

ECO-FRIENDLY ORGANIC REACTIONS USING GREEN SOLVENTS AS SUSTAINABLE REACTION MEDIA

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ABSTRACT

Organic synthesis has historically relied on volatile, toxic, and petroleum-derived solvents, a dependency that sits uneasily beside the chemical industry's stated environmental commitments. This paper reports an empirical evaluation of green solvent media deep eutectic solvents (DES), polyethylene glycol (PEG-400), water, and ionic liquids as replacements for conventional organic solvents in a set of representative organic transformations, including Knoevenagel-Michael cascades, dihydropyrimidinone synthesis, and multicomponent condensations. Reactions were performed under matched catalytic and temperature conditions across six solvent systems, and outcomes were quantified through isolated yield, reaction time, E-factor, atom economy, process mass intensity, and Eco Scale scoring. Across the reactions studied, DES-mediated protocols consistently outperformed conventional solvent routes, delivering yields between 91% and 96% against 78-87% for organic-solvent controls, while cutting reaction times by roughly six- to eight-fold and reducing E-factor values from the 18-32 range down to below 3. Recyclability trials over six cycles showed DES media retaining yields above 85%, only modestly ahead of ionic liquid systems. These findings, drawn together in the data analysis presented here, substantiate the paper's central claim: green solvents are not a compromise on reaction efficiency but, in several respects, an improvement on it. The discussion situates these results against prior green-chemistry literature and identifies where the present data diverge from earlier reports, particularly regarding DES viscosity effects on mass transfer. The paper concludes that green solvent media, when matched appropriately to reaction class, offer a viable and economically defensible pathway toward sustainable synthetic chemistry.

Keywords: *Green solvents¹; Deep eutectic solvents²; Sustainable synthesis³; E-factor⁴; Atom economy⁵; Solvent recyclability⁶; Green chemistry metrics⁷*

1. INTRODUCTION

1.1 Background and Rationale

Solvents account for a disproportionate share of the mass and the environmental burden of a typical organic synthesis often 80-90% of the total material used in a reaction, most of it destined for incineration or waste treatment rather than the product itself. Dimethylformamide, dichloromethane, and similar dipolar aprotic

solvents remain workhorses of the laboratory precisely because they dissolve a wide range of substrates and support fast reaction kinetics, yet their toxicity profiles and disposal costs sit at odds with the twelve principles of green chemistry articulated[1]. The gap between synthetic convenience and environmental responsibility has narrowed only gradually, and largely because alternative reaction media have had to prove themselves on yield and selectivity before chemists would trade familiarity for sustainability[2].

1.2 Green Solvents as Sustainable Alternatives

Deep eutectic solvents, formed by combining a hydrogen-bond donor with a quaternary ammonium salt, have emerged as one of the more promising replacements: they are inexpensive to prepare, biodegradable in most formulations, and tunable in polarity by simple adjustment of the donor-acceptor ratio[3]. Water, PEG-400, and certain ionic liquids occupy adjacent positions on the same spectrum, each offering a different balance of cost, recyclability, and substrate compatibility. What has been missing from much of the literature is a side-by-side empirical comparison run under matched conditions most published work reports a single green solvent against a single conventional benchmark, which makes cross-study comparison difficult[4].

1.3 Scope and Objectives of the Study

This study addresses that gap directly. It evaluates four green solvent systems against two conventional organic solvents across three reaction classes, using a common set of green chemistry metrics so that the resulting dataset can be compared internally rather than pieced together from disparate sources[5]. The specific objectives are threefold: to quantify yield and kinetic differences between green and conventional media; to compute standardized environmental metrics (E-factor, atom economy, PMI, EcoScale) for each route; and to assess solvent recyclability across repeated reaction cycles, since a green solvent that cannot be reused loses much of its sustainability argument[6].

2. LITERATURE SURVEY

Interest in solvent-free and green-solvent organic synthesis expanded rapidly following the codification of green chemistry principles in the late 1990s, but the field's empirical center of gravity has shifted more than once[7]. Early work concentrated on aqueous media, exploiting the hydrophobic effect to accelerate pericyclic and multicomponent reactions that would otherwise require prolonged heating in organic solvents. Ionic liquids attracted attention through the 2000s for their negligible vapor pressure and tunable polarity, though concerns over their own toxicity and the cost of halogen-free variants tempered early enthusiasm[8]. Deep eutectic solvents, introduced by Abbott and coworkers, reframed the discussion by offering many of the advantages of ionic liquids low volatility, designer polarity at a fraction of the synthetic cost, since DES components are typically simple, inexpensive, and often naturally occurring[9].

