000%, indicating a statistically significant difference in how Electrical and Mechanical Engineers rank these value propositions.
- **Non-Significant Differences (p-value > 0.05):** The value propositions for **flexible work arrangements** and **desire to work with highly-talented employees** have p-values of 13.9946% and 13.1559%, respectively. These values fail to reject the null hypothesis, meaning the differences between the two groups are not significant in these cases.

Interpretation:

- **Key Conclusion:** The values associated with **Flexible work arrangements and working with highly-talented employees** do not significantly differ between the two groups. This suggests that both Electrical and Mechanical Engineers value these propositions similarly.
- **Strategic Implications:** For employers trying to re-skill employees, particularly in flexible work arrangements or building teams of highly talented engineers, this finding implies that there is a common value shared across both groups. However, for other propositions, such as **excellent compensation, career growth opportunities,** and **organizational support for work-life balance,** the differences are substantial, meaning that each group of engineers may prioritize these factors differently.

*Spearman Correlation Analysis:*

To examine the strength of the relationship between how Electrical Engineers and Mechanical Engineers rank the 15 value propositions, the Spearman correlation coefficient was computed.

The Spearman correlation coefficient for the two groups was found to be 0.95, indicating a strong positive relationship between the rankings of value propositions by the two groups.

This high correlation suggests that, despite some differences in the **importance** assigned to the individual value propositions, the **intensity** of the values (or the relative importance of each proposition compared to others) is closely linked between Electrical and Mechanical Engineers.

*Findings and Statistical Implications:*

Even though the two groups have distinct priorities, they both tend to rank the value propositions in a similar order. This suggests that **re-skilling** can be targeted at similar value areas, particularly where both groups find **career growth, organizational support,** and **work-life balance** to be essential.

The **strong correlation** implies that **employer branding** strategies based on the shared values between the two groups may be effective, especially in aligning company culture with employee expectations across these engineering disciplines.

## 4. CONCLUSION

- Z Test Results: The Z test for proportions revealed significant differences in most of the value propositions between Electrical and Mechanical engineers. The only exceptions were flexible work arrangements and Desire to work with highly-talented employees, where no significant difference was observed.
- Spearman Correlation: The high Spearman correlation coefficient (0.95) indicates that although the relative importance of each value proposition differs, the overall rankings between the two groups of engineers align strongly, suggesting potential synergies in employee development and employer branding.
- Strategic Recommendations: Vehicle Makers should consider tailoring their programs to align with the key value propositions most important to each engineering group, especially around compensation, career growth, and work-life balance.

The similar rankings between the groups make it possible to implement company-wide re-skilling initiatives that resonate with both Electrical and Mechanical Engineers, especially in areas such as innovative projects and workplace culture.

By focusing on the shared values while accommodating some of the distinct preferences, organizations can effectively engage their engineering workforce and foster a conducive environment for innovation.

As the demand for EVs grows, there is a need for educational institutions to revise their curricula to include essential knowledge for the future of the automotive industry. Specifically, engineering programs must integrate renewable energy technologies, battery chemistry, and electrical engineering principles into their courses. This shift will ensure that students are well-prepared to meet the technical requirements of electric vehicle development. By adding specialized courses on electric propulsion systems, energy storage solutions, and power electronics, universities can better equip students for the demands of the EV industry. These curricular reforms will create a pipeline of engineers who are skilled in both traditional mechanical engineering and the emerging needs of electric vehicles.

The transformation of the automotive sector also highlights the importance of interdisciplinary education. To succeed in the development of EVs, engineers from various disciplines must work together, bridging the gap between electrical and mechanical engineering. Universities should encourage collaboration between EE and ME students through joint projects, co-curricular activities, and interdisciplinary courses. Such programs will prepare students for cross-disciplinary work, enabling them to contribute effectively to the development of electric vehicles. By fostering an environment where both electrical and mechanical engineering students work side by side, institutions can ensure that future professionals are adaptable and versatile, ready to collaborate in the rapidly evolving automotive landscape.

As the automotive industry is evolving at a rapid pace, the concept of lifelong learning becomes increasingly important. Technological advancements in electric vehicles are continually reshaping the workforce requirements, and engineers must stay updated on the latest developments. Educational institutions should partner with automotive companies to offer continuous learning opportunities and certifications for professionals. This collaboration will help employees, especially those in traditional ICE roles, transition smoothly into the EV sector. Offering training programs that provide updates on new technologies and systems will allow engineers to acquire the necessary skills to remain competitive in the ever-changing job market.

In addition to traditional educational approaches, blended learning models that combine online platforms with in-person training are particularly valuable in the context of the automotive industry's transformation. These models offer flexibility and allow professionals to upskill without interrupting their careers. Online courses, webinars, and virtual labs can provide professionals, especially those in mechanical engineering roles, with the opportunity to develop skills in electrical engineering and electric vehicle technologies. The flexibility of these programs ensures that working professionals can continue their education while maintaining their job responsibilities.

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