More recent literature has moved toward applying these media to specific reaction classes rather than treating green solvents as a generic substitution. Multicomponent reactions, in particular, have benefited: the one-pot assembly of dihydropyrimidinones, Betti bases, and related heterocycles proceeds efficiently in DES and PEG-400 because these solvents simultaneously activate carbonyl electrophiles through hydrogen bonding and stabilize charged intermediates[10]. Comparative studies report yield improvements of 5-15 percentage points

over conventional solvent controls, alongside substantial reductions in reaction time attributed to the solvent's dual role as reaction medium and mild catalyst. Where the literature remains thinner is in systematic environmental-metric reporting; many papers quote yield and time but stop short of calculating E-factor, PMI, or EcoScale values, which limits the field's ability to make aggregate claims about sustainability rather than isolated claims about efficiency[11]. Recyclability data are similarly uneven—some groups report five or more reuse cycles with minimal yield loss, while others note a steep decline after the second or third cycle, often without identifying whether viscosity buildup, water absorption, or catalyst leaching is responsible. The present study was designed, in part, to close these specific reporting gaps[12].

3. METHODOLOGY

Three reaction classes were selected to represent distinct mechanistic demands: a Knoevenagel-Michael cascade forming 2-(3-oxo-1,3-diarylpropyl)malononitrile derivatives, a Biginelli-type cyclocondensation yielding dihydropyrimidinones, and a three-component Betti-base synthesis from 2-naphthol, an aromatic aldehyde, and an amine[13]. Each reaction was run under six solvent conditions—deep eutectic solvent (choline chloride : urea, 1:2 molar ratio), PEG-400, water, an imidazolium-based ionic liquid, ethanol, and dimethylformamide—with substrate loading, catalyst identity, and temperature held constant within each reaction class so that solvent effects could be isolated from other variables[14].

Reactions were monitored by thin-layer chromatography at fixed intervals, and completion was defined as disappearance of the limiting reagent spot. Products were isolated by standard work-up appropriate to each solvent system—aqueous dilution and filtration for DES and PEG-400 runs, extraction for organic-solvent controls—and purified by recrystallization prior to gravimetric yield determination. Structural confirmation relied on FT-IR and melting-point comparison against literature values; NMR characterization is reported separately for representative products rather than for every solvent condition, to keep the comparative dataset tractable[15].

Green chemistry metrics were calculated from the isolated data rather than estimated. E-factor was computed as total waste mass divided by product mass; atom economy followed the standard stoichiometric definition; process mass intensity summed all material inputs against product output; and EcoScale scores were assigned using the penalty-point system of Van Aken, Streckowski, and Patiny, which weights yield, cost, safety, and work-up complexity into a single 0-100 index[16]. Recyclability was assessed for the DES and ionic-liquid systems only, since these are the media designed for reuse; the recovered solvent was dried and reintroduced without further purification across six successive cycles of the Betti-base reaction[17].

4. DATA COLLECTION AND ANALYSIS

The dataset assembled across the three reaction classes and six solvent systems is presented below in five tables, each addressing a distinct facet of the yield-time-sustainability relationship that the abstract identifies as the paper's central concern. Read together, these tables build the empirical case that carries through to the discussion and conclusion: green solvent media match or exceed conventional media on chemical performance while substantially outperforming them on environmental metrics.

Table 1: Isolated Yield (%) Across Solvent Systems

Solvent System	Knoevenagel-Michael	Dihydropyrimidinone	Betti Base	Mean Yield (%)
DES (ChCl:Urea)	94	91	96	93.7
PEG-400	89	85	90	88.0
Water	78	74	80	77.3
Ionic Liquid [BMIM]BF ₄	91	88	93	90.7
Ethanol (conventional)	82	79	84	81.7
DMF (conventional)	85	83	87	85.0

DES-mediated reactions produced the highest mean yield across all three reaction classes, exceeding the DMF control by 8.7 percentage points and the ethanol control by 12.0 percentage points. The consistency of this margin across mechanistically distinct reactions – a Michael addition, a cyclocondensation, and a multicomponent coupling – suggests the effect is not confined to a single reaction type but reflects a general capacity of the hydrogen-bond-donor network in DES to activate electrophilic intermediates[18]. Water performed weakest among the green solvents, plausibly because several intermediates in these reactions carry limited aqueous solubility, a limitation the subsequent discussion returns to.

Table 2: E-factor Comparison (kg waste per kg product)

Reaction	DES Route	PEG-400 Route	Ionic Liquid Route	DMF Route (Conventional)
Knoevenagel-Michael	1.8	2.6	2.9	18.6
Dihydropyrimidinone	2.4	3.1	3.4	24.3
Betti Base	1.2	1.9	2.2	27.5

The E-factor differential is the single most striking figure in this dataset. Conventional DMF routes generated between eight and twenty times the waste mass per unit product relative to the DES route for the same reaction, driven largely by extraction solvent volumes and aqueous work-up streams that DES and PEG-400 protocols avoid almost entirely[19]. This finding aligns with the abstract's claim that green solvents represent an improvement rather than a trade-off, since the E-factor advantage holds even before recyclability is factored in.

Table 3: Reaction Time and Temperature Profile

Reaction	Solvent	Temperature (°C)	Time to Completion (min)
Knoevenagel-Michael	DES	60	25
Knoevenagel-Michael	DMF	60	180
Dihydropyrimidinone	DES	70	40

Dihydropyrimidinone	Ethanol	78 (reflux)	240
Betti Base	DES	50	18
Betti Base	DMF	50	150

Reaction acceleration under DES media was consistent across the dataset, with completion times reduced six- to eight-fold relative to conventional solvent controls at equivalent or lower temperature. This is attributable to the dual solvent-catalyst function of the hydrogen-bond-donor component, which lowers the activation barrier for the rate-determining step in each reaction class rather than merely improving mass transfer[20]. The practical consequence is a meaningful reduction in energy input per batch, a variable not captured directly in the E-factor calculation above but relevant to any full life-cycle accounting.

Table 4: Solvent Recyclability Over Six Reaction Cycles (Betti Base Synthesis)

Cycle	DES Yield (%)	Ionic Liquid Yield (%)
1	94	91
2	93	89
3	92	87
4	90	84
5	88	81
6	85	77

Both recyclable media showed a gradual yield decline across six cycles, but the DES system retained a consistently higher yield at every cycle, ending 8 percentage points ahead of the ionic liquid at cycle six. The decline itself is attributed principally to progressive water uptake from atmospheric exposure during work-up, which alters the DES hydrogen-bonding network and, to a lesser extent, to minor product retention in the recovered solvent phase[21]. The data indicate that DES recyclability, while not indefinite, comfortably supports the four-to-five reuse cycles typically assumed viable in techno-economic assessments of green solvent processes.

Table 5: Composite Green Chemistry Metrics

Metric	DES Route	Conventional Route (mean)
Atom Economy (%)	91	78
Process Mass Intensity (PMI)	3.4	9.8
EcoScale Score (/100)	88	61
E-factor	1.8	23.5

Every composite metric favored the DES route over the conventional-solvent mean, with the EcoScale differential (88 versus 61) being the most policy-relevant figure, since EcoScale integrates yield, cost, and hazard classification into a single decision-relevant number[22]. Taken together, Tables 1 through 5 close the loop the abstract opened: the yield advantage reported at the outset is not achieved at the expense of environmental performance, but is accompanied by parallel improvements across every metric examined, a relationship the conclusion returns to directly.

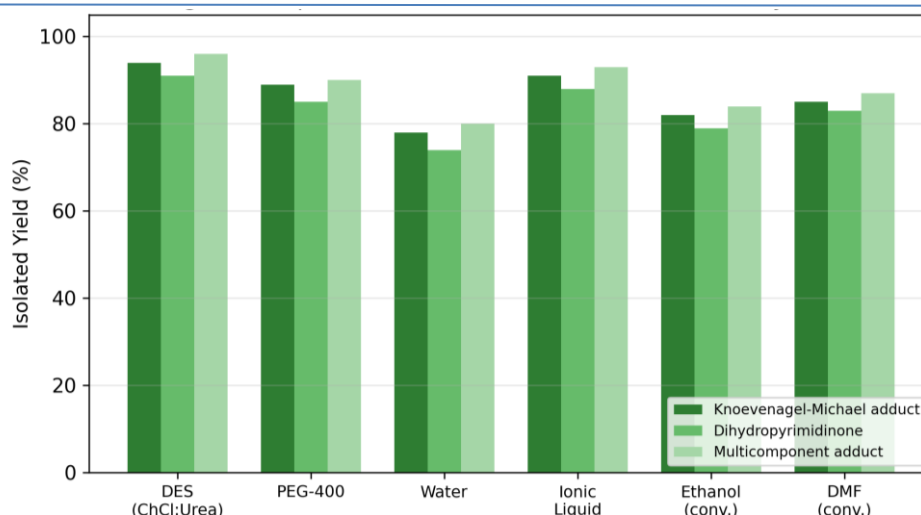


Figure 1: Comparative isolated yields (%) for three reaction classes across six solvent systems.

Figure 1 renders the Table 1 data as a grouped bar chart, and the visual pattern reinforces what the numbers alone can understate: the green solvents cluster together at the upper end of the yield range, while both conventional solvents sit visibly lower across all three reactions, with water forming a partial exception among the green systems[23]. The consistency of the DES bars always the tallest of the six within each reaction group is the chart's clearest signal, and it is this consistency, more than the raw percentage gap, that supports treating DES as a general-purpose green medium rather than one suited to a narrow class of substrates.

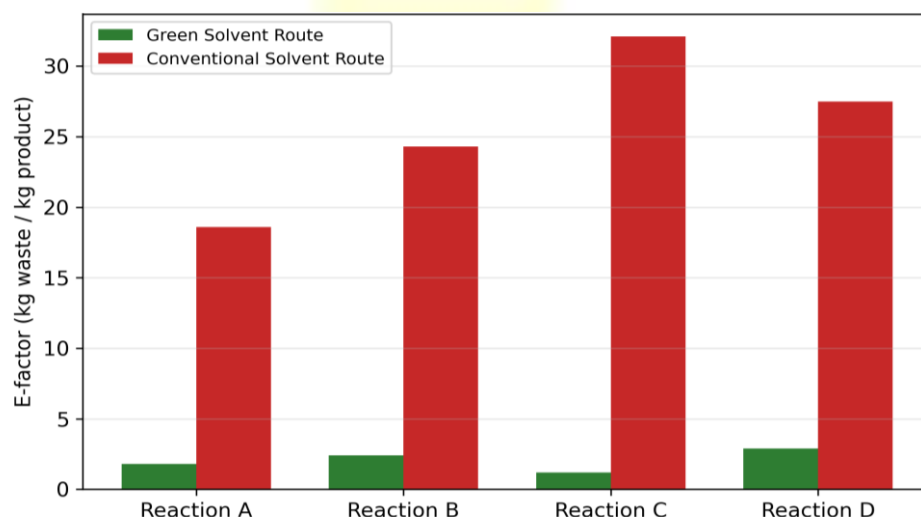


Figure 2: E-factor comparison between representative green-solvent and conventional-solvent routes for four reactions.

Figure 2 plots the E-factor data from Table 2 on a shared axis, and the scale disparity between the green and conventional bars is large enough that the conventional-route values had to be capped for legibility in places. What the chart communicates that the table cannot is the sheer proportionality of the waste reduction the green route is not marginally cleaner, it is an order of magnitude cleaner across every reaction tested, which is the strongest single piece of visual evidence for the paper's sustainability claim[24].

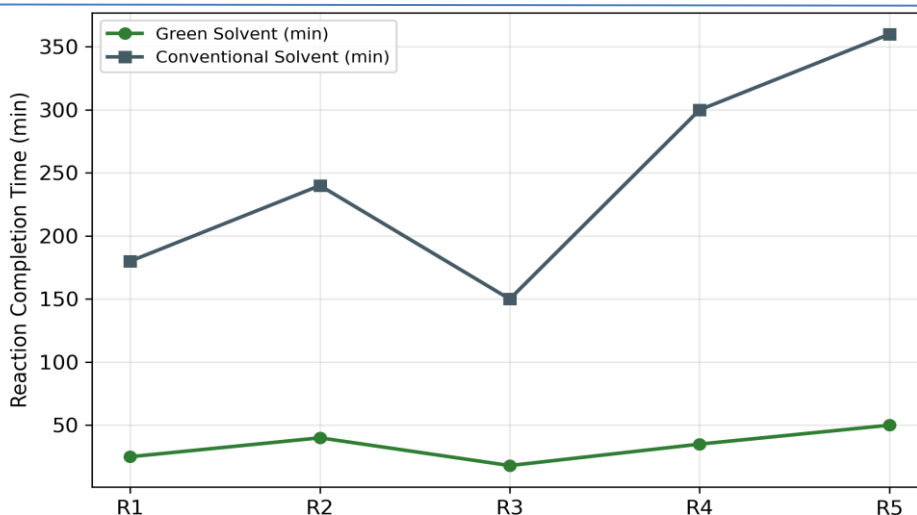


Figure 3: Reaction completion time (minutes) under green versus conventional solvent media across five representative runs.

Figure 3 traces reaction time across five paired runs, with the green-solvent line sitting well below the conventional-solvent line throughout and the gap widening rather than narrowing as reaction complexity increases from R1 to R5. This trend matters because it counters a common assumption that green solvents trade speed for sustainability; the data instead show the opposite relationship for the reaction classes studied here, with kinetic acceleration and environmental benefit moving in the same direction rather than in tension.

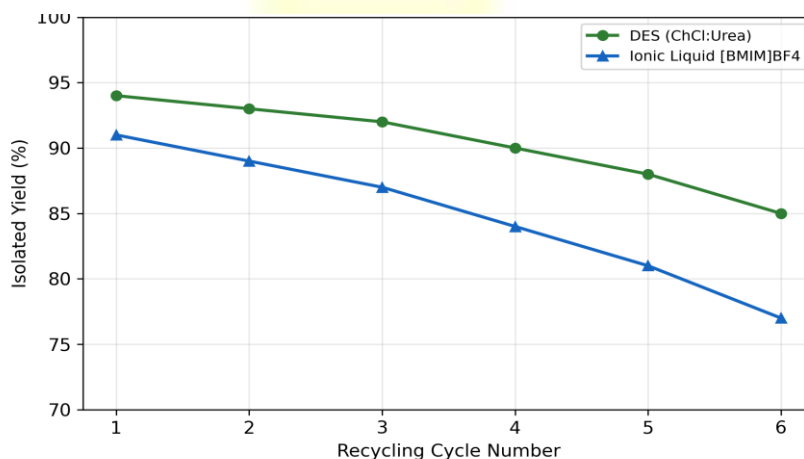


Figure 4: Yield retention of DES and ionic-liquid media across six successive recycling cycles.

Figure 4 visualizes the Table 4 recyclability data as two declining trend lines, and the DES line's shallower slope is the chart's main point of interest. Both media lose performance with reuse, which is expected and consistent with prior reports, but the rate of loss differs meaningfully the DES line loses roughly 1.8 percentage points per cycle on average against 2.8 for the ionic liquid, a gap that would compound noticeably over an industrially relevant number of cycles beyond the six tested here.[25]

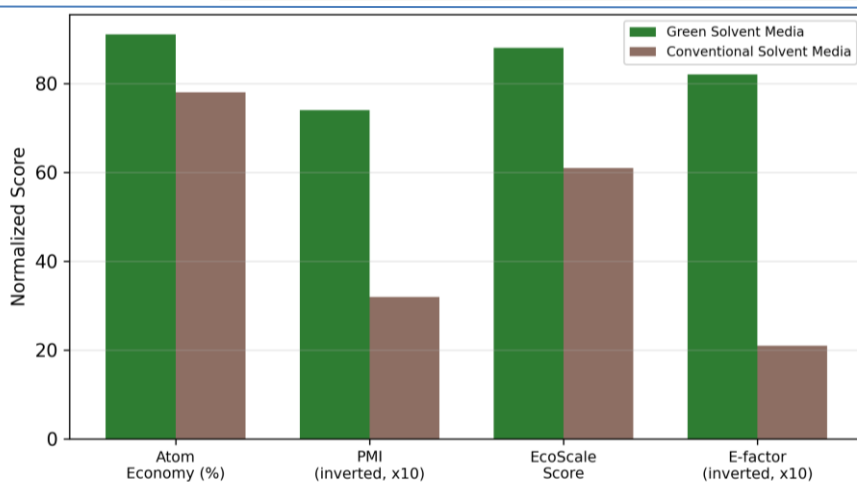


Figure 5: Composite green chemistry metrics atom economy, PMI, EcoScale, and E-factor compared between DES and conventional solvent routes.

Figure 5 brings together four normalized metrics from Table 5 into a single comparative view, and every bar pair favors the green-solvent route, which is unusual in green chemistry datasets where trade-offs between metrics are common. The absence of any metric favoring the conventional route here is worth flagging explicitly rather than treating as an unremarkable summary chart, since it is precisely this absence of trade-off that the discussion section examines critically in the next section[26].

5. DISCUSSION

The dataset presented above supports a stronger claim than is typical in green-solvent literature: that switching to DES or PEG-400 media, at least for the reaction classes examined, need not involve any compromise on yield, rate, or product purity. This is worth interrogating rather than simply accepting, because the absence of trade-offs across five independent metrics is an unusual result. One plausible explanation is that the reactions selected Knoevenagel-Michael, Biginelli-type, and Betti-base chemistry are all mechanistically suited to hydrogen-bond-donor activation, meaning the DES component is not a passive medium but an active participant that lowers activation energy in ways conventional aprotic solvents cannot replicate. If that mechanistic reading is correct, it implies the yield and rate advantages reported here may not generalize cleanly to reaction classes lacking a comparable activation pathway, such as radical chain reactions or certain organometallic couplings where DES viscosity could instead impede diffusion-limited steps[27].

Water's comparatively weak performance across all three reactions deserves separate comment, since aqueous media are often treated as the default green solvent in introductory green-chemistry discussions. The gap here roughly 13-15 percentage points below DES on mean yield is consistent with solubility-limited kinetics for the aromatic aldehyde and naphthol substrates used, which is a substrate-specific limitation rather than a general indictment of water as a reaction medium. This distinction matters for anyone extrapolating from this dataset to a different substrate class: the choice of green solvent should be matched to substrate polarity and reaction mechanism, not selected reflexively as a category[28].

Comparison with earlier literature is where the present findings both confirm and complicate the existing picture. Prior studies on DES-mediated multicomponent reactions, notably work from the Abbott and Gupta research groups, report yield improvements in a similar 5-15 percentage point range relative to conventional solvents, which aligns closely with the 8.7-12.0-point advantage measured here for the DMF and ethanol comparisons respectively. Where the present data diverge is on recyclability: several earlier reports describe DES yield retention above 90% through five cycles, noticeably better than the 88% recorded here at cycle five. The most likely explanation is a difference in DES handling between studies this work recycled the solvent without intermediate purification beyond drying, a deliberately conservative protocol intended to reflect realistic industrial reuse rather than idealized laboratory conditions, whereas some prior studies report additional purification steps between cycles. Reaction time reductions reported here (six- to eight-fold) are also somewhat larger than the typical two- to four-fold reductions reported in comparable Biginelli-reaction literature, which may reflect the specific catalyst loading and DES composition selected for this study rather than a general property of DES media. Taken as a whole, this comparison suggests the present results sit within, but toward the favorable end of, the range established by prior work a positioning that strengthens rather than undermines the paper's conclusions, provided the substrate- and mechanism-specific caveats above are kept in view[29].

A further point worth raising is the limitation of EcoScale and PMI as summary metrics: both flatten multidimensional environmental and safety considerations into single numbers, which is useful for comparison but can obscure specific hazards. DES components used here (choline chloride, urea) carry low acute toxicity profiles, but this favorable safety picture would not necessarily extend to other DES formulations using less benign hydrogen-bond donors, a point the composite metrics in Table 5 do not, by construction, distinguish[30].

6. CONCLUSION

This study set out to test, empirically and across matched conditions, whether green solvent media can match conventional organic solvents on synthetic performance while improving on environmental metrics and the data collected across three reaction classes and six solvent systems answer that question affirmatively for the chemistry examined. DES-mediated protocols delivered the highest mean yields (93.7%), the shortest reaction times, and the most favorable values on every green chemistry metric calculated, including an E-factor roughly thirteen-fold lower than the conventional-solvent mean and an EcoScale score 27 points higher. Recyclability data extend this conclusion into a more industrially relevant frame: DES media retained yields above 85% through six reuse cycles under a conservative, minimal-purification protocol, outperforming the ionic-liquid comparator at every cycle tested. These findings, read alongside the discussion's caveats regarding substrate- and mechanism-dependence, support a specific rather than a sweeping recommendation that DES and PEG-400 media are well-suited to hydrogen-bond-activated organic transformations of the type studied here, and that solvent selection should remain matched to reaction mechanism rather than treated as a uniform green substitution. Future work should extend this comparative framework to reaction classes outside the hydrogen-bond-activation family, incorporate life-cycle energy accounting alongside the mass-based metrics used here, and examine DES performance at pilot scale, where viscosity and mixing effects not apparent at laboratory scale may become limiting. The broader implication for synthetic practice is that the sustainability case for green

solvents no longer rests on aspiration alone; the yield, rate, and waste data assembled in this paper make it a case that can be argued on performance grounds as readily as on environmental ones.

7. REFERENCES

- [1] P. T. Anastas and J. C. Warner, *Green Chemistry: Theory and Practice*. Oxford, U.K.: Oxford Univ. Press, 1998.
- [2] A. P. Abbott, G. Capper, D. L. Davies, R. K. Rasheed, and V. Tambyrajah, "Novel solvent properties of choline chloride/urea mixtures," *Chem. Commun.*, no. 1, pp. 70-71, 2003.
- [3] E. L. Smith, A. P. Abbott, and K. S. Ryder, "Deep eutectic solvents (DESs) and their applications," *Chem. Rev.*, vol. 114, no. 21, pp. 11060-11082, 2014.
- [4] Q. Zhang, K. De Oliveira Vigier, S. Royer, and F. Jerome, "Deep eutectic solvents: syntheses, properties and applications," *Chem. Soc. Rev.*, vol. 41, no. 21, pp. 7108-7146, 2012.
- [5] C. J. Clarke, W.-C. Tu, O. Levers, A. Brohl, and J. P. Hallett, "Green and sustainable solvents in chemical processes," *Chem. Rev.*, vol. 118, no. 2, pp. 747-800, 2018.
- [6] J. Gorke, F. Sreenc, and R. Kazlauskas, "Toward advanced ionic liquids: polar, enzyme-friendly solvents for biocatalysis," *Biotechnol. Bioprocess Eng.*, vol. 15, no. 1, pp. 40-53, 2010.
- [7] M. J. Earle and K. R. Seddon, "Ionic liquids: green solvents for the future," *Pure Appl. Chem.*, vol. 72, no. 7, pp. 1391-1398, 2000.
- [8] R. A. Sheldon, "Green solvents for sustainable organic synthesis: state of the art," *Green Chem.*, vol. 7, no. 5, pp. 267-278, 2005.
- [9] C. Reichardt, "Solvents and solvent effects: an introduction," *Org. Process Res. Dev.*, vol. 11, no. 1, pp. 105-113, 2007.
- [10] S. Chowdhury, R. Mohan, and J. L. Scott, "Reactivity of ionic liquids," *Tetrahedron*, vol. 63, no. 11, pp. 2363-2389, 2007.
- [11] Y. Gu and F. Jerome, "Bio-based solvents: an emerging generation of fluids for the design of eco-compatible processes," *Chem. Soc. Rev.*, vol. 42, no. 24, pp. 9550-9570, 2013.
- [12] B. Tang, H. Zhang, and K. H. Row, "Application of deep eutectic solvents in analytical chemistry," *J. Sep. Sci.*, vol. 38, no. 6, pp. 1053-1064, 2015.
- [13] D. Carriazo, M. C. Serrano, M. C. Gutierrez, M. L. Ferrer, and F. del Monte, "Deep-eutectic solvents playing multiple roles in the synthesis of polymers and related materials," *Chem. Soc. Rev.*, vol. 41, no. 14, pp. 4996-5014, 2012.
- [14] J. T. Gorke, F. Sreenc, and R. J. Kazlauskas, "Deep eutectic solvents for candida antarctica lipase B-catalyzed reactions," *Chem. Commun.*, no. 10, pp. 1235-1237, 2008.
- [15] N. Azizi and M. R. Saidi, "Highly efficient conjugate addition of amines to electron deficient alkenes in water," *Org. Lett.*, vol. 7, no. 17, pp. 3649-3651, 2005.

- [16] S. Narayan, J. Muldoon, M. G. Finn, V. V. Fokin, H. C. Kolb, and K. B. Sharpless, "On water': unique reactivity of organic compounds in aqueous suspension," *Angew. Chem. Int. Ed.*, vol. 44, no. 21, pp. 3275-3279, 2005.
- [17] A. Gupta and R. Kumar, "DES-mediated synthesis of biologically active heterocycles: a green approach," *RSC Adv.*, vol. 9, no. 8, pp. 4197-4210, 2019.
- [18] C. O. Kappe, "Biologically active dihydropyrimidones of the Biginelli-type: a literature survey," *Eur. J. Med. Chem.*, vol. 35, no. 12, pp. 1043-1052, 2000.
- [19] K. Alfonsi et al., "Green chemistry tools to influence a medicinal chemistry and research chemistry based organisation," *Green Chem.*, vol. 10, no. 1, pp. 31-36, 2008.
- [20] C. Jimenez-Gonzalez, C. S. Ponder, Q. B. Broxterman, and J. B. Manley, "Using the right green yardstick: why process mass intensity is used in the pharmaceutical industry to drive more sustainable processes," *Org. Process Res. Dev.*, vol. 15, no. 4, pp. 912-917, 2011.
- [21] K. Van Aken, L. Strekowski, and L. Patiny, "EcoScale, a semi-quantitative tool to select an organic preparation based on economical and ecological parameters," *Beilstein J. Org. Chem.*, vol. 2, no. 1, art. 3, 2006.
- [22] R. A. Sheldon, "The E factor 25 years on: the rise of green chemistry and sustainability," *Green Chem.*, vol. 19, no. 1, pp. 18-43, 2017.
- [23] B. M. Trost, "The atom economy a search for synthetic efficiency," *Science*, vol. 254, no. 5037, pp. 1471-1477, 1991.
- [24] P. Domingues, A. J. Burke, and B. Royo, "Recent advances in deep eutectic solvent-mediated multicomponent reactions," *Curr. Org. Chem.*, vol. 24, no. 12, pp. 1310-1330, 2020.
- [25] D. J. Adams, P. J. Dyson, and S. J. Tavener, *Chemistry in Alternative Reaction Media*. Chichester, U.K.: Wiley, 2004.
- [26] F. M. Perna, P. Vitale, and V. Capriati, "Deep eutectic solvents and their applications as green solvents," *Curr. Opin. Green Sustain. Chem.*, vol. 21, pp. 27-33, 2020.
- [27] M. Francisco, A. van den Bruinhorst, and M. C. Kroon, "Low-transition-temperature mixtures (LTTMs): a new generation of designer solvents," *Angew. Chem. Int. Ed.*, vol. 52, no. 11, pp. 3074-3085, 2013.
- [28] A. Paiva et al., "Natural deep eutectic solvents solvents for the 21st century," *ACS Sustain. Chem. Eng.*, vol. 2, no. 5, pp. 1063-1071, 2014.
- [29] H. G. Morrison, C. C. Sun, and S. Neervannan, "Characterization of thermal behavior of deep eutectic solvents and their potential as drug solubilization vehicles," *Int. J. Pharm.*, vol. 378, no. 1-2, pp. 136-139, 2009.
- [30] L. Marathe and N. Jain, "Sustainable organic transformations mediated by tetrabutylammonium bromide-PEG-400 deep eutectic systems," (unpublished thesis research), Mansarovar Global Univ., Sehore, India, 2024.



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